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Planary Lectures and Boltzmann Medal Winners

Evolutionary tradeoffs and the geometry of biological design space

Uri Alon * [1]

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Organisms, tissues and molecules often need to perform multiple tasks. But usually no design (phenotype) can be optimal at all tasks at once. This situation leads to a fundamental tradeoff. We study this using the concept of Pareto optimality from engineering and economics, which we apply in a new way that is particular to biology in which we do not know the tasks in advance. Tradeoffs lead to an unexpected simplicity in the range of optimal phenotypes: they fall on low-dimensional polytopes in trait space such as lines, triangles and tetrahedrons. At the vertices of these polytopes are designs that specialize at a single task. This allows us to understand what the tasks are from the data. We demonstrate this using data from animal and fossil morphology, bacterial gene expression and other biological systems.

*Speaker

Light-controlled Active Brownian Motion

Clemens Bechinger * [1]

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Despite their structural simplicity, active colloidal particles exhibit many properties of motile microorganisms including formation of clusters and biofilms, swarming or their response to external fields. Accordingly, active colloids provide an intriguing chance to understand the formation of dynamical structures in living systems but may also find use as micro robots which – similar to their biological counterparts – autonomously navigate through complex environments. In this talk, we will present recent advances in this field with a particular view on light-activated microswimmers, where the particle's motility is controlled by the amount of incident laser light. Using several examples, such as clustering, gravitactic behaviour and phototactic response of active colloids, we demonstrate a close relationship between artificial and biological microswimmers. Finally, we also investigate the motion of active colloids in viscoelastic fluids. Contrary to Newtonian liquids, we observe a drastic increase of the particle's rotational diffusion with increasing velocity. Such enhancement is attributed to the coupling between the particle's directed motion and the microstructural relaxation of the surrounding fluid.

*Speaker

Statistical Physics for Real Biological Networks

William Bialek * [1]

[1] Princeton University and CUNY – United States.

Many of life's most fascinating phenomena emerge from interactions among many elements ? many amino acids determine the structure of a single protein, many genes determine the fate of a cell, many neurons are involved in shaping our thoughts and memories. Physicists have long hoped that these collective behaviors could be described using the ideas and methods of statistical mechanics. In the past few years, new, larger scale experiments have made it possible to construct statistical mechanics models of biological systems directly from real data. I'll describe the surprising successes of this ?inverse? approach, using examples from families of proteins, networks of neurons, and flocks of birds. Remarkably, in all these cases the models that emerge from the data are poised near a critical point in their parameter space. This suggests there may be some deeper theoretical principle behind the behavior of these diverse systems.

*Speaker

Phase ordering kinetics, aggregation and percolation in two dimensions

Leticia F. Cugliandolo * [1]

[1] Sorbonne Universités, Université Pierre et Marie Curie - Paris 6 – France

A system taken across a second order phase transition from its disordered into its symmetry-broken phase undergoes a phase ordering process. It is commonly accepted that after the quench the system enters a dynamic scaling regime. The celebrated classical two-dimensional Ising model with non-conserved order parameter dynamics (used to model magnetic systems) is a typical example in this class of systems. We recently revisited this problem from a geometric perspective finding a number of surprising features that were not appreciated before, and that I will discuss in this talk. In particular, we showed that the dynamics after an instantaneous quench actually proceeds in two steps: in a first regime the dynamics approaches critical percolation, while in a subsequent regimes the system phase orders in the expected way. This phenomenon also exists in other two dimensional models with different microscopic dynamics. It opens the way to intriguing connections between coarsening, aggregation and percolation theory.

*Speaker

The disorder created by entropy is in the mind

Daan Frenkel * [1]

[1] University of Cambridge, Department of Chemistry – United Kingdom

So much has been said about entropy that it is probably best to remain silent on the subject. Somewhat unwisely, I will nevertheless talk about this dangerous subject because in numerical simulations one is confronted very directly with what entropy is and, more importantly, with what it is not. I will therefore talk about entropy from the perspective of numerical simulations. Specifically, I will discuss (well known) examples where entropy increases with increasing order, I will briefly touch on a common misinterpretation Gibbs' paradox and I will discuss how recent numerical tools allow us to compute close and distant relatives of the Statistical Mechanical entropy.

*Speaker

Force from non-equilibrium fluctuations

Mehran Kardar * [1]

[1] Massachusetts Institute of Technology – United States

Equilibrium fluctuation-induced forces are abundant in nature, ranging from quantum electrodynamic (QED) Casimir and van der Waals forces, to their thermal analogs in fluctuating soft matter. Manifestations of QED fluctuations out of thermal equilibrium are also well-known, as in the Stefan-Boltzmann laws of radiation pressure and heat transfer. These laws, however, acquire non-trivial twists in the near-field regime of sub-micron separations. Non-equilibrium fluctuation forces for particulate matter also hold surprises which I present in the contexts of diffusive transport, and active matter: For the simple case of a current of diffusive particles between parallel slabs, we find a force that falls off with slab separation d as kT/d (at temperature T, and in all spatial dimensions), but that can be attractive or repulsive. For a wide wide class of active systems, we find that the pressure exerted on a container depends on details of interactions with the confining walls, as well as wall curvature.

*Speaker

Visualization and characterization of quantum fluid flows

Daniel Lathrop * [1]

[1] University of Maryland – United States

Long-range quantum order underlies a number of related physical phenomena including superfluidity, superconductivity, the Higgs mechanism, Bose-Einstein condensates, and spin systems. While superfluidity in Helium-4 was one of the earliest discovered of these, it is not the best understood, owing to locally-strong interactions which make theoretical progress difficult, and a lack of local experimental probes. Our group discovered that micron-sized hydrogen particles and fluorescent nanoparticles may be used to label quantized vortices in flows of superfluid helium. Particles not on vortices trace the motion of the normal component of the superfluid. This diagnostic tool has given us a new perspective on an old subject. By directly observing and tracking these particles, we have confirmed the two-fluid model, observed vortex rings and reconnection, characterized thermal counter-flows, observed Kelvin waves, and taken local observations of the very peculiar nature of quantum turbulence. One of many surprising observations is the existence of power law tails in the probability distribution of velocity for these flows. That was predicted by our group and verified as stemming from the reconnection of quantized vortices. We conclude that quantum turbulence is dominated by reconnection and vortex ring collapse, making turbulence in a quantum liquid distinct from classical turbulence of a Newtonian fluid. Our observations highlight open questions regarding the formation of vortices while cooling through the phase transition with implications on superconductors and phase transitions in the early universe.

*Speaker

Thermodynamics and order beyond equilibrium – the physics of periodically driven quantum systems

Roderich Moessner * [1], Arnab Das, Vedika Khemani, Achilleas Lazarides, Shivaji Sondhi

[1]Max Planck Institute for the Physics of Complex Systems – Germany

Thermodynamics and order beyond equilibrium – the physics of periodically driven quantum systems The field of thermodynamics is one of the crown jewels of classical physics. However, only comparatively recently, due to the advent of experiments in cold atomic systems with long coherence times, has our detailed understanding of its connection to quantum statistical mechanics seen remarkable progress. Extending these ideas and concepts to the non-equilibrium setting is a challenging topic, in itself of perennial interest. Here, we study perhaps the simplest non-equilibrium class of quantum problems, namely Floquet systems, i.e. systems whose Hamiltonians depend on time periodically, $H(t+T) = H(t)$. For these, there is no energy conservation, and hence not even a natural concept of temperature. We find that it is nonetheless possible to identify several fundamentally distinct thermodynamic ensembles. We also ask if there exists a sharp notion of a phase in such driven, interacting quantum systems. Disorder turns out to play a crucial role, enabling the existence of states which are straightforward analogues of equilibrium states with broken symmetries and topological order, while others–genuinely new to the Floquet problem–are characterized by a combination of order and non-trivial periodic dynamics. References: Phys. Rev. Lett. 112, 150401 (2014); Phys. Rev. E 90 , 012110 (2014); Phys. Rev. Lett. 115, 030402 (2015); arXiv:1508.03344.

*Speaker

Ultimate statistical physics: fluorescence of a single atom or ion

Yves Pomeau * [1]

[1] U. of Arizona – France

Experiments have shown remarkable properties of a single atom or ion illuminated by one or two laser beams at the resonance frequency(ies) of one (or two) atomic transitions between excited state(s) and the ground state. The statistical properties of the emitted fluorescence depend on fundamental properties of quantum systems, like the irreversibility of the measurement process (or the reduction of the wave packet). We derive those properties from a statistical theory in the spirit of Koimogorov theory of Markov process. This approach can be used because there is a large difference in time scales of the two fundamental processes taking place: the quick quantum jumps when an excited state decays and the much slower build-up of the excited state by the optical Rabi oscillations. This built-up may be partial or total, depending on the values of the lifetimes of the atomic levels and on the Rabi frequencies associated to the transitions. This approach yields solvable Kolmogorov equations giving access to various interesting properties of fluorescence light. Among them is the irreversibility in the sense that higher order time correlations show (theoretically) the breaking of time reversal invariance due to the quantum jumps.
This reports joint work with Martine Le Berre and some mathematical contribution by Jean Ginibre.

*Speaker

Active Matter

Sriram Ramaswamy * [1]

[1] TIFR Hyderabad and IISc – India

The study of systems with sustained energy uptake and dissipation at the scale of the constituent particles is an area of central interest in nonequilibrium statistical physics. Identifying such systems as a distinct category – Active Matter – unifies our understanding of collective movement in living matter and in some surprising inanimate imitations. My talk will mention briefly our group's early work, discuss the active-matter framework, and then present our recent results on single-particle and collective behaviour. I will make contact with experiments on active granular monolayers as well as systems made of purified biological components.

*Speaker

Fluid models as scaling limits of systems of particles

Laure Saint-Raymond * [1], Thierry Bodineau Isabelle Gallagher

[1]ENS Paris – France

In his sixth problem, Hilbert asked for an axiomatization of gas dynamics, and he suggested to use the Boltzmann equation as an intermediate description between the (microscopic) atomic dynamics and (macroscopic) fluid models. The main difficulty to achieve this program is to prove the asymptotic decorrelation between the local microscopic interactions, referred to as propagation of chaos, on a time scale much larger than the mean free time. This is indeed the key property to observe some relaxation towards local thermodynamic equilibrium. This control of the collision process can be obtained in fluctuation regimes. In a series of joint works with T. Bodineau and I. Gallagher, we have established a long time convergence result to the linearized Boltzmann equation, and eventually derived the acoustic and incompressible Stokes equations in dimension 2. The proof relies crucially on symmetry arguments, combined with a suitable pruning procedure to discard super exponential collision trees.

*Speaker

Topic 1: General and Mathematical Aspects-Oral

Non-self-averaging transport coefficients in single-particle tracking: Beyond annealed approach

Takuma Akimoto * [1], Eli Barkai, Keiji Saito

[1] Keio University – Japan

Local transport coefficients in disordered systems such as amorphous semiconductor and living cells are highly heterogeneous. Such disordered systems are described by quenched disorder. However, annealed models are usually studied because of difficulties for analytical treatments in quenched models. Here, we report on non-self-averaging effects in spatial diffusion in the quenched trap model with finite lattice sites. We prove that the time-averaged mean square displacement converges to the ensemble average as the measurement time goes to infinity in a single disorder realization but it strongly depends on the disorder when the temperature is below the glass transition temperature. In other words, the system is ergodic but non-self-averaging. We find that the inverse Lévy distribution is a universal distribution for diffusivity in a sense that it can be applied for arbitrary dimension. The effects found are very different from the annealed version where concepts of weak ergodicity breaking hold. Non-self-averaging effects under confinement and relevance to experimental situations are also discussed.

*Speaker

Biologically-inspired functional clustering in logical networks and games

Matthieu Barbier * [1], Mohamad Dia and Nicolas Macris.

[1] CBTM Moulis – France

How much of the functional organization of an artificial system can one recover by mimicking empirical approaches from biology, devised to reverse-engineer molecular, neural and ecological networks? I take interest in basic methods, such as knockouts and substitutions, that do not target specific structural or dynamical features but functionality, i.e. the role played by one element in the system's response to external selection. By testing them on simple abstract systems - logical networks and combinatorial games - I attempt to shed light on their explanatory power, and on their limitations: What sort of structures confound them? Can they deal with multiple levels of abstraction? Are they robust under refactoring? The main result is that the existence of distinct failure modes for the system greatly helps with functional identification.

*Speaker

Is Boltzmann's equation reversible? A new large deviation perspective on the irreversibility paradox.

Freddy Bouchet * [1], Laure Saint Raymond

[1] ENS de Lyon and CNRS – France

In this talk we will review the classical heuristic understanding of the irreversibility paradox for Boltzmann's equation, the related Lanford's results, and the recent mathematical achievements. We will then propose a new perspective based on a large deviation estimate for the probability of the empirical distribution dynamics. Assuming Boltzmann's chaotic hypothesis, we derive a large deviation rate function, or action, that describes asymptotically for large N, the stochastic process for the empirical distribution. This action has the entropy as a quasi-potential, as should be expected. While Boltzmann's equation appears as the most probable evolution (corresponding to a law of large numbers), the action describes a genuine reversible stochastic process, in agreement with the microscopic reversibility. As a consequence, this large deviation action not only gives the expected meaning to Boltzmann's equation, but also quantifies the probability of any dynamical evolution departing from solutions of Boltzmann's equation. This picture, fully compatible with the heuristic classical view, makes it much more precise in various ways. It gives its full dynamical meaning to the entropy in relation with recent fluctuation theorems. Moreover, our approach clarifies several important points ; for instance the irreversibility of Boltzmann's equation is not a consequence of the chaotic hypothesis (stosszahlansatz), as often stated, but rather a consequence of confusing the evolution of the average of the empirical distribution with the evolution of the empirical density itself. Proving the validity of this action for describing the large deviation of the empirical distribution of Hamiltonian dynamics remains a challenge for the future.

*Speaker

Off-critical properties of three dimensional Conformal Field Theories.

Michele Caselle * [1], Gianluca Costagliola, Nicodemo Magnoli

[1] I.N.F.N. Sez. di Torino – Italy

In the past few years a lot of interesting results on 3d Conformal Field Theories have been obtained using the Conformal Bootstrap approach. Conformal symmetry is so powerful that several non trivial predictions can also be obtained outside the critical point, in the scaling region, using conformal perturbation techniques. In this talk we shall discuss a few relevant results in this framework, ranging from the numerical determination of the OPE coefficients [1] to the determination of critical scattering functions or of the critical structure factors. We discuss, as a a prototypical example, the case of the 3d Ising model for which both high precision Montecarlo estimates and a wide range of experimental results exist. Our predictions turn out to be in good agreement both with Montecarlo simulations and with experimental estimates of the same quantities. [1] M. Caselle, G. Costagliola and N. Magnoli "Numerical determination of the operator-product-expansion coefficients in the 3D Ising model from off-critical correlators" Phys.Rev. D91 (2015) no.6, 061901 (arXiv:1501.04065)

*Speaker

Thermal fluctuations and 1/f noise from nanothermodynamics

Ralph V. Chamberlin * [1]

[1] Arizona State University – United States

Standard statistical mechanics is based on the thermodynamic limit, which requires an effectively infinite and homogeneous heat bath. However, several experimental techniques have shown that the primary response of most materials comes from a heterogeneous distribution of independently-relaxing nanometer-sized regions. Hill's small-system thermodynamics ("nanothermodynamics") establishes the mathematical foundation for treating the fluctuations of small regions in thermal contact with their own local bath. One result is a subdivision potential that must be included if total energy is to be conserved. A related result is a nonlinear correction to Boltzmann's factor that maintains maximum entropy during equilibrium fluctuations. Such strict adherence to the laws of thermodynamics provides a common explanation for several empirical formulas, including 1/f noise in the power spectral-density of thermal fluctuations. I will emphasize how specific models based on nanothermodynamics yield 1/f-like noise, with deviations that mimic the measured behavior in many materials.

*Speaker

Exact $n \to \infty$ results for the $O(n)$ ϕ^4 model on a three-dimensional strip bounded by free surface planes via inverse scattering methods

H. W. Diehl * [1], Sergei B. Rutkevich

[1] Fakultaet für Physik, U. Duisburg-Essen – Germany

The $O(2)$ ϕ^4 model on a three-dimensional strip $\mathbb{R}^2 \times [0, L]$ bounded by a pari of parallel free surface planes is relevant for the explanation of the thinning of wetting layers of ^{4}He caused by critical Casimir forces near and below the λ-transition. Just as its $O(n)$ analog, it has long-range order below the bulk critical temperature T_c if $L = \infty$, but remains disordered for all $T > 0$ when $L < \infty$. A proper analysis of the scaling behavior of the $O(n)$ model near T_c is quite challenging because it involves a nontrivial dimensional crossover in addition to bulk, boundary, and finite-size critical behaviors. The model can be solved exactly in the limit $n \to \infty$ in terms of the eigenvalues and eigenfunctions of a self-consistent Schrödinger equation involving a potential $v(z)$ that becomes singular at the boundary planes. Complementing recent exact results based on numerical solutions of this self-consistent equation, we derive various exact analytical results for a number of properties such as series expansion coefficients of $v(z)$, the scattering data of $v(z)$ in the semi-infinite case $L = \infty$ for all values of the termperature scaling field $m \gtrless 0$, and the low-temperature asymptotic behavior of the residual free energy and the Casimir force using a combination of boundary-operator and short-distance expansions, proper extensions of inverse scattering theory, new trace formulae, and semi-classical expansions.

*Speaker

Critical speeding-up

Eren Metin Elci * [1], Timothy Garoni, Andrea Collevecchio, Gregory Markowsky

[1] School of Mathematical Sciences, Monash University – Australia

Critical *slowing-down* is a dynamical manifestation of phase transitions, deteriorating the efficiency of many Markov chain Monte Carlo algorithms. In a nutshell, it describes the *super*-linear scaling of dynamical timescales, such as relaxation, mixing or autocorrelation times, with the volume of the underlying physical system. This effect often occurs in form of a power law, characterised by positive dynamical critical exponents. Quite a number of (cluster) algorithms have been devised in order to reduce or eliminate the effect of critical slowing-down. The standard lore is that large-scale altering cluster algorithms are superior to locally perturbing Markov chains in reducing critical slowing-down.
Surprisingly, a number of recent numerical studies have not only shown that locally perturbing Markov chains for geometric loop and Fortuin-Kasteleyn representations of Ising and Potts models can have smaller dynamical critical exponents than cluster algorithms, they also revealed that these Markov chains exhibit critical *speeding-up*. In contrast to the "negative" slowing-down mechanism, this is a "positive" manifestation of collective fluctuations at criticality, yielding a *sub*-linear scaling of dynamical timescales with *negative* dynamical critical exponents.
In this talk we present a spectral characterisation of the critical speeding-up phenomenon and we prove critical speeding-up for crossing- and wrapping events in critical two-dimensional percolation. We then further present our ongoing research that aims to extend the spectral analysis to geometric susceptibility and order-parameter estimators, higher dimensional lattices and correlated models.

*Speaker

A universal approach to classical and quantum wave localization in disordered systems

Marcel Filoche * [1], Svitlana Mayboroda, Douglas N. Arnold, David Jerison, Guy David

[1] Ecole Polytechnique, CNRS – France

Localization of Laplacian or bi-Laplacian waves plays a major role in the behavior of numerous physical systems. It can be the result of a complex medium, of the geometry of the vibrating structure, or even due to the presence of disorder. We present here a universal theory of localization applicable to all vibratory systems [1]. The main tool of this theory, the localization landscape, controls the amplitude of the stationary vibrations, and predicts the spatial regions where vibrations will be localized as well as the frequencies above which a delocalization transition occurs. For second order operators such as the Schrödinger operator, this localization landscape is simply the solution of a Dirichlet problem with uniform right-hand side. Moreover, we show that the reciprocal of this landscape plays the role of an effective potential which finely governs the confinement of the quantum states. In this picture, the boundaries of the localization subregions for low energy eigenfunctions correspond to the barriers of this effective potential, and the long range exponential decay characteristic of Anderson localization is explained as the consequence of multiple tunneling in the dense network of barriers created by this effective potential [2]. This effective potential allows us also to derive a remarkably accurate Weyl's formula for the density of states for a large variety of systems, periodic or random, 1D, 2D, or 3D. Finally, we will present ongoing applications of this theory to the understanding of various physical systems.

[1] M. Filoche and S. Mayboroda, Proceedings of the National Academy of Sciences of the USA **109**, 14761 (2012).

[2] D. N. Arnold, G. David, D. Jerison, S. Mayboroda, M. Filoche, Phys. Rev. Lett. **116**, 056602 (2016).

*Speaker

Percolation on trees as a Brownian excursion

Francesc Font-Clos * [1], Nicholas R. Moloney

[1] ISI Foundation – Italy

The Kolmogorov-Smirnov distribution, widely used in nonparametric statistics, is known to appear also in seemingly unconnected contexts such as hitting times of Bessel processes or percolation on trees. Focusing on the latter case, we try to untangle such an interesting connection. We calculate the distribution of the size of the percolating cluster on a tree in the subcritical, critical and supercritical phase by exploiting a mapping between continuum trees and Brownian excursions, and arrive at a diffusion equation with suitable boundary conditions. The exact solution to the problem, which can be exactly computed in Laplace space, is a continous family of distributions that goes from a Gaussian (supercritical phase), to the Kolmogorov-Smirnov distribution (critical phase), to an exponential (subcritical phase). In this way, we provide an intuitive explanation for the connection between the Kolmogorov-Smirnov test and the percolating cluster on a tree.

*Speaker

Critical properties of an integrable intersecting loop model

Holger Frahm * [1], Marcio J. Martins

[1] Institut für Theoretische Physik, Leibniz Universität Hannover – Germany

The low energy spectrum of a spin chain with $OSp(3|2)$ supergroup symmetry is studied based on the Bethe ansatz solution of the related vertex model. This model is a lattice realization of intersecting loops in two dimensions with loop fugacity $z = 1$ which provides a framework to study the critical properties of the unusual low temperature Goldstone phase of the $O(N)$ sigma model for $N = 1$ in the context of an integrable model. Our finite-size analysis provides strong evidence for the existence of continua of scaling dimensions, the lowest of them starting at the ground state. Based on our data we conjecture that the so-called watermelon correlation functions decay logarithmically with exponents related to the quadratic Casimir operator of $OSp(3|2)$.

*Speaker

Field-theoretic construction of invariants for topological insulators

Krzysztof Gawedzki * [1]

[1] Laboratoire de Physique, ENS Lyon – France

I shall describe how to obtain the bulk invariants for time-reversal-symmetric topological insulators, both static and periodically driven, using simple tools of topological field theory.

*Speaker

Burstyness, localization and Griffiths effects in network models

Géza ódor * [1], Ronald Dickman, Gergely Ódor, S.C. Ferrreira, W. Cota

[1] MTA-EK-MFA Res. Inst. for Materials Science – Hungary

Quenched disorder is known to play a relevant role in dynamical processes and phase transitions. By studying the Contact Process (CP) we showed that Griffiths Phases (GP) and other rare region effects, leading generically to anomalously slow (algebraic, logarithmic, ...) relaxation on Erdos-Renyi networks with explicit quenched disorder. More surprisingly, we found that GPs can also emerge solely as the consequence of topological heterogeneity on generalized small world networks, exhibiting finite topological dimensions [1,2]. Similar power-law dynamics can also be observed on hierarchical modular networks [3] and on scale-free graphs [4,5]. Recently I have pointed out that localization, described by quenched mean-field approximations is related to the existence of rare region effects and GPs in case of Susceptible Infected Susceptible (SIS) models on various complex networks [6-8], in particular on Barabasi-Albert type of networks with aging connections. I also provide numerical evidence for power-law type of intercommunication time distributions by simulating the CP and SIS. This observation suggests that in non-stationary bursty systems the observed non-poissonian behavior can emerge as the consequence of an underlying hidden poissonian network process, which is either critical or exhibits strong rare-region effects [9,3]. [1] M. A. Muôz, R. Juhśz, C. Castellano, and G. Odor, Phys. Rev. Lett. 105, 128701 (2010). [2] R. Juhśz, G. Odor, C. Castellano, M. A. Munoz, Phys. Rev. E 85, 066125 (2012). [3] G. Odor, R. Dickman, G. Odor, Sci. Rep. 5, 14451 (2015). [4] G. Odor, R. Pastor-Satorras, Phys. Rev. E 86, 026117 (2012). [5] W. F. C. Cota, S. C. Ferreira and G. Odor, arXiv:1512.05274, PRE in press. [6] G. Odor, Phys. Rev. E 87, 042132 (2013). [7] G. Odor, EPJ Web of Conferences 44, 04005 (2013). [8] G. Odor, Phys. Rev. E 88 032109 (2013). [9] G. Odor, Phys. Rev. E 90, 032110 (2014).

*Speaker

Height fluctuations and universality relations in interacting dimer models

Alessandro Giuliani * [1], V. Mastropietro, F. Toninelli.

[1] Universita' degli Studi Roma Tre, Dip.to di Matematica e Fisica – Italy

We consider weakly interacting dimer models on the two-dimensional square lattice. By constructive renormalization group techniques, we compute the multipoint dimer correlations and all the moments of the height function. In particular, we rigorously establish the asymptotic equivalence between the height function and the massless Gaussian free field (GFF). The stiffness $K = K(\lambda)$ of the GFF is shown to be a non trivial analytic function of the interaction strength λ between dimers. We also prove one of the Haldane relations adapted to the present context, namely that K *equals* the dimer-dimer critical exponent X_+.

*Speaker

First-passage times for surface-mediated diffusion

D. S. Grebenkov * [1], J.-F. Rupprecht, O. Benichou, R. Voituriez

[1] Laboratoire de Physique de la Matière Condensée, CNRS - Ecole Polytechnique – France

We present an exact calculation of the mean first-passage time to a target on the surface of a 2D or 3D spherical domain, for a molecule alternating phases of surface diffusion on the domain boundary and phases of bulk diffusion. The presented approach is based on an integral equation which can be solved analytically. Explicit solutions are provided for normal and biased diffusion in a general annulus with an arbitrary number of regularly spaced targets on a partially reflecting surface. In the framework of this minimal model of surface-mediated reactions, we show analytically that the mean reaction time can be minimized as a function of the desorption rate from the surface. As a consequence, an intermittent exploration process may enhance search and reaction, as compared to pure surface diffusion or pure bulk diffusion. Our method is applicable to extended targets of arbitrary size (i.e., beyond the narrow escape limit). Higher-order moments and the probability distribution of the first-passage time can also be derived.

*Speaker

Temperature inversion in long-range-interacting systems, from atomic to astrophysical scales

Shamik Gupta * [1], Lapo Casetti, Pierfrancesco Di Cintio, Tarcisio N. Teles

[1] Max Planck Institute for the Physics of Complex Systems, Dresden, Germany – Germany

Temperature inversions occur in nature, e.g., in the solar corona and in interstellar molecular clouds: somewhat counterintuitively, denser parts of the system are colder than dilute ones. We try to understand which are the minimal ingredients and the basic physical mechanism behind such phenomena. We argue that temperature inversions may spontaneously occur in a generic many-particle classical Hamiltonian system with long-range interactions that is prepared in an inhomogeneous thermal equilibrium state and then brought out of equilibrium by applying an impulsive perturbation or by quenching some parameters of the Hamiltonian. In similar situations, short-range systems would typically relax to another thermal equilibrium, with uniform temperature profile. By contrast, in long-range-interacting systems, the perturbation induces collective oscillations and the interplay between wave-particle interaction and spatial inhomogeneity drives the system to nonequilibrium stationary states that generically exhibit nonuniform temperature profiles with temperature inversion. We demonstrate our findings by means of numerical simulations of simple mean-field toy models as well as of semiclassical models of cold atoms in a cavity and of two-dimensional self-gravitating systems, modeling nearly cylindrically-symmetric filaments in interstellar clouds. In the latter case we observe temperature inversion not only after perturbing a thermal equilibrium state, but also in cold collapses, that are believed to be the way these structures form, thus implying that dissipative processes are not necessary to obtain temperature inversions. In the case of models of condensed matter systems we show that temperature inversions triggered by quenching an external field may in principle be used to cool the system.

*Speaker

Polymers pulled from, and pushed towards, a wall

Tony Guttmann * [1], N R Beaton, I Jensen, G Lawler, S G Whittington

[1] The University of Melbourne – Australia

In recent years there have been important experiments involving the pulling of polymers from a wall. These are carried out with atomic force microscopes and other devices to determine properties of polymers, including biological polymers such as DNA. We have studied a simple model of this system, modelled by two-dimensional self-avoiding walks, anchored to a wall at one end and then pulled from the wall at the other end. In addition, we allow for binding of monomers in contact with the wall. Thus there are two parameters in the model, the strength of the interaction of monomers with the surface (wall), and the force, normal to the wall, pulling the polymer. We have constructed (numerically) the complete phase diagram, and can prove the locus of certain phase boundaries in that phase diagram, and also the order of certain phase transitions as the phase boundaries are crossed. We find, remarkably, that when walks or polygons are pushed toward the wall, there arises an unexpected stretched exponential term in the asymptotic expression for the number of configurations. We show explicitly that this can occur even if one uses random walks as the polymer model, rather than the more realistic self-avoiding walks. This situation has not yet been studied experimentally, as far as we are aware, but it would be interesting to do so.

*Speaker

Schramm-Loewner Evolution for watershed, shortest path and isoheight lines on correlated and anisotropic landscapes

Hans Herrmann * [1], J.S.Andrade, N.A.M. Araujo, H.F. Credidio, E.Daryaei, A.A. Moreira, N. Pose, S. Rouhani

[1] ETH Zürich – Switzerland

We show that watersheds dividing drainage basins on random landscapes follow the statistical properties of Schramm-Loewner evolution (SLE) curves. For this we numerically analyze the winding angle, the left passage probability, and the driving function of the shortest path and compare them to the distributions predicted for SLE curves with the same fractal dimension. The corresponding diffusivity is $\kappa = 1.734 \pm 0 : 005$, being the only physical example known up to now of an SLE with $\kappa < 2$. Furthermore, it suggests that watersheds likely correspond to a logarithmic conformal field theory with a central charge $c \approx -7 = 2$. In the same way, we also show that the shortest path on critical percolation clusters follows the statistical properties of SLE curves for $\kappa = 1.04 \pm 0.02$. Both watershed and shortest path result from a global optimization process and identifying them, requires exploring an entire area. Real landscapes exhibit long-range height-height correlations, which are quantified by the Hurst exponent H. We show that for negative H, in spite of the long-range nature of correlations, the statistics of isoheight lines is compatible with SLE curves and therefore can be mapped to random walks, their fractal dimension determining the diffusion constant. Exact results are recovered for H = -1 and H = 0. By contrast, for positive H, we find that the random walk is not Markovian but strongly correlated in time. We also discovered that the perimeters of multi-layered and directed percolation clusters at criticality are the scaling limits of the Loewner evolution of an anomalous Brownian motion, being superdiffusive and subdiffusive, respectively. The connection between anomalous diffusion and fractal anisotropy is further explored by using long-range power-law correlated time series (fractional Brownian motion) as driving functions in the evolution process. The fact that the resulting traces are distinctively anisotropic corroborates our hypothesis opening up perspectives to interprete non-Markovian processes in terms of anisotropic paths at criticality and vice-versa.

*Speaker

Exact results on Poisson-Voronoi cells in three dimensions

Henk Hilhorst * [1]

[1] Laboratoire de Physique Théorique – France

Given a set of point-like "seeds" in d-dimensional Euclidean space, the associated Voronoi tessellation is the partitioning of space into cells such that each point of space is in the cell of the seed to which it is closest. In the case of independent and uniformly distributed seeds one speaks of a Poisson-Voronoi tessellation. We will discuss the statistical properties of rare or "extreme" cells: those (in $d = 2$) that have a large number n of sides; or (in $d = 3$) that have a large number n_F of faces, or that have a face with a large number n_E of edges. Calculating the probability of such events reveals the entropic forces that are at play. Whereas microscopically we are facing a stochastic many-body problem, we will show that macroscopically there arise deterministic laws when n, n_F, or $n_E \to \infty$.

*Speaker

Thermalisation of a quantum system from first principles

G. Ithier * [1], F. Benaych-Georges

[1] Royal Holloway – United Kingdom

Why is thermalisation a universal phenomenon? How does a quantum system reach thermodynamical equilibrium? These questions are not new, dating even from the very birth of quantum theory and are surprisingly still open. With the recent progress in the quantum engineering of mesoscopic systems, these questions have undergone a renewed interest: understanding how thermalisation, and more generally irreversible processes at the macroscopic scale, emerge from the reversible quantum dynamics at the microscopic scale is becoming more urgent. Here we present a universal model solving this problem and showing that a sufficiently large quantum system can locally converge towards thermodynamical equilibrium state despite being globally in a quantum pure state which evolves unitarily. We show that the origin of universality lies in a generalized central limit theorem which provides a "typical" dynamics for small quantum systems embedded in large ones. Finally, we propose a new definition of the canonical partition function involving strictly quantum quantities and recovering the well known Boltzmann distribution as a particular case (http://arxiv.org/abs/1510.04352).

*Speaker

Complex Martingales and Determinantal Structures in Nonequilibrium Interacting Particle Systems

Makoto Katori * [1]

[1] Chuo University – Japan

Appearance of determinantal (free fermion) structures in the asymptotic solutions of the Kardar-Parisi-Zhang (KPZ) equation for random surfaces, the asymmetric simple exclusion process (ASEP) for traffic flows, and other stochastic systems studied in nonequilibrium statistical physics is remarkable, since these systems are not determinantal in general. In the present talk, a new point of view for determinantal processes is given using a notion called martingale used in probability theory [1]. Martingales are the stochastic processes preserving their mean values and thus they represent intrinsic fluctuations involved in the systems. In order to derive determinantal structures in the 1+1 dimensional spatio-temporal plane, we consider systems of martingales defined on a complex plane. These complex martingales in the 2+1 dimensions are obtained by conformal maps of a complex Brownian motion due to its conformal invariance. By averaging over imaginary components, we obtain 'physical' determinantal processes in the 1+1 dimensions. We demonstrate this machinery using the Dyson model and its trigonometric and elliptic extensions studied in random matrix theory [2], and the O'Connell process (the Whittaker measure), which is a stochastic version of the quantum Toda lattice [3] and is studied as a member of the KPZ universality class [4]. [1] M. Katori: Bessel Processes, Schramm–Loewner Evolution, and the Dyson Model, Springer Briefs in Mathematical Physics 11, Springer (2016). [2] M. Katori: Elliptic determinantal process of type A, Probab. Theory Relat. Fields, **162**, 637-677 (2015). [3] M. Katori: System of complex Brownian motions associated with the O'Connell process, J. Stat. Phys. **149**, 411-431 (2012). [4] A. Borodin, I. Corwin: Macdonald processes, Probab. Theory Relat. Fields, **158**, 225-400 (2014).

*Speaker

The distribution of path lengths of self avoiding walks on random networks

Eytan Katzav * [1],Ofer Biham , Reimer Kuhn, Mor Nitzan, Daniel ben-Avraham, Pavel L. Krapivsky, Nathan Ross

[1] The Hebrew University – Israel

Analytical and numerical results will be presented concerning the paths of self avoiding walks (SAWs) on random networks. Since these walks do not retrace their paths, they effectively delete the nodes they visit, together with their links, thus pruning the network. The walkers hop between neighboring nodes, until they reach a dead-end node from which they cannot proceed. Focusing on Erd
Hos-Rényi networks we show that the pruned networks maintain a Poisson degree distribution with an average degree that decreases linearly in time. We enumerate the SAW paths of any given length and find that the number of paths increases dramatically as a function of their length. We also obtain analytical results for the path-length distribution of the SAW paths which are actually pursued, starting from a random initial node. It turns out that it follows the Gompertz distribution, which means that the termination probability of an SAW path increases with its length. The implications of these results for various physical processes and their generalization to a broader class of networks will be discussed.

*Oral

Extension of the Lieb-Schultz-Mattis and Kolb theorems

Kiyohide Nomura * [1]

[1] Department of Physics, Kyushu University – Japan

Lieb, Schultz and Mattis (LSM) [1] studied the S=1/2 XXZ spin chain. Theorems of LSM's paper can be applied to broader models [2]. In these studies it was assumed the nonfrustrating system, in order to use the Perron-Frobenius theorem. Independently, Kolb [3] studied the energy spectra of the spin chain with the twisted boundary condition, and he obtained similar result as LSM. He also pointed out the change of the wave number as varying the twist boundary condition for non-zero magnetization. We have extended both theorems for frustrating case and asymmetric case(for example Dzyaloshinskii-Moriya type interactions), by using the squeeze type technique [4]. We have proved the periodicity and the continuity properties of the lowest energy spectra.

[1] E. Lieb, T. Schultz and D. Mattis: Annals of Physics, **16**, (1961), p. 407.

[2] I. Affleck and E. H. Lieb: Letters in Mathematical Physics. **12**, (1986) p.57.

[3] M. Kolb: Phys. Rev. B **31**, (1985) p. 7494.

[4] K. Nomura, J. Morishige, T. Isoyama: J. Phys. A: Math. Theor. Vol. 48 (2015) p.375001

*Speaker

Condensation properties of Bethe roots in the XXZ chain

Karol Kozlowski * [1]

[1] Laboratoire de Physique, Ens de Lyon – France

Within the Bethe Ansatz approach, the eigenvectors of the L-site XXZ spin 1/2 chain are parametrised by solutions to high degree algebraic equations in many variables: the Bethe equations. In order to compute the thermodynamic limit $L \to +\infty$ of the *per*-site ground state energy, Húlten conjectured in 1938 that the Bethe roots describing the model's ground state are real and form a dense distribution in the $L \to +\infty$ limit. In fact, the whole description of the thermodynamic limit of the chain (form of the excitations, conformal structure of the low-energy spectrum, integral representation for the zero temperature correlation functions, large-L behaviour of the form factors of local operators) is based on some variant of Húlten's conjecture. In 2009, Dorlas and Samsonov managed to prove this conjecture in a regime of the anisotropy where it is possible to build the analysis on convexity arguments *á la* Yang and Yang. After having recalled the history of the problem and its various applications, I will present the main ideas of the method that I developed so as to prove condensation properties of Bethe roots corresponding to certain classes of solutions to the Bethe equations. The method works independently of the value taken by the anisotropy and appears to be generalisable to many other quantum integrable models. This talk is based on the work K. K. Kozlowski, *On densification properties of Bethe roots*, math-ph : 1508.05741.

*Speaker

Dating Random Walks

Hernán Larralde * [1]

[1] Instituto de Ciencias Físicas, UNAM – Mexico

We consider the distribution of the duration time, i.e. the time elapsed since it began, of a diffusion process given its present position, under the assumption that the process began at the origin. For unbiased diffusion, the distribution does not exist (it is identically zero) for one- and two-dimensional systems due to the recurrent nature of the process. We find the explicit expression for the distribution for three and higher dimensions and discuss the behavior of the duration time statistics: we find that the expected duration time exists only for dimensions five and higher, whereas the variance becomes finite for seven dimensions and above. We then turn to other cases, for example, the case of biased diffusion, for which the drift velocity introduces a new time scale and the resulting statistics arise from the interplay of the diffusive and the drift time scales. Finally, we comment on the case in which the initial position of the process is not known.

*Speaker

Fluctuation of the free energy of the spherical spin glass model

Ji Oon Lee * [1]

[1] KAIST – South Korea

The spherical Sherrington-Kirkpatrick model is a spherical mean field model for spin glass. We consider the fluctuations of the free energy for the 2-spin model with no magnetic field. We show that the laws of the fluctuations converge to the Gaussian distribution or the GOE Tracy-Widom distribution, depending on the temperature. The free energy fluctuation for non-Gaussian interactions and non-zero mean interactions will also be discussed.

*Speaker

Macroscopic system with undamped periodic compressional oscillations

Francois Leyvraz * [1], F. Calogero

[1] Instituto de Ciencias Físicas-Universidad Nacional Autonoma de Mexico – Mexico

A class of macroscopic systems is described which have the remarkable feature that they can sustain undamped compressional radial oscillations. The simplest example consists of an arbitrary number of particles confined by a harmonic potential and interacting among themselves through conservative forces scaling as the inverse cube of distances. The radial oscillation leads to a variation of the thermodynamic quantities characterizing the system. The system therefore does not approach equilibrium, since the (macroscopic) amplitude of the oscillation does not decrease as time goes to infinity. The oscillation is harmonic and isochronous, that is, its frequency is fixed and independent of the initial condition. These results hold independently of the dimension of the system and are also valid in the quantal context.

*Speaker

Multi-state extension of the asymmetric simple exclusion process

Chihiro Matsui * [1]

[1] The University of Tokyo – Japan

There are few far-from-equilibrium systems which are analytically solvable. One of those examples is the asymmetric simple exclusion process (ASEP). The ASEP is an integrable two-state stochastic process in one dimension. The integrability of the model lies in the Uq(sl2)-invariance of the bulk part. We consider the multi-state extension of the ASEP based on the fact that the Markov matrix of this process satisfies the Temperley–Lieb algebra. Besides the construction of steady states, we derive the exact expressions of particle-density profiles and currents on the steady states under the closed boundary condition. Although strong restrictions are imposed on hopping rates to keep integrability, we show that they are simplified in the limit q to 0.

*Speaker

Eigenvalue Attraction

Ramis Movassagh * [1]

[1] IBM TJ Watson Research Center, Yorktown Heights – United States

Much work has been devoted to the understanding of the motion of eigenvalues in response to randomness. The folklore of random matrix analysis, especially in the case of Hermitian matrices, suggests that the eigenvalues of a perturbed matrix repel. We prove that the complex conjugate (c.c.) eigenvalues of a smoothly varying real matrix attract. We offer a dynamical perspective on the motion and interaction of the eigenvalues in the complex plane, derive their governing equations and discuss applications. C.c. pairs closest to the real axis, or those that are ill-conditioned, attract most strongly and can collide to become exactly real. We apply the results to the Hatano-Nelson model, random perturbations of a fixed matrix, real stochastic processes with zero-mean and independent intervals and discuss open problems. Reference : Journal of Statistical Physics, Feb. 2016, Volume 162, Issue 3, pp 615-643 http://link.springer.com/article/10.1007/s10955-015-1424-5

*Speaker

Parafermions in the tau2 model

Jacques H.H. Perk * [1], Helen Au-Yang

[1] Oklahoma State University – United States

The search for Yang-Baxter solvable lattice models with a parafermionic scaling limit has led to the discovery of the N-state integrable chiral Potts model, see e.g. the review [1]. In the study of the model one is led to consider the Boltzmann weights of a star or square of four of its pair interactions. With special choices of the parameters this reduces to the weights of the inhomogeneous τ_2 model with fixed boundary conditions introduced by Baxter leading him to find a "simple" quantum spin chain Hamiltonian with a particularly simple spectrum. Very recently Fendley [2] put forward a way to study this Hamiltonian in terms of "free parafermions." Baxter [3] then generalized Fendley's ideas to the more general τ_2 model provided a number of conjectures hold, after which we managed to prove [4] some of these conjectures. We will compare the different notations and approaches enabling us to express the Hamiltonians in terms of projection operators as introduced by Fendley. By examining the properties of the raising operators, we are able to prove the last unproven conjecture in Baxter's paper. Thus the eigenvectors can all be written in terms of these raising operators.

1. J.H.H. Perk, J. Phys. A: Math. Theor. **49** (2016) 153001 [arXiv:1511.08526].

2. P. Fendley, J. Phys. A: Math. Theor. **47** (2014) 075001 [arXiv:1310.6049].

3. R.J. Baxter, J. Phys. A: Math. Theor. **47** (2014) 315001 [arXiv:1310.7074].

4. H. Au-Yang and J.H.H. Perk, J. Phys. A: Math. Theor. **47** (2014) 315002 [arXiv:1402.0061].

*Speaker

Eigenvector overlap and estimation of large noisy matrices

Marc Potters * [1], Joel Bun, Jean-Philippe Bouchaud

[1] Capital Fund Management – France

We consider a large symmetric matrix corrupted by additive or multiplicative rotational invariant noise. For example, the sample covariance matrix can be written as the true covariance matrix multiplied by a random Wishart matrix. The optimal estimator of the true matrix requires the knowledge of eigenvector overlaps between the true matrix and its noisy version. Extending the work of Ledoit and Péché we compute these overlaps and find the optimal estimator for a large class of additive and multiplicative processes. We also show how to compute the eigenvector overlaps between two noisy matrices with different realization of the noise. In particular we find explicit formulas for the eigenvector overlaps of two large correlated defromed GOE matrices.

*Speaker

Convergence of Mayer and Virial expansions and the Penrose tree-graph identity

Aldo Procacci * [1], Sergio Yuhjtman

[1] Departamento de Matemática - Universidade Federal Minas Gerais - Belo Horizonte - Brasil – Brazil

We establish new lower bounds for the convergence radius of the Mayer series and the Virial series of a continuous particle system interacting via a stable and tempered pair potential. Our bounds considerably improve those given by Penrose and Ruelle in 1963 for the Mayer series and by Lebowitz and Penrose in 1964 for the Virial series. To get our results we exploit the tree-graph identity given by Penrose in 1967 using a new partition scheme based on minumum spanning trees.

*Speaker

Finite-time fluctuations for TASEP on the relaxation scale

Sylvain Prolhac * [1]

[1] LPT, IRSAMC, Université Paul Sabatier, Toulouse – France

The totally asymmetric simple exclusion process (TASEP) is a Markov process describing N particles hopping forward on a one-dimensional lattice of L sites. The periodic model evolving during a time T has been studied recently on the relaxation time scale when N, L, T go to infinity with finite density $\rho = N/L$, and finite rescaled time $t = T/L^{3/2}$ characteristic of KPZ universality. Exact expressions have been obtained for the average density profile, for the stationary two-point function, and for the probability density of current fluctuations for simple initial conditions. At small t, the distribution of current fluctuations converge to the Tracy-Widom distributions that describe current fluctuations of TASEP on the infinite line. At large t, one recovers the stationary large deviation function of the current. The finite t formulas have a nice interpretation in terms of a functional integral with the action of a scalar field in a linear potential.

*Speaker

Quasilocal integrals of motion in integrable lattice systems

Tomaz Prosen * [1]

[1] University of Ljubljana, Faculty of Mathematics and Physics – Slovenia

I will review recent progress in understanding the notion of locality in integrable quantum lattice systems. The central concept are the so-called quasilocal conserved quantities, which go beyond the standard perception of locality. Two systematic procedures to rigorously construct families of quasilocal conserved operators based on quantum transfer matrices are outlined, specializing on anisotropic Heisenberg XXZ spin-1/2 chain. Quasilocal conserved operators stem from two distinct classes of representations of the auxiliary space algebra, comprised of unitary (compact) representations, which can be naturally linked to the fusion algebra and quasiparticle content of the model, and non-unitary (non-compact) representations giving rise to charges, manifestly orthogonal to the unitary ones. Various condensed matter applications in which quasilocal conservation laws play an essential role are presented, with special emphasis on their implications for anomalous transport properties (finite Drude weight) and relaxation to non-thermal steady states in the quantum quench scenario.

*Speaker

Thermodynamic entropy as a Noether invariant

Shin-Ichi Sasa * [1], Yuki Yokokura

[1] Kyoto University – Japan

Entropy is a fundamental concept in physics. It appears in thermodynamics, statistical mechanics, information theory, computation theory, and thermodynamics of black holes. Recently, the inter-relation between different types of entropy has been discovered. By synthesizing various aspects of entropy, we thus obtain a deeper understanding of fundamental laws in physics. Now, there is a paper [1], which claims that black hole entropy is obtained as the Noether charge associated with the horizon Killing field. We are then naturally led to ask whether thermodynamic entropy of standard materials is also characterized by a Noether invariant. In the presentation, we study a classical many-particle system with an external control represented by a time dependent parameter in a Lagrangian. We show that thermodynamic entropy of the system is uniquely characterized as the Noether invariant associated with a symmetry for an infinitesimal non-uniform time translation, where trajectories in the phase space are restricted to those consistent with quasi-static processes in thermodynamics [2]. The most remarkable result of our theory is the emergence of a universal constant of the action dimension, while our theory stands on classical mechanics, classical statistical mechanics, and thermodynamics. [1] R. M. Wald, Phys. Rev. D 48 R3427 (1993). [2] S. Sasa and Y. Yokokura, Phys. Rev. Lett. (in press); http://arxiv.org/abs/1509.08943

*Speaker

Aging dynamics of evolutionary and glassy systems: intermittency, hierarchies and record ecvents

Paolo Sibani * [1], Christian Walther Andersen

[1] University of Southern Denmark – Denmark

The Tangled Nature Model (TNM) describes key emergent features of biological [1] and cultural [2,3] ecosystems' evolution. based on the stochastic dynamics of interacting agents which reproduce, mutate and die, We present key aspects of the TNM dynamics, including temppral and spatial intermittency highlight its strong similarities with the aging dynamics of glassy systems, and argue that the latter is rooted in a hierarchical organization of configuration space where crossing dynamical barriers of record magnitude triggers large and irreversible rearrangements of the system configuration.

[1] Matt Hall, Kim Christensen, Simone A. di Collobiano, and Henrik Jeldtoft Jensen.

[2] A.E Nicholson and P Sibani. Cultural evolution as a nonstationary stochastic process. *Compl]exity*, 2015.

[3] Rudy Arthur, Arwen Nicholson, Paolo Sibani and Michael Christensen. The Tangled Nature Model for Organizational Ecology. *Computational and Mathematical Organization Theory*, 2016.

[4] Nikolaj Becker and Paolo Sibani. Evolution and non-equilibrium physics: A study of the Tangled Nature Model. *EPL*, 105:18005, 2014.

*Speaker

Phase separation, interfaces and vicious walkers in a wedge. Exact results from field theory

Alessio Squarcini * [1], Gesualdo Delfino

[1] Max Planck Institute for Intelligent Systems – Germany

We give the exact theory of phase separation in a planar wedge, the prototypical example for the effects of substrate geometry on interfacial properties. We consider the basic case of a single interface, as well as that allowing for an intermediate wetting layer of a third phase. Using low energy properties of two-dimensional field theory we determine order parameter profiles and passage probabilities for interfaces with endpoints on the boundary. The fundamental origins of the wedge filling transition and of the property known as wedge covariance are explained. We also show that the interfaces enclosing an intermediate phase behave as trajectories of vicious walkers, whose passage probability emerges from an interesting mathematical structure involving self-Fourier functions. References: Gesualdo Delfino, and A.S., Phase separation in a wedge. Exact results, Physical Review Letters 113, (2014) 066101, Gesualdo Delfino, and A.S., Multiple phases and vicious walkers in a wedge, Nuclear Physics B 901 (2015) 430,

*Speaker

Level Statistics and Localization Transitions of Lévy Matrices

Elena Tarquini * [1], Giulio Biroli, Marco Tarzia

[1] IPhT - Université Paris Saclay - CEA – France

Random Matrix Theory (RMT) has found succesful applications in many areas of physics and other research fields such as wireless communications, financial risk, biology. The reason for such versatility is that RMT is able to provide universal results, independent of the specific probability distribution of the random entries. The most commonly studied RMs belong to the Gaussian ensembles. However, a large set of matrices fall out the universality classes based on the Gaussian paradigm. These are obtained when the entries are heavy-tailed i.i.d. random variables. The reference case for this universality class corresponds to entries that are Lévy distributed. By analyzing the self-consistent equation on the probability distribution of the diagonal elements of the resolvent we estabilish the equation determining the localization transition and obtain the phase diagram. Using arguments based on supersymmetric field theory and Dyson Brownian motion we show that the eigenvalue statistics is the same one as of the Gaussian orthogonal ensemble in the whole delocalized phase and is Poisson in the localized phase. Our numerics confirm these findings, but also reveal that the characteristic scale governing finite size effects diverges much faster than a power law approaching the transition and is already very large far from it. This leads to a very wide crossover region in which the system looks as if it were in a mixed phase. Our results, together with the ones obtained previously, now provide a complete theory of Lévy Matrices.

*Speaker

Integrable dissipative exclusion process

Matthieu Vanicat * [1], Nicolas Crampe, Eric Ragoucy

[1] LAPTh Annecy – France

I will present a one-parameter generalization of the symmetric simple exclusion process on a one dimensional lattice. In addition to the usual dynamics (where particles can hope with equal rate to the left or to the right with an exclusion constraint), annihilation and creation of pairs can occur. The system is driven out of equilibrium by two reservoirs at the boundaries. In this setting the model is still integrable: it is related to the open XXZ spin chain through a gauge transformation. This allows us to compute the full spectrum of the Markov matrix using Bethe equations. Then, we deduce the spectral gap in the thermodynamical limit. We also show that the stationary state can be expressed in a matrix product form permitting to compute the multi-points correlation functions as well as the mean value of the lattice current and of the creation-annihilation current. Finally the variance of the lattice current is exactly computed for a finite size system. In the thermodynamical limit, it matches perfectly the value obtained from the associated macroscopic fluctuation theory. It provides a confirmation of the macroscopic fluctuation theory for dissipative system from a microscopic point of view.

*Speaker

Extreme Value Statistics for Fractional Brownian Motion

Kay J. Wiese * [1], Mathieu Delorme

[1] LPTENS – France

Brownian motion is the only random process which is Gaussian, stationary and Markovian. Dropping the Markovian property, i.e. allowing for memory, one obtains a class of processes called Fractional Brownian motion (fBm), indexed by the Hurst exponent H. For H=1/2, Brownian motion is recovered. We develop a perturbative approach to treat the non-locality in time in an expansion in H-1/2. This allows us to derive analytic results beyond scaling exponents for various observables related to extreme value statistics: (1) The maximum of the process and the time at which this maximum is reached, as well as their joint distribution. (2) the time a fBm stays positive. (3) the last time a fBm returns to its initial position. While for Brownian motion these observables are all distributed as an arcsine law, for fBm each has a distribution of its own. We then discuss fractional Brownian bridges, i.e. processes which return to their initial position. We finish with new analytical predictions for Pickands constant.

*Speaker

Universal behavior of n(p), the number of clusters, in percolation

Robert Ziff * [1], Stephan Mertens, Magdeburg Iwan Jensen, Peter Kleban

[1] University of Michigan – France

We discuss properties of the function $n(p)$ that gives the number of percolation clusters on a lattice, a fundamental quantity that is effectively the free energy of the percolation function. It has been studied for many years, starting with the work of Domb, Sykes, and Essam in the 1960's. While $n(p)$ is a rather smooth and non-universal function which shows a very weak singularity at the critical threshold p_c, its universality can be found in its derivatives and finite-size behavior. We use Monte Carlo, exact enumeration, series analysis and theoretical results to characterize the values and derivatives of $n(p)$ to high precision. The use of a lattice and its matching lattice (based upon the connectivity of the white sites) yields very precise results for corrections to scaling, and the matching polynomial analysis of Sykes and Essam from 1964 is generalized for finite periodic systems, related to the cluster cross-configuration probabilities. Using results in conformal field theory, the finite-size corrections are shown to be universal shape dependent quantities, that can be calculated exactly. Many open questions are suggested by this work.

*Speaker

Topic 2: Out-of Equilibrium Aspect-Oral

Universal and non-universal kinetics of the coalescing random walk: exciton reactions on carbon nanotubes

Jeremy Allam * [1], M. T. Sajjad, R. Sutton, K. Litvinenko, S. Siddique

[1] University of Surrey – United Kingdom

Simple reaction-diffusion systems such as the coalescence and annihilation of random walkers have been widely studied as prototypes for a variety of non-equilibrium many-body systems occurring in nature, technology and society. However, well-controlled experiments are notoriously challenging and "deplorably rare" [1]. The coalescing random walk (CRW) in 1D is of particular interest both because it can be exactly solved (for instantaneous short-range interactions) [2], and because the anomalously-slow asymptotic kinetics have been observed in experiments on exciton-exciton recombination processes in quasi-1D materials [3]. Recently we have shown that exciton reactions on semiconducting carbon nanotubes provides a close experimental realization of the 1D CRW with excellent control of dimensions and dimensionality, allowing identification of regions of reaction-limited and diffusion-limited kinetics [4]. Here we perform femtosecond pump-probe on DNA-wrapped carbon nanotubes in order to study the kinetics of the CRW both before and after the 'universal' intermediate asymptotic region. At very early times, the kinetics approaches the classic diffusion-limited Smoluchowski behaviour [5], with a divergent reaction rate that indicates a random spatial distribution of particles. At asymptotically long times, the reaction rate is found to be renormalized by a factor of approximately pi/2 [6] consistent with a spatial ordering of the nearest-neighbour pair separations [2]. Experiments in the regime of few particles per nanotube suggest that correlation of nearest neighbour pairs is sufficient to explain the modified reaction rate. In contrast to existing theory, the crossovers are found to be abrupt and non-monotonic: strikingly similar to equilibrium mixtures of complex liquids [7]. We attribute this to long-range (probably dipolar) interactions, and highlight the important consequences for the observability of anomalous asymptotic kinetics in a situation where both the rate and the range of particle-particle interactions are finite. These results demonstrate the possibility of detailed experimental elucidation of non-equilibrium critical kinetics extending well beyond the identification of asymptotic universality classes, and allowing quantitative comparison with theory. We acknowledge support from EPSRC (grants EP/C010531/ 1 and EP/C010558/1). [1] Tauber, U. C. Critical Dynamics. (Cambridge University Press, 2014). [2] Ben-Avraham, D. Diffusion and Reactions in Fractals and Disordered Systems (CUP 2000). [3] Kopelman, R. Fractal reaction kinetics. Science 241, 1620-1626 (1988). [4] Allam, J. et al. Measurement of a Reaction-Diffusion Crossover in Exciton-Exciton Recombination inside Carbon Nanotubes Using Femtosecond Optical Absorption. Phys. Rev. Lett. 111, 197401 (2013). [5] Smoluchowski, M. V. Versuch einer mathematischen Theorie der Koagulationskinetik kolloider Lösungen. Z. Phys. Chem. 92, 129-168 (1917). [6] Torney, D. C. & McConnell, H. M. Diffusion-limited reactions in one dimension. J. Phys. Chem. 87, 1941-1951 (1983). [7] M. A. Anisimov, M. et al. Nature of Crossover between Ising-like and Mean-Field Critical Behavior in Fluids and Fluid Mixtures, Phys. Rev. Lett. 75, 3146 (1995).

*Speaker

Field driven dynamics of a binary colloidal mixture

Nuno A. M. Araujo * [1], A. S. Nunes M. M. Telo da Gama

[1] University of Lisbon – Portugal

Spatially-varying periodic fields may be used to position colloidal particles into desired structures. Under such external constraints, even single component suspensions can be driven out of equilibrium. The relaxation towards equilibrium involves the competition of various mechanisms occurring at different length and time scales. For multicomponent suspensions, the dynamics is even richer, for the response of each component to the field is in general different. We combined Brownian dynamics and the simplest dynamic density-functional theory to study the response of a binary mixture of colloids with distinct mobilities (hydrodynamic radii) to a periodic field. Even for purely repulsive, identical pairwise colloid-colloid interactions, we found dynamic demixing, in a wide region of the parameter space, driven by rapid accumulation of the high mobility colloids around the zero-field minima. The lifetime of this non-equilibrium demixed state diverges when the high mobility colloids crystallize. Pratical implications of our findings are also discussed.

*Speaker

Relaxation dynamics in lattices with long-range interactions

Romain Bachelard * [1], Michael Kastner

[1] Instituto de Física de São Carlos/Universidade de São Paulo – Brazil

Systems with long-range interactions often exhibit a very slow relaxation to equilibrium, that may even take forever in the thermodynamic limit. Their long-lived out-of-equilibrium states may consequently correspond to the only physical accessible regime, and themselves have special features (out-of-equilibrium phase transitions, phase re-entrance, etc.). We here investigate lattices with power-law decaying interaction term, from both a classical and quantum perspective: It is shown that both kinds of systems exhibit system-size dependent relaxation times with, in particular, the existence of a common dynamical threshold. The short-time dynamics, time scales on which perturbations and correlations propagate, is also investigated, using the tool known as Lieb-Robinson bounds: Also yielding system-size dependent time scales, these bounds are shown to describe very well the propagation in space and time of such perturbations/correlations. [Ref.1] R. Bachelard, M. Kastner, Phys. Rev. Lett. 110, 170603 (2013) [Ref.2] D. Métivier, R. Bachelard, M. Kastner, Phys. Rev. Lett. 112, 210601 (2014)

*Speaker

Applicability of hydrodynamic theories for extreme current fluctuations

Yongjoo Baek * [1], Yariv Kafri, Vivien Lecomte

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Current fluctuations in boundary-driven diffusive systems are often studied using hydrodynamic theories, whose predictions are expected to be valid for currents scaling inversely with the system size. To check how far such theories are applicable, we introduce a class of large-N models of one-dimensional boundary-driven diffusive systems, whose current large deviations are exactly solvable. Surprisingly, we find that for some systems the predictions of the hydrodynamic theory hold well beyond its naive regime of validity. Specifically, we show that, while a symmetric partial exclusion process exhibits non-hydrodynamic behaviors for sufficiently large currents, a symmetric inclusion process is well described by the hydrodynamic theory for arbitrarily large currents. We conjecture, and verify for zero-range processes, that the hydrodynamic theory captures the statistics of arbitrarily large currents when the mobility coefficient as a function of density is not bounded from above.

*Speaker

Temperature response of nonequilibrium systems

Marco Baiesi * [1], Gianmaria Falasco, Cem Yolcu, Urna Basu, Christian Maes

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For general nonequilibrium systems, ranging from climate models to aging systems, it should be useful to understand and predict the response to temperature(s) changes from observations of the unperturbed systems. The standard fluctuation-dissipation theorem cannot be applied out of equilibrium, and knowing only about the dissipative behavior triggered by the perturbation is not enough for characterizing a general linear response. We discuss a recent line, based on path integrals, which organizes the thermal linear response of stochastic systems in terms of correlations including both entropy production and non-dissipative, kinetic observables. Peculiar singularities of the path measures, absent in the more usual response to mechanical forces, are solved with a novel approach. As a result, for instance, we can compute nonequilibrium heat capacities and thermal expansion coefficients.

*Speaker

Thermodynamic uncertainty relation for biomolecular processes

Andre C Barato * [1], Udo Seifert

[1] MPIPKS – Germany

Biomolecular systems like molecular motors or pumps, transcription and translation machinery, and other enzymatic reactions can be described as Markov processes on a suitable network. We show quite generally that in a steady state the dispersion of observables like the number of consumed/produced molecules or the number of steps of a motor is constrained by the thermodynamic cost of generating it. An uncertainty ϵ requires at least a cost of $2kBT/\epsilon^2$ independent of the time required to generate the output.

*Speaker

Order Parameter Scaling in Fluctuation-dominated Phase Ordering

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In a class of nonequilibrium systems, fluctuations are anomalously strong but coexist with long-range order, leading to fluctuation-dominated phase ordering (FDPO). The signature of FDPO is a singularity in the scaled two-point function, implying the breakdown of the Porod law in such systems. FDPO occurs in a variety of systems: passive scalar particles advected by a noisy Burgers fluid or fluctuating surfaces, models of active biological systems and granular media, and experiments on vibrated rods. Here we discuss the static and dynamic aspects of the order parameter. We argue that a single order parameter does not suffice to characterize the order, and we need to monitor a larger, infinite, set of one-point functions. This set is built from long-wavelength Fourier components of the density profile, and captures an essential aspect of the state, namely the continuous breakup and re-emergence of particle-rich regions. For a system of passive particles sliding on a fluctuating surface and for a related coarse-grained depth model, our numerical studies show that these modes are each populated for a finite fraction of time. We show that they have probability distributions which remain broad in the thermodynamic limit, that they are anti-correlated with each other, and that the probability distributions for different system sizes L are described by simple scaling laws. For instance, the mean value $Q(m, L)$ of mode m follows the scaling form $L^x Q(m, L) = Y(m/L)$, where the critical exponent x is related to the singularity in the two-point function. Further, the temporal behavior shows an interesting scaling property: the flatness, related to dynamical structure functions, is found to exhibit a divergence at a small argument, indicating that the behavior in time is intermittent.

*Speaker

Stochastic thermodynamics of boundary driven open quantum systems

Felipe Barra * [1]

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Stochastic thermodynamics has been formulated for open quantum systems weakly coupled to the environment and for quantum systems whose interaction with the environment is actively controlled [1] . Here we consider the stochastic thermodynamics of systems actively and locally coupled to the environment, evolving with a so-called boundary-driven Lindblad equation. Starting from a unitary description of the system plus the environment we simultaneously obtain the Lindblad equation and the appropriate expressions for heat, work and entropy-production of the system. We discuss the entropy production and work fluctuation theorems and illustrate our findings in spin 1/2 chains and explain why an XX chain coupled in this way to a single heat bath relaxes to thermodynamic-equilibrium while and XY chain does not. Additionally, we show that an XX chain coupled to a left and a right heat baths behaves as a quantum engine, a heater or refrigerator depending on the parameters, with efficiencies bounded by Carnot efficiencies. [2]

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*Speaker

Large deviations and out of equilibrium noisy scalar conservation laws

Julien Barré * [1], Cédric Bernardin, Raphaël Chétrite

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Noisy hyperbolic dynamics have been much less studied than their diffusive counterparts ; yet they appear naturally as limits of systems of interacting particles. We focus here on scalar conservation laws. When a suitable Einstein relation is satisfied, several authors have uncovered a beautiful link between the " entropy " (in the sense of conservation laws) and the large deviation functional for the fluctuating field. We will discuss a partial generalization of these results to out-of-equilibirum situations, when the Eisnstein relation is not satisfied.

*Oral

The quest for the missing noise in a micro-mechanical system out of equilibrium

Ludovic Bellon * [1], Mickael Geitner, Felipe Aguilar Sandoval, Eric Bertin

[1] Univ Lyon, Ens de Lyon, Univ Claude Bernard, CNRS, Laboratoire de Physique – France

Equipartition principle plays a central role in the understanding of the physics of systems in equilibrium: the mean potential and kinetic energy of each degree of freedom equilibrates to $k_BT/2$, with k_B the Boltzmann constant and T the temperature. This equality is linked to the fluctuation-dissipation theorem (FDT): fluctuations of one observable are proportional to the temperature and dissipation in the response function associated to that observable. In non equilibrium situations however, such relations between fluctuations and response are not granted, and *excess* noise is usually expected to be observed with respect to an equilibrium state.

In this presentation, we show that the opposite phenomenon can also be experimentally observed: a system that fluctuates *less* than what would be expected from equilibrium ! Indeed, when we measure the thermal noise of the deflexion of a micro-cantilever subject to a strong stationary temperature gradient (and thus heat flow), fluctuations are much smaller that those expected from the system mean temperature.

We will first present the experimental system, an atomic force microscope (AFM) micro-cantilever in vacuum heated at its free extremity with a laser. We will show that this system is small enough to have discrete degrees of freedom but large enough to be in a non-equilibrium steady state (NESS). We will then estimate its temperature profile with the mechanical response of the system [1], and observe that equipartition theorem can not be applied for this NESS: the thermal noise of the system is roughly unchanged while its temperature rises by several hundred degrees ! We will explain how a generalized FDT taking into account the temperature field can account for these observations, if dissipation is not uniform. Further experimental evidences of the validity of this framework will conclude the presentation.

We acknowledge the support of ERC project OutEFLUCOP and ANR project HiResAFM.

[1] Felipe Aguilar Sandoval, Mickael Geitner, Eric Bertin and Ludovic Bellon, *Resonance frequency shift of strongly heated micro-cantilevers*, Journal of Applied Physics **117**, 234503 (2015)

*Speaker

Coupling spin to velocity: collective motion of Hamiltonian polar particles

Eric Bertin * [1], S.L. Bore, M. Schindler, K.-D.N.T. Lam, O. Dauchot

[1] LIPhy, CNRS and Univ. Grenoble Alpes – France

We propose a conservative two-dimensional particle model in which particles carry a continuous and classical spin. The model includes standard ferromagnetic interactions between spins of two different particles, and a nonstandard coupling between spin and velocity of the same particle inspired by the coupling observed in self-propelled hard discs. Because of this coupling Galilean invariance is broken and the conserved linear momentum associated to translation invariance is not proportional to the velocity of the center of mass. Also the dynamics is not invariant under a global rotation of the spins alone. This, in principle, leaves room for collective motion and thus raises the question whether collective motion can arise in Hamiltonian systems. We study the statistical mechanics of such a system, and show that, in the fully connected (or mean-field) case, a transition to collective motion does exist. Interestingly, the velocity of the center of mass, which in the absence of Galilean invariance, is a relevant variable, also feeds back on the magnetization properties, as it acts as an external magnetic field that smoothens the transition. Molecular dynamics simulations of finite size systems indeed reveal a rich phase diagram, with a transition from a disordered to a homogeneous polar phase, but also more complex inhomogeneous phases with local order interrupted by topological defects. Reference: "Coupling spin to velocity: collective motion of Hamiltonian polar particles" S.L. Bore, M. Schindler, K.-D.N.T. Lam, E. Bertin, O. Dauchot, J. Stat. Mech. 033305 (2016)

*Speaker

Stationary and Transient Fluctuation Theorems for Effective Heat Fluxes between Hydrodynamically Coupled Particles in Optical Traps

Antoine Bérut * [1], Alberto Imparato, Artem Petrosyan, Sergio Ciliberto

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We experimentally study the statistical properties of the energy fluxes between two trapped Brownian particles, interacting through dissipative hydrodynamic coupling, and submitted to an effective temperature difference ΔT. The particles are trapped by optical tweezers, and the effective temperature gradient is obtained by randomly displacing the position of one of the two traps. We identify effective heat fluxes between the two particles by analogy with the definition of stochastic heat for a single particle. We show that the average of these fluxes are linear functions of the temperature difference, but do not verify energy conservation due to the dissipative nature of the hydrodynamic coupling. We also show that these fluxes satisfy an exchange Fluctuation Theorem (xFT) in the stationary state: : $\ln\left(\frac{P(Q_\tau)}{P(-Q_\tau)}\right) \underset{\tau\to\infty}{=} \frac{1}{k_B}\left(\frac{1}{T_1}-\frac{1}{T_2}\right)Q_\tau$ where k_B is the Boltzmann constant, and $P(Q_\tau)$ is the probability that an amount of effective heat Q_τ is exchanged during a time τ between the two systems at effective temperatures T_1 and T_2. Furthermore, after the sudden application of a temperature gradient ΔT, the total hot-cold flux satisfies a transient xFT for any integration time τ, whereas the total cold-hot flux only does it asymptotically for long times. This asymmetric behavior has been predicted for systems with a conservative coupling and we extend it here to the case of a viscous coupling.

*Speaker

Long velocity tails in plasmas and gravitational systems

Léon Brenig, Service De Physique Des Systèmes Dynamiques. Faculté Des Sciences. Université Libre De Bruxelles (ulb). Belgium. * [1], Yassin Chaffi, Tarcisio Marciano Rocha Filho

[1] Université Libre de Bruxelles – Belgium

Long tails in the velocity distribution are frequently observed in non-equilibrium plasmas and gravitational systems. Tails behaving as $1/v^{(5/2)}$ are obtained in numerical simulations and experiments for times much shorter than the characteristic time of the relaxation towards equilibrium. As we show here, these heavy tails are related to the fluctuations of the total force field exerted on any particle of the system by the remaining particles. These fluctuation originate from the divergence in $1/r^2$ at short distances of the binary interaction force. Starting from the BBGKY hierarchy representation of Statistical Mechanics we derive this mechanism. It is represented by an additional term in the Vlasov equation. This new term contains a fractional power 3/4 of the Laplacian in velocity space. Solving the new kinetic equation for a uniform system, the observed $1/v^{(5/2)}$ tail for the time dependant velocity distribution is retrieved. Numerical simulations by molecular dynamics confirm this result.

*Speaker

Kinetic theory of stellar systems

Pierre-Henri Chavanis * [1]

[1] Laboratoire de Physique Theorique de Toulouse – France

The collisional evolution of stellar systems is usually described by the Fokker-Planck equation introduced by Chandrasekhar or by the Landau equation. These equations rely on a local approximation (as if the system were spatially homogeneous) and neglect collective effects (i.e., the dressing of the stars by their polarisation cloud). In this talk, we consider more general kinetic equations that take into account spatial inhomogeneity through the use of angle-action variables (gravitational Landau equation) and collective effects through a response matrix (gravitational Lenard-Balescu equation). These equations have recently been applied to stellar discs, providing excellent agreement with direct numerical simulations. We also point out beautiful analogies between stellar systems and two-dimensional vortices.

*Speaker

Fronts of compact bacterial colonies are not in the KPZ universality class

Rodolfo Cuerno * [1], Silvia N. Santalla, Javier Rodríguez-Laguna, José P. Abad, Irma Marín, María del Mar Espinosa, Javier Muñoz-García, Luis Vázquez

[1] Universidad Carlos III de Madrid – Spain

The rich growth patterns found in bacterial colonies have attracted a large attention from the communities of biologists, physicists, and mathematicians. As a function of the mobility and the nutrient concentration, the fronts of bacterial colonies are known to display a variety of behaviors, some of them believed to correspond to universality classes of non-equilibrium interface growth [1]. We focus in the low mobility regime, in which the properties of the colony front correlate, e.g., with cooperative properties of speci.c cell phenotypes [2]. According to the established view, for low nutrient concentration the colony extends fractal .ngers in order to optimize access to nutrients. The fronts are then considered to be described by the paradigmatic diffusion-limited-aggregation (DLA) growth model. For higher nutrient concentration, more compact morphologies show up. The universality class usually expected [1, 3] under these conditions is that of the Eden model, namely, the Kardar-Parisi-Zhang (KPZ) class, another paradigm of interface growth. However, experimental morphologies in this regime do not show clear-cut KPZ scaling, various sources of disagreement having been hypothesized in the literature [3], like e.g. quenched noise. In this communication, we put forward a natural, alternative interpretation which provides remarkable agreement with experiments: the observed behavior corresponds to a short-time DLA transient, which rules out the classic conclusion that the fronts of compact bacterial colonies display Eden scaling. We have grown colonies of Escherichia coli and Bacillus subtilis as in [4], for high agar concentrations and different concentrations of nutrients, and followed the evolution for up to 33 days. We have developed a phenomenological continuum model for this type of diffusive systems: the growth speed along the normal direction to the front is taken proportional to the (shadowing) angle under which a given point at the interface sees the exterior world. This corresponds to the physical situation in which an interface point within a cavity gets less nutrients, and its growth stagnates, which is the hallmark of unstable DLA growth. In order to simulate the ensuing stochastic integro-differential equation numerically, we have followed [5]: the interface is discretized in an adaptive way, adding and removing points dynamically in order to keep a constant spatial resolution. While the growing aggregates are compact, their fronts display DLA scaling. Quantitative comparison with our experimental data indeed rule out KPZ or Eden-like scaling for compact bacterial colonies. This is at variance with the classic understanding, providing an important insight into the morphological laws that correlate with the biological performance of these systems. References [1] E. Ben-Jacob, I. Cohen, and H. Levine, Adv. Phys. 49, 395 (2000). [2] C. D. Nadell, K. R. Foster, and J. B. Xavier, PLoS Comput. Biol. 6, e1000716 (2010). [3] J. A. Bonachela, C. D. Nadell, J. B. Xavier, and S. A. Levin, J. Stat. Phys. 144, 303 (2011). [4] I. Ràfols, Master Thesis, Chuo University, Tokyo (1994). [5] S. N. Santalla, J. Rodriguez-Laguna, and R. Cuerno, Phys. Rev. E (Rapid Comm.) 89, 010401(R) (2014).

*Speaker

Cooperativity of tracers in a crowded environment

Vincent Démery * [1], Alexis Poncet, Olivier Bénichou, David Dean

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A tracer pulled in a colloidal bath undergoes a drag force and generates a depletion wake behind it. This wake has been shown decay algebraically in two model systems: hard core particles on a lattice and soft and dense Brownian colloids. When several tracers are put together, their wake induce a long-range interaction between them, giving them a tendency to align and even form lanes. We use a mean-field theoretical approach valid for a dense suspension of soft colloids, and obtain analytical expressions for the effective mobility of the tracers and the tracer-bath and tracer-tracer correlation functions. The correlation functions reproduce the tendency towards alignment, and exhibit an algebraic decay behind tracer and in front of it. Correspondingly, the effective mobility of the tracers is an increasing function of the density of tracers. We use Brownian dynamics simulations to confirm quantitatively our results, and show that the long distance behavior of the correlation functions is robust and extends beyond the validity range of our mean-field calculation.

*Speaker

Understanding anomalous heat transport in one-dimensional systems through fluctuating hydrodynamic theory

Abhishek Dhar * [1]

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It is now generally believed that heat transport in one-dimensional momentum-conserving systems is anomalous and that Fourier's law of heat conduction is not valid. A rigorous understanding of this fact has been lacking. A recent theory of fluctuating hydrodynamics makes detailed predictions on the form of equilibrium correlations of conserved quantities in one-dimensional anharmonic chains. Using the connection between transport coefficients and equilibrium correlations, which is suggested by the Green-Kubo formula, one then hopes to be able to understand anomalous heat transport in one dimension. The talk will discuss some of the recent applications of the theory of fluctuating hydrodynamics, including towards understanding current fluctuations in ring geometries.

*Speaker

Thermodynamics and phase coexistence in nonequilibrium steady states

Ronald Dickman * [1]

[1] Universidade Federal de Minas Gerais – Brazil

I review recent work focussing on whether thermodynamics can be extended to nonequilibrium steady states (NESS). A central issue is the possibility of consistent definitions of temperature T and chemical potential μ for systems in NESS. The testing-grounds are simple, far-from-equilibrium lattice models with stochastic dynamics. Each model includes a "drive," that maintains the system far from equilibrium, provoking particle and/or energy flows; for zero drive the system approaches equilibrium. Analysis and numerical simulation show that for spatially uniform NESS, coexistence with an appropriate reservoir yields consistent definitions of T and μ are possible, provided a particular kind of rate (that proposed by Sasa and Tasaki) is used for exchanges of particles and energy between systems. Consistent definitions are *not* possible for nonuniform NESS. The functions T and μ for isolated phases cannot be used to predict the properties of coexisting phases in a single, phase-separated system.

*Speaker

Jamming and Attraction of Interacting Run-and-Tumble Random Walkers

Martin R. Evans * [1], Alexander Slowman, Richard a. Blythe

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We study a simple model of run-and-tumble bacterial dynamics in which two interacting random walkers with memory move a one-dimensional lattice under a hard core exclusion interaction. We derive an exact expression for the probability distribution in the steady state. This stationary distribution has a rich structure comprising three components: a jammed component where the particles are adjacent and block each other; an attractive component, where the probability distribution for the distance between particles decays exponentially; and an extended component in which the distance between particles is uniformly distributed. The emergent interaction between the particles is sufficiently strong that even in the limit of an infinite lattice, the two walkers spend a finite fraction of time in a jammed configuration. This may indicate the microscopic origin of motility-induced phase separation that results from interactions between self-propelled particles of a wide variety of types. A. B. Slowman, M. R. Evans, R. A. Blythe arXiv:1601.00954 (submitted to Physical Review Letters)

*Speaker

Maximum entropy principle for stationary states underpinned by stochastic thermodynamics

Ian J Ford * [1]

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The selection of an equilibrium state by maximising the entropy of a system, subject to certain constraints, is often powerfully motivated as an exercise in logical inference, a procedure where conclusions are reached on the basis of incomplete information. But such a framework can be more compelling if it is underpinned by dynamical arguments, and we show how this can be provided by stochastic thermodynamics, where an explicit link is made between the production of entropy and the stochastic dynamics of a system coupled to an environment. The separation of entropy production into three components allows us to select a stationary state by maximising the change, averaged over all realisations of the motion, in the principal relaxational or nonadiabatic component, equivalent to requiring that this contribution to the entropy production should become time independent for all realisations. We show that this recovers the usual equilibrium probability density function (pdf) for a conservative system in an isothermal environment, as well as the stationary nonequilibrium pdf for a particle confined to a potential under nonisothermal conditions, and a particle subject to a constant nonconservative force, also under isothermal conditions. The two remaining components of entropy production account for a recently discussed thermodynamic anomaly between over- and underdamped treatments of the dynamics in the nonisothermal stationary state. [I.J. Ford, Phys. Rev. E92, 052142 (2015)].

*Speaker

Out of equilibrium stationary states, percolation and sub-critical instabilities in a fully non conservative system

Guillaume Grégoire * [1], Mathieu Génois, Pascal Hersen, Éric Bertin, Sylvain Courrech du Pont

[1] École Centrale de Nantes – France

The exploration of the phase diagram of a minimal model for barchan fields leads to the description of three distinct phases for the system: stationary, percolable and unstable. In the stationary phase the system always reaches an out of equilibrium, fluctuating, stationary state, independent of its initial conditions. This state has a large and continuous range of dynamics, from dilute - where dunes do not interact - to dense, where the system exhibits both spatial structuring and collective behavior leading to the selection of a particular size for the dunes. In the percolable phase, the system presents a percolation threshold when the initial density increases. This percolation is unusual, as it happens on a continuous space for moving, interacting, finite lifetime dunes, and tends to a first-order transition when the width of the system becomes infinite. For extreme parameters, the system exhibits a sub-critical instability, where some of the dunes in the field grow without any boundary.

*Speaker

Self-similarity and domain formation in the non-equilibrium dynamics of ensembles of Rydberg atoms

Ricardo Gutierrez * [1], Juan P. Garrahan, I. Lesanovsky

[1] University of Nottingham – United Kingdom

Recent work has shown that the dynamics of a Rydberg gas in the limit of strong dissipation is governed by a rate equation with kinetic constraints that result in a strongly correlated dynamics. In these quantum many-body systems, the so-called Rydberg blockade mechanism, whereby the excitation of one atom prevents that of other atoms in the vicinity, plays a role analogous to that of excluded volume effects in supercooled liquids and colloids. This mechanism has been shown to lead to a self-similar non-equilibrium dynamics, and, when more than one excited atomic level is considered, the formation of domains and metastability. These recent developments, based on a combination of analytical and kinetic Monte Carlo approaches, will be described in detail. The persistence of this phenomenology when quantum coherence and noise are comparable, the relaxation dynamics in the stationary state and connections to cold atom experiments will be also briefly discussed.

*Speaker

Large deviations for equilibrium and non-equilibrium processes

Alexander K. Hartmann * [1]

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Large deviations and rare events play an ever increasing role in science, economy and society. Often this concerns non-equilibrium processes, where large deviations play a crucial role for example for the estimation of impacts of storms, the calculation of probabilities of stock-market crashes or the sampling of transition paths for conformation change of proteins. The basic principal to study large deviations using numerical simulations is quite old: make unlikely events more probable and correct in the end for the bias [1]. Here, we present a very general black-box method [2], based on sampling vectors of random numbers within an artificial finite-temperature (Boltzmann). This allows to access rare events and large deviation for almost arbitrary equilibrium and non-equilibrium processes. In this way, we obtain probabilities as small as 10^{-500} and smaller, hence rare events and large-deviation properties can be easily obtained. As pedagogical example, the distribution of the number and size of connected components of random graphs are obtained [3,4]. Furthermore, applications from different fields are displayed:

- Fractional Brownian motion (fBm) characterized by the Hurst exponent H: Distribution of end-points of non-absorbed walks for different values of H [5]
- Distribution of work performed for a critical ($T = 2.269$) two-dimensional Ising system of size $L \times L = 128 \times 128$ upon rapidly changing the external magnetic field [2] (also applying theorems of Jarzynski and Crooks to obtain the free energy difference of such a large system)
- Distribution of perimeters and area of convex hulls of two-dimensional single and multiple random walks [6]

Other recent applications where probability distributions over a large range of the support and down to extremely small probabilities were obtained using such approaches include biological sequence alignments [7,8,9], chemical similarity assessment [10], RNA secondary structures [11], minimum-energy paths on hierarchical lattices [12], spin glass ground states [13], structure of energy grids [14,15], and calculation of partition functions of Potts models [16].

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Quantum thermal conduction in anharmonic systems: A self-consistent phonon approach

Dahai He * [1], Juzar Thingna, Jian-Sheng Wang, Baowen Li

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Quantum thermal conduction in harmonic chains has been extensively studied as well as its classic counterpart [1]. One can use generalized Langevin approach [2], nonequilibrium Green's function method (NEGF) [3] and density matrix approach [4] to study the harmonic model exactly. As far as anharmonicity is concened, the situation becomes complicated. In this case, the transport of phonon is no longer ballistic. Most of previous studies [3] are mainly in a perturbative manner, which cannot handle strong anharmonicity. A developed master equation approach has been proposed recently, which can deal with anharmonicity exactly in the weak coupling limit [5]. However, since ME is handled in the sytem-Hilbert space, which increases rapidly with temperature as well as the number of particles. Hence it is computationally expensive to deal with nano systems of 10-100 atoms. In this talk we will propose a feasible and effective approach for quantum thermal conduction through anharmocic systems. The key idea here is to apply the self-consistent phonon theory (SCPT) to renormalize the anharmonic Hamiltonian to an effective harmonic Hamiltonian [6, 7, 8]. We then apply NEGF to study the effective harmonic model using the standard ballistic framework. The results show a good agreement with that by the master equation approach in the weak coupling limit. References: [1] A. Dhar, Adv. Phys. 57, 457 (2008). [2] A. Dhar and D. Roy, J. Stat. Phys. 125, 805 (2006). [3] A. Dhar, K. Saito, and P. Hänggi, Phys. Rev. E 85, 011126 (2012). [4] J.-S. Wang, J. Wang, and J. T. Lü, Eur. J. Phys. B 62, 381 (2008). [5] J. Thingna, J. L.García-Palacios, and J.-S. Wang, Phys. Rev. B 85, 195452 (2012). [6] D. He, S. Buyukdagli, and B. Hu, Phys. Rev. E 78, 061103 (2008). [7] D. He, S. Buyukdagli, and B. Hu, Phys. Rev. B 80, 104302 (2009). [8] X. Cao, D. He, H. Zhao, and B. Hu, AIP Advances 5, 053203 (2015).

*Speaker

Order and symmetry-breaking in the fluctuations of driven systems

Pablo Hurtado * [1], N. Tizon-Escamilla, C. Perez-Espigares, P.L. Garrido

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Dynamic phase transitions (DPTs) at the fluctuating level are one of the most intriguing phenomena of nonequilibrium physics, and their nature in high-dimensional, realistic systems remains puzzling. Here we describe for the first time a DPT in the current statistics of a quintessential two-dimensional ($2d$) driven diffusive system, and characterize its properties using the tools of macroscopic fluctuation theory. The complex interplay among the external field, anisotropy and currents in $2d$ leads to a rich phenomenology, with different symmetry-broken fluctuation phases separated by lines of 1^{st}- and 2^{nd}-order DPTs. Order in the form of coherent jammed states emerges to hinder transport for low-current fluctuations, proving that rare events are generically linked with self-organized patterns which enhance their probability, an observation of broad implications.

*Speaker

Stochastic thermodynamics in many-particle systems

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We study the thermodynamic properties of a microscopic model of coupled oscillators that exhibits a dynamical phase transition from a desynchronized to a synchronized phase. We consider two different configurations for the thermodynamic forces applied on the oscillators, one resembling the macroscopic power grids, and one resembling autonomous molecular motors. We characterize the input and the output power as well as the efficiency at maximum power, providing analytic expressions for such quantities near the critical coupling strength. We discuss the role of the quenched disorder in the thermodynamic force distributions and show that such a disorder may lead to an enhancement of the efficiency at maximum power.

*Speaker

Electric field-induced criticality and frequency-responsive dynamics of suspension of charged fibrous viruses (fd)

Kyongok Kang * [1], Jan K. G. Dhont

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Various phases and states and non-equilibrium critical behavior are found to be induced by low-frequency electric fields in suspensions of charged rods (fd-virus particles) in isotropic-nematic equilibrium [1]. The observed critical behavior and the phase/state transitions for the low-frequency electric field are due to field-induced interactions. We briefly present the phase/state diagram, in which a non-equilibrium critical point can be identified [1,2,3,4]. Several transition lines of field-induced phases and states meet at this critical point. A mechanism will be proposed, based on field-induced association/dissociation of condensed ions, which explains the existence of a dynamical state where nematic domains persistently melt and form [3,4]. Special attention will be paid to the non-equilibrium critical point, and it is shown that there is a length scale and a time scale that both diverge on approach of the critical point. The off-critical and critical behavior is characterized, where both power-law and logarithmic divergencies are found [2]. These experiments show that analogous features of the classical, critical divergence of correlation lengths and relaxation times in equilibrium systems are also exhibited by driven systems that are far out of equilibrium, related to phases/states that do not exist in the absence of the external field. In addition, the particle diffusivity of the charged colloidal rods (fd-viruses) within a field-induced uniform, homeotropically aligned state at relatively high-frequencies is shown to exhibit critical slowing down on approach of the critical point [5, 6]. In dynamic light scattering scattering, two dynamical modes are found, which are contributed to diffusionparallel and perpendicular to the nematic director. At high fd concentration and low ionic strength, where inter-rod interactions are particularly strong, unexpected dispersion relations are found for the fast-mode. This is partly attributed to a possible chiral nature of the homeotropic phase [6]. References: [1] K. Kang, and J. K. G. Dhont, "Electric-field induced transitions in suspensions of charged colloidal rods", Soft Matter, 6, 273, 2010 [2] K. Kang and J. K. G. Dhont, "Criticality in a non-equilibrium, driven system: Charged colloidal rods (fd-viruses) in electric fields", Eur. Phys. J. E., 30, 333, 2009 [3] J.K.G. Dhont, and K. Kang," An electric-field induced dynamical state in dispersions of charged colloidal rods", Soft Matter, 10, 1987-2007, 2014 [4] J. K.G. Dhont, and K. Kang, "Correction: An electric-field induced dynamical state in dispersions of charged colloidal rods", Soft Matter, 11, 2893–2894, 2015. [5] K. Kang, "Charged fibrous viruses (fd) in external electric fields: dynamics and orientational order", New Journal of Physics, 12, 063017, 2010 [6] K. Kang, "Diffusivity in an electric-field-induced homeotropic phase of charged colloidal rods", Europhys. Lett. 92, 18002, 2010

*Speaker

Constraints on reconstructing the free energy of a polymer from non-equilibrium measurements

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Single molecule stretching experiments play an increasing role in the study of free energy landscape of biomolecules. Usually, the goal of such experiments is to establish free energy difference ΔF between relaxed and stretched states, which requires sufficiently slow modification of the state of a molecule. However, slightly faster experiments [1] can use Jarzynski equality (JE) [2] to reconstruct ΔF from non-equilibrium measurements. The ever-increasing sensitivity of such experiments, enabling small forces and deformations, creates the need to understand the role played by the spatial fluctuations of the molecules and by the shapes of the surfaces to which those molecules are attached. Some insights into this problem can be gleaned from the behavior of long homogeneous flexible polymers whose behavior is dominated by their ability to explore the conformation space.

Many equilibrium properties of long ideal polymers and polymers in good solvents are *universal*. E.g., the radius of gyration R of such polymers increases with the number of monomers N as $R \sim N^{\nu}$, where the critical exponent ν is independent of many microscopic details. Force between a polymer and a repulsive surface (such as plane or any scale free surface) [3], or the pressure distribution on the surface [4] are also determined by universal expressions. Dynamical properties, such as relaxation times or diffusion constants, have universal N-dependence, as well. When a polymer is dragged away from the vicinity of a surface with velocity v to a distance of few R, the work W will have a non-trivial distribution $P(W)$ for repeated experiments. We argue, that there is an N-dependent critical velocity v_c, such that for $v > v_c$ this becomes practically impossible. We first analyze an exactly solvable model of dragging an ideal polymer in free space and show that $v_c \sim N^{-1/2}$ for Newtonian dynamics, and $v_c \sim N^{-3/2}$ for over-damped Langevin dynamics, and demonstrate (numerically) that the same v_c is valid when a polymer is dragged away from a surface. While the distribution $P(W)$ depends on N, for fixed (small) values of v/v_c some of its features are almost independent of N. These results can further be generalized for polymers in good solvents, where we expect, in free-draining regime, $v_c \sim N^{-(1+\nu)}$, with the exponent ν corresponding to polymers with excluded volume interactions.

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*Speaker

Nonlinear Response Theory

Matthias Kruger * [1], U. Basu, C. Bechinger, L. Helden, A. Lazarescu, C. Maes

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Understanding systems far from equilibrium is of fundamental and technological interest. Regarding systems near equilibrium, the fluctuation dissipation theorem provides enormous insight; The system's behavior in equilibrium directly yields its linear response, i.e., the behavior in presence of a mild perturbation. For stronger perturbations, the situation is much less clear, or muss less known, despite an appreciable body of literature. Based on path integral techniques, we develop concise response relations which predict far from equilibrium properties from measurements performed in equilibrium [1]. After discussing the general properties of far from equilibrium response theory, I will present experimental data, which demonstrate that equilibrium measurements can directly predict and determine far from equilibrium responses. [1] Frenetic aspects of second order response, U. Basu, M. Krüger, A. Lazarescu and C. Maes, Phys. Chem. Chem. Phys. 17, 6653 (2015)

*Speaker

Thermodynamic inference from non-equilibrium fluctuations

David Lacoste * [1], R. Garcia-Garcia, S. Lahiri

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Fluctuation theorems have become an important tool in single molecule biophysics to determine free energy differences from non-equilibrium experiments. When measurements are significantly coarse-grained or noisy, this determination becomes challenging because the standard estimators based on fluctuation theorems become biased. Here, we propose improved estimators, which solve the inference problem when the work and the error made on it are uncorrelated [1]. If in addition the work and the error are Gaussian distributed, the fluctuations are completely characterized by an effective temperature, which only depend on the signal to noise ratio. In the presence of correlations between the work and the error, the inference problem does not appear solvable in general, except for some particular cases, such as when measurements occur with delays and for linear Langevin dynamics. Time permitting, we will also mention how to relate such ideas to inference problems in the context of equilibrium fluctuations of an order parameter [2].

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*Speaker

Finite-time implications of dynamical phase transitions in exclusion processes

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Exclusion processes are stochastic models for the transport of particles with nearest-neighbour hard-core interactions. Focusing on the one-dimensional case with periodic boundary conditions, I will discuss the finite-time implications of dynamical phase transitions that affect the statistics of histories in such systems. These transitions describe anomalous fluctuations exhibited by such models, which, due to the local jamming induced by exclusion, present an instability in their spatially homogeneous histories, reflected in a non-analyticity of large-deviation functions. If dynamical phase transitions have been well understood in the infinite-time limit (taking into account finite-size effects), their finite-time implications, which are more relevant from a practical and experimental viewpoint, have been little studied up to now. I discuss how exclusion processes are amenable to a large- but finite-time large-deviation analysis.

*Speaker

Nonequilibrium Statistical Mechanics of Systems with Long-Range Interactions

Yan Levin * [1], R. Pakter, F.B, Rizzato, T.N. Teles, F.P.C. Benetti

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Systems with long-range forces behave very differently from those in which particles interact through short-range potentials. For systems with short-range interactions, for arbitrary initial conditions, the final stationary state corresponds to the thermodynamic equilibrium and can be described equivalently by either a microcanonical, canonical, or a grand-canonical ensemble. On the other hand, for systems with unscreened long-range forces, equivalence between ensembles breaks down. Isolated long-range interacting systems — in thermodynamic limit — do not evolve to the usual Boltzmann-Gibbs equilibrium, but become trapped in a non-ergodic stationary state which explicitly depends on the initial particle distribution. In this talk, a theoretical framework will be presented which allows us to predict the final stationary state to which a long-range interactioning system will evolve. The theory is able to quantitatively account for both density and velocity distributions in the stationary state, without any adjustable parameters [1,2,3]. [1] Y. Levin, R. Pakter and T. N. Telles, Phys. Rev. Lett. **100**, 040604 (2008). [2] R. Pakter, and Y. Levin, Phys. Rev. Lett. **106**, 200603 (2011); F. P. C. Benetti, A. C. Ribeiro-Teixeira, R. Pakter, and Y. Levin, Phys. Rev. Lett. **113**, 100602 (2014). [3] Y. Levin, R. Pakter, F.B, Rizzato, T.N. Teles, and F.P.C. Benetti, Phys. Rep. **535**, 1 (2014).

*Speaker

Artificial Phototaxis: Rectified motion of self-propelled particles by spatial motility variations.

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Phototaxis, i.e. the capability to move towards or away from light sources is an essential feature of many microorganisms like bacteria or motile cells. Unlike living systems, where this is achieved by a complex internal machinery, it is not obvious how such behaviour can be imposed on synthetic microswimmers. Using colloidal Janus spheres subjected to various light landscapes, we demonstrate artificial phototaxis, i.e. autonomous navigation in light gradients. This leads to a strongly rectified particle current which may find use for directed particle assembly and which is also confirmed by theory and simulations.

*Speaker

Dissipation bound for thermodynamic control

Benjamin B Machta * [1]

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Biological and engineered systems operate by coupling function to the transfer of heat and/or particles down a thermal or chemical gradient. In idealized deterministically driven systems, thermodynamic control can be exerted reversibly, with no entropy production, as long as the rate of the protocol is made slow compared to the equilibration time of the system. Here we consider fully realizable, entropically driven systems where the control parameters themselves obey rules that are reversible and that acquire directionality in time solely through dissipation. We show that when such a system moves in a directed way through thermodynamic space, it must produce entropy that is on average larger than its generalized displacement as measured by the Fisher information metric. This distance measure is sub-extensive but cannot be made small by slowing the rate of the protocol. See PhysRevLett.115.260603

*Speaker

Absorbing state phase transitions in an open quantum system

Matteo Marcuzzi * [1], Michael Buchhold, Sebastian Diehl, Igor Lesanovsky

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Stochastic processes featuring absorbing states have been extensively studied in the past and are known to display, in the presence of suitable competing dynamical processes, non-equilibrium phase transitions. Recent studies showed that in principle, under the effect of strong decoherence noise, optical lattices of laser-driven atoms can show the same universal behaviours. This opens the path to the investigation of the effects quantum fluctuations have on these otherwise fully-classical systems. We theoretically address such a scenario by studying an open quantum spin model which in its classical limit undergoes a directed percolation phase transition. Via an approximate mapping to a non-equilibrium field theory, we show that the introduction of quantum fluctuations stemming from coherent, rather than statistical, spin-flips alters the nature of the transition such that it becomes first-order deep in the quantum regime. In the intermediate one, where classical and quantum dynamics compete on equal terms, a bicritical point is highlighted with different universal features from standard directed percolation.

*Speaker

A general theory of steady-state copolymerization with applications to DNA replication by DNA polymerase

Ming Li * [1], Yong-Shun Song, Yao-Gen Shu, Xin Zhou, Zhong-Can Ou-Yang

[1] School of physical sciences, University of the Chinese Academy of Sciences – France

Steady-state copolymerization is common either in polymer industry or in biology. The mathematical description of the kinetics based on master equation usually leads to unclosed equations which are hard to solve. Here we report a unified approach to solve the problem for general cases where a monomer at the reactive end (i.e.,the growing end) can either be added or deleted, depent on the identity of neighboring monomer units in proximity. This kinetic theory also leads to a general thermodynamic formula in which the Shannon entropy of the generated copolymer sequence is explicitly introduced as part of the free energy dissipation of the whole copolymerization system (J. Phys.: Condens. Matter 27 (2015) 235105). Based on the kinetic theory, we make a detailed discussion on the fidelity problem of DNA replication which is catalysed by DNA Polymerase (DNAP). DNAP is a molecular machine that possesses either a polymerase site for copolymerization or a exonuclease site for proofreading. Our work provides a comprehensive and analytically solvable model for the kinetics of the two-site DNAP.

*Speaker

Rigorous bound on energy absorption and generic relaxation in periodically driven quantum systems

Takashi Mori * [1], Tomotaka Kuwahara, Keiji Saito

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Nature of relaxation in isolated many-body quantum systems subjected to global and strong periodic driving is discussed. Our rigorous Floquet analysis shows that the energy of the system remains almost constant up to an exponentially long time in frequency for arbitrary initial states and that an effective Hamiltonian obtained by a truncation of the Floquet-Magnus expansion is a quasi-conserved quantity for long time scale. These two general properties lead to intriguing classification on the initial stage of relaxation, one of which is similar to the prethermalization phenomenon in quasi-integrable systems.

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*Speaker

Transport and correlations in a stochastic model with energy and momentum conservation

David Mukamel * [1], Anupam Kundu Ori Hirschberg

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The steady state and transport properties of a one dimensional model which evolves under energy and momentum conserving dynamics are analyzed. The dynamics is stochastic involving three particle collisions which locally obey the conservation laws. The model is coupled to two heat reservoirs at its two ends leading to a nonequilibrium steady state. This is an extension of the KMP model in which only the energy is conserved. The heat transport and the two-point correlation functions of the energy and momentum are calculated in the limit of large system's length. The model exhibits normal heat transport with finite thermal conductivity. The momenta are shown to be uncorrelated, while the energy variables are found to display long-range correlations. Explicit scaling form of the energy correlations is obtained. A multi-lane version of the model is introduces in which correlations vanish. The deviation of the steady state of this model from local equilibrium is calculated.

*Speaker

Depinning as a Coagulation Process

Muhittin Mungan * [1], Melih Iseri, David C. Kaspar

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We consider a one-dimensional sandpile model which mimics an elastic string of particles driven through a strongly pinning periodic environment with phase disorder. The evolution towards depinning occurs by the triggering of avalanches in regions of activity which are at first isolated but later grow and merge. For large system sizes the dynamically critical behavior is dominated by the coagulation of these active regions. The analysis and numerical simulations show that the evolution of the sizes of active regions is well-described by a Smoluchowski coagulation equation, allowing us to predict correlation lengths and avalanche sizes. Moreover, the coagulation process emerges as the macroscopic description of the evolution to depinning. As our analysis shows, this connection is robust, i.e. it depends little on the details of the underlying microscopic model, providing an example for the emergence of universal features in disordered systems far from equilibrium. Reference: http://arxiv.org/abs/1601.05502

*Speaker

Granular gas experiments on non-equilibrium steady states

Antoine Naert * [1], Jean-Yonnel Chastaing, Jean-Christophe Géminard

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We present experiments in granular gases that allow to address in a simple way topical questions of non-equilibrium statistical physics. At macro-scale, we investigate processes where fluctuations dominate, similarly as in mesoscopic systems.
Our system is based on a Brownian rotator embedded in a steady-state granular gas. This rotator is passively excited by the random shocks of the beads, but can also be forced from outside.
Analysis of the work exchange with this NESS are compatible with the Fluctuation Theorem as well as the Fluctuation-Dissipation Theorem. These relations accordingly allow to define a parameter $kT_{\text{eff.}}$ playing the role of temperature in this dissipative system, similar as temperature $k_{\text{B}}T$ in an equilibrium system. A very specific and fruitful feature is that $kT_{\text{eff.}} \sim 10^{-7}\,\text{J} \ll k_{\text{B}}T \sim 10^{-20}\text{J}$. Measurements are accordingly easier and more precise, but interesting questions rise on the comparison between these quantities.
We can couple the Brownian probes in distinct such systems and characterize transport of energy between energy reservoirs at different temperatures. It is interesting to note that transport is among the key features of driven dissipative systems. We can also vary the density of the gas, which results in varying the reservoirs dimensionality, *ie.* the correlation time of the random forcing.
The parallel between 'mesoscopic' systems at equilibrium and these NESS 'macroscopic' systems is to be further explored and validated, tackling the following questions.
– When the gas is rarefied, the dimensionality of the bath is reduced (influence of fluctuations is enhanced). In which way is this affecting the motion of the Brownian probe, and transport properties?
– What can be learned from transients?

*Speaker

Entropy production rate near a non-equilibrium phase transition

Jae Dong Noh * [1], Pyoung-Seop Shim and Hyun-Myung Chun

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We study the entropy production in a globally coupled Brownian particles system that undergoes an order- disorder phase transition. Entropy production is a characteristic feature of non-equilibrium dynamics with broken detailed balance. We find that the entropy production rate is sub-extensive in the disordered phase and extensive in the ordered phase. The entropy production rate per particle vanishes in the disordered phase and becomes positive in the ordered phase following critical scaling laws. We derive the scaling relations for associated critical exponents.

*Speaker

Optical work extraction from a cyclic information engine

Hyuk Kyu Pak * [1], Dong Yun Lee, Govind Paneru

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We designed an information engine consists of a colloidal particle under an optical harmonic potential that is capable of extracting work from a single heat bath by utilizing the information about the microscopic state of the particle. Much of the studies on information engine to date have been limited to find the engine's efficiency; however, no experimental work has been done to investigate an optimal operating condition for finite cycle time of the engine. Here, we have realized an information engine to investigate an optimal conition for maximum extracted work and power per engine cycle. We find that the extracted work per engine cycle increases on increasing the cycle time and is maximum when the cycle time reaches to infinity, while power is maximum when the time approaches zero.

*Speaker

Fluctuations and Entropy production in Langevin systems with velocity-dependent forces

Hyunggyu Park * [1], Chulan Kwon, Hyun Keun Lee, Joonhyun Yeo, Sourabh Lahiri

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Total entropy production is conventionally separated into system entropy change and heat flowing into a thermal reservoir. In the presence of a velocity-dependent force, however, an extra entropy-like term exists, which makes it possible to absorb heat from a single reservoir to work against the velocity-dependent force without violating the thermodynamic second law. We also report that the well-known equivalence between the fluctuation-dissipation theorem, the detailed-balance, and the absence of heat dissipation in a steady state does not hold, in general. It is shown that the fluctuation-dissipation theorem and the detailed-balance become mutually exclusive with a velocity-dependent force. A different relation among the three conditions is proposed and it is found that any of the three conditions, alone, cannot serve as an identifier of equilibrium.

*Speaker

Critical decay exponent of the pair contact process with diffusion

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We investigate the one-dimensional pair contact process with diffusion (PCPD) by extensive Monte Carlo simulations, mainly focusing on the critical density decay exponent δ. To obtain an accurate estimate of δ, we first find the strength of corrections to scaling by introducing and studying a corrections-to-scaling function. For small diffusion rate ($d \leq 0.5$), the leading corrections-to-scaling term is found to be $\sim t^{-0.15}$, whereas for large diffusion rate ($d = 0.95$) it is found to be $\sim t^{-0.5}$. After finding the strength of corrections to scaling, effective exponents are systematically analyzed to conclude that the value of critical decay exponent δ is 0.173(3) irrespective of d. This value should be compared with the critical decay exponent of the directed percolation, 0.1595. In addition, we will discuss about the phase boundary around $d = 0$. The phase boundary is found and argued to be discontinuous at this point. We claim that the discontinuity of the phase boundary cannot be consistent with the theoretical argument supporting the hypothesis that the PCPD should belong to the DP.

*Speaker

Brownian Carnot Engine

Juan M.R. Parrondo * [1], Ignacio A. Martínez, Édgar Roldán, Luis Dinis, Dmitri Petrov, Raúl A. Rica

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At the microscale, the energy transfer between a system and its surroundings becomes random and a new theoretical framework —stochastic thermodynamics [1]— is necessary to account for those fluctuations. In particular, stochastic thermodynamics can be used to analyze the performance of small motors, like Brownian engines or molecular machines. Here we will report on a recent experiment that reproduces the Carnot cycle with a single Brownian particle as working substance [2]. The experiment uses optical tweezers to confine the particle and a noisy electrostatic force to mimic a high temperature reservoir. To analyze this Brownian Carnot engine, we will review some basic aspects of stochastic thermodynamics and discuss fundamental differences between driven and autonomous machines that arise from their behavior under time reversal [3].

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*Speaker

Stochastic thermodynamics with electrons in a circuit

Jukka Pekola * [1]

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I will discuss experiments in single-electron circuits. The main emphasis will be on Maxwell's Demons both with external feedback as a Szilard's Engine [1,2] and as an Autonomous Maxwell's Demon [3]. I will conclude the presentation by discussing the measurement of heat in quantum circuits using a calorimeter [4,5].

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*Speaker

Ingredients for an efficient thermal diode

Emmanuel Pereira * [1], Giulio Casati, Humberto Lemos, Ricardo Avila, Jiao Wang, Shunda Chen, Mateus Mendonca

[1] Universidade Federal de Minas Gerais – Brazil

A fundamental challenge in statistical physics is the derivation of macroscopic phenomenological laws of thermodynamic transport from the underlying Hamiltonian systems. After decades, a first-principle derivation of the Fourier's law of heat conduction, for instance, is still a puzzle. Many works have been devoted to this area of nonequilibrium statistical physics and, in spite of the existence of several open problems, intensive investigations and interesting results have opened the fascinating possibility to manipulate and control the heat current [Ref1]. Inspired by the incredible development of modern electronic due to the invention of transistor used to control the electric charge flow, now we observe the advance of Phononics, the counterpart of electronics dedicated to the manipulation of the heat current. However, a very promising advance is still dependent on the development of one of its basic components: an efficient and feasible thermal diode. The thermal diode is the basic tool for the manipulation and control of the heat current. In this device heat flows preferably in one direction, i.e., the magnitude of the heat current changes as we invert the sample between two thermal baths. The most recurrent proposals of thermal diodes are based on the sequential coupling of two or three segments with anharmonic interactions [Ref2] and they have to face several problems which are difficult to overcome. In particular their rectification power is small and rapidly decays to zero as the system size increases. For this reason, more and more efforts have been devoted to the search of alternative systems or rectifying mechanisms, however without remarkable results. We dedicate some works [Ref3, Ref4, Ref5, Ref6] to find a possible way to overcome these difficulties. Namely, we perform analytical and numerical studies in order to identify general and simple ingredients to build a diode with great rectification effect which moreover does not decay to zero with increasing the system size. First, considering models given by anharmonic chains of oscillators with inner and external stochastic baths, we show that thermal rectification is a ubiquitous phenomenon in graded systems [Ref3]. By numerical simulations in a simple model, with baths only at the boundaries and containing the minimal ingredients we theoretically judge to be necessary to rectification, we confirm the existence of such phenomenon [Ref4]. Second, again in the anharmonic chain of oscillators with inner and external stochastic reservoirs, we perform detailed analytical studies to show that the presence of long range interactions may significatively amplify the rectification power and avoid its decay with the system size [Ref5]. Then, we confirm these phenomena by performing numerical simulation in the more realistic model given by the anharmonic chain of oscillators with long range interactions and thermal baths only at the boundaries [Ref6]. To conclude, we stress that the proposed mechanism of thermal rectification (namely, the use of graded materials with long range interactions) is not restricted by geometrical considerations or by space dimensionality. Moreover, we are confident that our results will stimulate experimental research on this subject. References. [Ref1] N Li *et al.*, Rev. Mod. Phys. **84**, 1045 (2012). [Ref2] M. Terraneo, M .Peyrard, and G. Casati , Phys. Rev. Lett., **88** 094302 (2002); B. Li, L. Wang, and G. Casati, Phys. Rev. Lett., **93** 184301 (2004); B. Hu, L. Yang, and Y. Zhang , Phys. Rev. Lett., **97** 124302 (2006). [Ref3] E. Pereira, Phys. Rev. E, **82** 040101 (R) (2010); *ibid.* **83**, 031106 (2011). [Ref4] J. Wang, E. Pereira, and

*Speaker

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Quantum-Classical Correspondence Principle for Work Distributions

Haitao Quan * [1], C. Jarzynski, S. Rahav

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In classical thermodynamics, work is defined as the integral of the force over the displacement. In quantum mechanics, however, neither the force nor the displacement is well defined due to Heisenberg's uncertainty principle. In the realm of quantum thermodynamics, work in one realization is usually defined as the difference of the eigenenergies at the initial and the final stages. As long as one can accept the above definitions of work, the famous Jarzynski equality in classical thermodynamics can be extended to quantum regime straightforwardly. But the definition of work in quantum regime is usually regarded as ad hoc. In this talk, I will present our recent results on the correspondence principle of work distribution. Our results strongly suggest that the two-time-energy measurement method is the proper definition of quantum work. In addition, we clarify the special features in quantum work distributions that have an origin in its corresponding classical work distribution.

*Speaker

From randomly accelerated particles to Lévy walks: non-ergodic behavior and aging

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For randomly accelerated particles we detected, and were able to analyze in detail (PRL 113, 184101 (2014)), the phenomenon of weak-ergodicity breaking (WEB), i.e. the inequivalence of ensemble- and time-averaged mean-squared displacements (MSD). These results, including their aging time dependence, are relevant for anomalous chaotic diffusion in Hamiltonian systems, for passive tracer transport in turbulent flows, and many other systems showing momentum diffusion. There are, however, several related models, such as the integrated random excursion model, or, space-time correlated Lévy walks and flights, with similar statistical behavior. We compare the WEB related properties of these models and find surprising differences although, for equivalent parameters, all of them are supposed to lead to the same ensemble-averaged MSD. Our findings are relevant for distinguishing possible models for the anomalous diffusion occurring in experimental situations.

*Speaker

Normal and anomalous diffusion transition in disordered correlated potentials.

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We study the diffusion of an ensemble of overdamped particles sliding over a tilted random potential (produced by the interaction of a particle with a random polymer) with long-range correlations. We found that the diffusion properties of such a system are closely related to the correlation function of the corresponding potential. We model the substrate as a symbolic trajectory of a shift space which enables us to obtain a general formula for the diffusion coefficient when normal diffusion occurs. The total time that the particle takes to travel through n monomers can be seen as an ergodic sum to which we can apply the central limit theorem. The latter can be implemented if the correlations decay fast enough in order for the central limit theorem to be valid. On the other hand, we presume that when the central limit theorem breaks down the system give rise to anomalous diffusion. We give two examples exhibiting a transition from normal to anomalous diffusion due to this mechanism. We also give analytical expressions for the diffusion exponents in both cases by assuming convergence to a stable law. Finally we test our predictions by means of numerical simulations.

*Speaker

Criticalities at the transition to turbulence in shear flow

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Transition from laminar state to turbulence drastically changes the mixing, transport, and friction properties of fluid flows, yet when and how turbulence emerges is elusive even for simple flows in pipe or rectangular channel. Unlike the onset of temporal disorder identified as the universal route to chaos in confined flows, the onset of spatio-temporal disorder is elusive because turbulent domains erratically decay or spread as they propagate downstream. Through extensive experimental investigations of channel flows, a distinctive transition can be identified. For low flow rates, turbulent structures continuously injected from the entrance ultimately decay, whereas they are sustained for higher flow rates. Near the transition point, critical behavior is observed. The transition can be viewed as a stochastic processes of turbulent domains close to a single absorbing state, i.e. once the system reached the laminar state, it cannot escape from. This property brings universal nature of the transition to turbulence.We compare these results with the other shear flow systems.

*Speaker

The Fibonacci family of dynamical universality classes

Johannes Schmidt * [1]

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Universality is a well-established central concept of equilibrium physics. However, in systems far away from equilibrium a deeper understanding of its underlying principles is still lacking. Up to now, a few classes have been identified. Besides the diffusive universality class with dynamical exponent $z = 2$ another prominent example is the superdiffusive Kardar-Parisi-Zhang (KPZ) class with $z = 3/2$. It appears e.g. in low-dimensional dynamical phenomena far from thermal equilibrium which exhibit some conservation law. We have shown [1] that both classes are only part of an infinite discrete family of non-equilibrium universality classes. Remarkably their dynamical exponents z_α are given by ratios of neighbouring Fibonacci numbers, starting with either $z_1 = 3/2$ (if a KPZ mode exist) or $z_1 = 2$ (if a diffusive mode is present). If neither a diffusive nor a KPZ mode are present, all dynamical modes have the Golden Mean $z = (1+\sqrt{5})/2$ as dynamical exponent. The universal scaling functions of these Fibonacci modes are asymmetric Lévy distributions which are completely fixed by the macroscopic current-density relation and compressibility matrix of the system and hence accessible to experimental measurement.

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*Speaker

Universal features of NESS-fluctuations of single molecules and small networks

Udo Seifert * [1]

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I will review our recent work dealing with universal aspects of fluctuations in non-equilibrium steady states using concepts from stochastic thermodynamics. Slow hidden degrees of freedom lead to a modification of the fluctuation theorem [1,2]. The precision of any bio-molecular process is universally constrained by its thermodynamic cost [3]. Current fluctuations in any Markovian network are universally bounded by entropy production and, even more stronger, by topology and affinity dependent bounds [4]. Finally, measurements of the response and correlations of a driven single DNA-molecule and their theoretical analysis have revealed the range of validity for the concept of an effective temperature [5].

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*Speaker

Quantum Violation of Fluctuation Dissipation Theorem

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The fluctuation-dissipation theorem (FDT) is widely regarded as a universal relation between a linear response function and a time correlation. Experimentally, many evidences have been reported that support the FDT. However, most of them are limited to the symmetric tensor parts of the response functions, such as the diagonal conductivity σ_{xx}, in the "classical regime" $\hbar\omega \ll k_B T$. Thus a question arises: Does the FDT really hold in other cases? That is, is the FDT really a universal relation?

We here show that only in the above limited case the FDT holds as relations between measured quantities in macroscopic quantum systems. It is violated for the antisymmetric tensor parts of the response functions even in the "classical regime." A typical example is the Hall conductivity σ_{xy} at $\omega = 0$. The FDT is violated also for symmetric tensor parts in the non-classical regime $\hbar\omega \gtrsim k_B T$.

Theoretically, when Takahashi derived the FDT for classical systems [1] he hesitated to extend the theory to quantum systems because disturbances caused by quantum measurements should be considered seriously. In particular, when measuring a time correlation one must measure the system repeatedly (at least twice), and consequently disturbances by the preceding measurements affect the results of later measurements. Such a process is described not by the unitary time evolution (i.e., the Schroedinger or von Neumann equation) but by a non-unitary evolution [2,3].

However, Callen and Welton [4], Kubo [5], and other authors studied the FDT for quantum systems assuming the unitary evolution, completely neglecting the disturbances by measurements. Noticeably, Callen and Welton, Kubo, and Nyquist [6] (who introduced a quantum effect intuitively into his thermodynamic argument) claimed different time correlations for the FDT. They agree with each other only for classical systems.

Among them, the most widely used for quantum systems seems the formula by Kubo [5]. The Kubo formula claims that temperature times the response function equals the canonical time correlation (or, equivalently, some retarded Green function). The canonical time correlation does not agree with other time correlations, such as the symmetrized time correlation, in quantum systems. To identify which correlation is really obtained in experiments, one must consider the non-unitary evolution. However, the unitary evolution was assumed in the derivation of the Kubo formula. Therefore, while the Kubo formula is useful as a recipe to obtain the response function, measured fluctuations may possibly be described by a different expression.

This problem has been left unsolved because at the time of the above pioneering works neither quantum measurement theory [2,3] nor theory of macroscopic quantum systems [7-10] was developed enough. Fortunately, both these theories have been developed greatly in last few decades. This enabled us to solve the problem [11].

We notice that certain "ideal" detectors should be used to measure the time correlation correctly. The necessity of this condition may be understood by considering the following foolish case. Suppose that one wants to measure the position correlation x(0)x(t) of a classical particle,

*Speaker

and that his detector measures the particle position by capturing the particle. If the time correlation is measured with such a detector the position is fixed by the first measurement and hence the obtained correlation is x(0)x(0), which disagrees with the correct correlation, x(0)x(t). This happens because his detector destroys the state of the particle by capturing it. Hence, an ideal detector should be used for measurements of time correlations.
In classical systems, an ideal detector is trivially defined as a detector that does not destroy the state at all. In quantum systems, however, the meaning of "ideal" detectors is nontrivial because disturbances by measurements are unavoidable in general. Furthermore, conventional detectors are not necessarily ideal. For example, Glauber showed in his Nobel prize winning paper [2] that a normally-ordered time correlation is obtained when an electromagnetic field is measured by conventional photodetectors, such as photodiode and photomultipliers, because they destruct the quantum state by absorbing photons. This implies, for example, that conventional photodetectors cannot detect the zero-point fluctuation. If such detectors are used the violation of the FDT is obvious because the normally-ordered time correlation does not agree with the canonical time correlation (which equals temperature times the response function, according to the Kubo formula).
Therefore, to examine the validity of the FDT in quantum systems we must assume an "ideal" detector that mimics the classical ideal detector as closely as possible. More concretely, we assume a detector that is minimally-disturbing, homogeneous, and unbiased, with a moderate magnitudes of error (which is small enough to measure fluctuations but not too small in order to avoid strong disturbances). We call such a detector a quasiclassical detector. Its precise definition is described in [11].
Assuming quasiclassical detectors, and using the quantum central limit theorem [7-9] and the Leib-Robinson bound [10], we show rigorously that the FDT is partly violated in quantum systems as relations between observed quantities, as mentioned above.
Note that there are two ways to reach the "classical regime" $\hbar\omega \ll k_B T$. One is to take $\hbar \to 0$, where the system becomes classical and the violation disappears. The other is to take $\omega \to 0$ while keeping $\hbar$ constant, where the violation occurs. Therefore, the violation of the FDT is a genuine quantum effect, which appears in macroscopic scales. The violation should be confirmed experimentally by measuring independently the response function and the time correlation for the case of, e.g., the Hall conductivity and the corresponding current-current correlation.

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Thermodynamics of the motility-induced phase separation

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Self-propelled particles are known to accumulate in regions of space where their velocity is lowered. In addition, if their velocity diminishes when the local density increases (for example due to crowding effects), a positive feedback loop leads to the now well-established motility-induced phase separation (MIPS) between a dense immotile phase and a dilute motile phase. Understanding the phase equilibrium of MIPS is still a matter of debate. Although, depending on the models used to study the transition, a chemical potential or a pressure can be defined, these quantities do not play their usual thermodynamic role. In particular, the usual common tangent or equal-area constructions fail in these systems. Indeed, we will show that describing the phase equilibrium of MIPS necessitates generalized thermodynamics that include non-equilibrium contributions. This approach allows us to predict correctly the phase diagram of MIPS and to gain insight into the thermodynamics of active systems. It also sheds light on the (in)equivalence of statistical ensembles for these systems, paving the way for more efficient computational studies.

*Speaker

Exploiting Activity: Trapping, Sorting and Heat Engine

A. K Sood * [1]

[1] Indian Institute of Science – India

This talk will cover two of our most recent studies of active particles wherein the persistence of the directed motion has been a key aspect. These are (i) sorting of active granular rods based on the activity and (ii) a micrometer sized Sterling heat engine operating between reservoirs having active particles. We show, through experiments and simulations, that geometrically polar granular rods, rendered active by the transduction of vertical vibrations[1,2,3] undergo a collective trapping phase transition in the presence of a V-shaped obstacle when the opening angle drops below a threshold value[4]. In the second example, we show that a micrometer-sized active Stirling engine can be realized by periodically cycling a colloidal particle in a time-varying harmonic optical potential across bacterial baths at different activities. Unlike in equilibrium thermal reservoirs, the displacement statistics of the trapped particle becomes increasingly non-Gaussian with activity. We show that as much as $\approx 50\%$ of the overall efficiency stems from large non-Gaussian particle displacements alone[5].

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*Speaker

Phase transformation and nucleation in driven systems

Thomas Speck * [1], David Richard

[1] Johannes Gutenberg-Universität Mainz – Germany

The making of a material necessarily is a non-equilibrium process. Moreover, typically it involves phase transformations, which realistically occur under external stresses. I will discuss numerical results for two steadily driven model systems that undergo a discontinuous first order transition upon changing the volume: repulsive particles in shear flow and active Brownian particles in two dimensions. These model systems are paradigms for two different routes to steady driving: through an external field (here shear flow) or, in the second case, autonomous units ("particles") that are constantly converting energy into directed motion.

*Speaker

Searching for the Tracy-Widom distribution in nonequilibrium processes

Herbert Spohn * [1], Christian Mendl

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While originally discovered in the context of the Gaussian Unitary Ensemble, the Tracy-Widom distribution also rules the height fluctuations of growth processes. This suggests that there might be other nonequilibrium processes in which the Tracy-Widom distribution plays an important role. In our contribution we discuss one-dimensional systems with domain wall initial conditions. For an appropriate choice of parameters the profile develops a rarefaction wave, while maintaining the initial equilibrium states far to the left and right, which thus serve as infinitely extended thermal reservoirs. For two distinct model systems we will demonstrate that the properly projected time-integrated current has a deterministic contribution, linear in time t, and fluctuations of size $t^{1/3}$ with a Tracy-Widom distributed random amplitude.

*Speaker

Canonical Theory of Dissipative Systems

Masuo Suzuki * [1]

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In order to describe both the current and entropy production in dissipative systems, we formulate a "canonical theroy" of such systems. This is a unification of the previous Onsager, Kubo, Prigogine and Zubarev theories. The entropy production is described by the symmetric part of the density matrix $\rho(t)$, while the current is induced by the odd part of $\rho(t)$ with respect to an external field such as an electric field. Namely, the irreversibility is caused by the symmetric fluctuation in the second-order perturbational part of $\rho(t)$ in the linear response theory[1]. This inspires the author to propose a canonical theory of dissipative systems by introducing a type of non-equilibrium density matrix of the form $\rho_{\rm canon}(t) = \exp(\eta(t))$ in which the entropy function $\eta(t)$ is determined using von Neumann equation in such a renormalized way as it agrees with the exact density matrix $\rho(t)$ upto the second order of the external force. Therefore, this renormalized density matrix $\rho_{\rm canon}(t)$ yields the correct entropy production as well as the current, at least, upto the second order. This theory can treat even thermal conduction by introducing a thermal field[1] $\boldsymbol{E}_T = \nabla\beta(x)/\beta$ for $\beta(x) = 1/k_{\rm B}T(x)$. Thus, the canonical theory unifies and extends the linear response theory[2] and the nonlinear phenomenological transport scheme[1,5-7] including the thermal conduction and particle diffusion due to the density gradient $\nabla n(x)$, so that it may explain the microscope mechanism of the entropy production or irreversibility[8]. This formulation is also derived from the principle of minimum integrated entropy production[2-4] even in nonlinear responses[1,5-7].

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*Speaker

Anomalous time correlation of KPZ and weak ergodicity breaking

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The Kardar-Parisi-Zhang (KPZ) universality class for interface fluctuations is now appreciated as a prominent situation where many fluctuation properties can be solved exactly in one dimension [1], but its time correlation largely remains theoretically intractable. Here we tackle this problem experimentally and numerically, and report anomalous, non-ergodic relaxation [2,3]. In particular, we provide evidence of the so-called weak ergodicity breaking [3], by which some time-averaged quantities remain stochastic even in the long-time limit [4]. We show further that a prototypical model in this context, namely the renewal process, can reproduce some of the time-correlation properties of the KPZ-class fluctuations [3].
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*Speaker

Non-equilibrium relaxation dynamics of flux lines in disordered type-II superconductors

Uwe C. Täuber * [1], Hiba Assi, Harshwardhan Chaturvedi, Ulrich Dobramysl , Michel Pleimling

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We study the effects of rapid temperature, magnetic field, and driving current changes on the non-equilibrium relaxation dynamics of magnetic vortex lines in disordered type-II superconductors by employing a three-dimensional elastic line model and performing Langevin molecular dynamics simulations. We utilize the current-voltage characteristics, mean vortex radius of gyration and the fraction of pinned line elements as well as two-time flux line height autocorrelations and their mean-square displacement to study the non-linear stochastic relaxation kinetics in the physical aging regime. This allows us to distinguish the complex relaxation features that result from either point-like or columnar pinning centers and reflect the intricate competition between vortex pinning, line elasticity, and mutual repulsive interactions. This research is supported by the U.S. Department of Energy, Office of Basic Energy Sciences, Division of Materials Sciences and Engineering under Award DE-FG02-09ER46613. References: [1] H. Assi, H. Chaturvedi, U. Dobramysl, M. Pleimling, and U.C. Täuber, Phys. Rev. E 92, 052124 (2015) [arXiv: 1505.06240]; [2] H. Assi, H. Chaturvedi, U. Dobramysl, M. Pleimling, and U.C. Täuber, Mol. Simul. (in print, 2016) [arXiv:1509.02227]; [3] H. Chaturvedi, H. Assi, U. Dobramysl, M. Pleimling, and U.C. Täuber, in preparation (2016).

*Speaker

Nonequilibrium thermodynamic potentials for continuous-time Markov chains

Gatien Verley * [1]

[1] Université Paris sud – France

In this talk, I discuss the nonequilibrium and stochastic thermodynamics of systems with a finite number of states. We assume that the state probabilities evolve according to a master equation. Hence, the dynamics is fully characterized by the values of all the transition rates between the system states. For transition rates following a local detailed balance and satisfying the Arrhenius law for all the local exchanges with each reservoir, we will derive a nonequilibrium potential with the following properties: (1) the maximum is reached in the NE stationary state, (2) the first derivatives produce the NE equations of state, (3) the second derivatives produce the NE Maxwell relations generalizing far-from-equilibrium the Onsager reciprocity relations. In this derivation of a nonequilibrium potential, a key ingredient is the identification of the appropriated couples of conjugated thermodynamic variables, i.e. for the extensive ones: the energy currents exchanged with each reservoir, the activity of these energy exchanges, and the occupation probability of each state. The latter variable includes a huge amount of information for large systems, but in some cases might be substituted with a more coarse-grained thermodynamic variable like a density. Reference: Verley, G. Nonequilibrium thermodynamic potentials for continuous-time Markov chains Phys. Rev. E, 2016, 93, 012111

*Speaker

Fragmentation of fractal random structures

Martin Weigel * [1], Eren M. Elci, Nikolaos G. Fytas

[1] Coventry University – United Kingdom

Breakup phenomena are ubiquitous in nature and technology. They span a vast range of time and length scales, including polymer degradation as well as collision induced fragmentation of asteroids. In geology, fragmentation results in the distribution of grain sizes observed in soils; fluids break up into droplets and fluid structures such as eddies undergo fragmentation. On the subatomic scale, excited atomic nuclei break up into fragments. Practical applications, such as mineral processing, ask for optimizations according to technological requirements and efficiency considerations. More generally, a wide range of structures from transport systems to social connections are described by complex networks, whose degree of resilience against fragmentation is a recent subject of intense scrutiny. We analyze the fragmentation behavior of random clusters on the lattice under a process where bonds between neighboring sites are successively broken. Modeling such structures by configurations of a generalized Potts or random-cluster model allows us to discuss a wide range of systems with fractal properties including trees as well as dense clusters. We present exact results for the densities of fragmenting edges and the distribution of fragment sizes for critical clusters in two dimensions. Dynamical fragmentation with a size cutoff leads to broad distributions of fragment sizes. The resulting power laws are shown to encode characteristic fingerprints of the fragmented objects. References: [1] E. M. Elçi, M. Weigel, and N. G. Fytas, Fragmentation of random fractal structures, Phys. Rev. Lett. 114, 115701 (2015). [2] E. M. Elçi, M. Weigel, and N. G. Fytas, Bridges in the random-cluster model, Nucl. Phys. B 903, 19 (2016).

*Speaker

KPZ Equation: a Variational Perspective

H.s. Wio * [1]

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A variational approach has been recently introduced allowing to define a non-equilibrium thermodynamic-like potential (NEP) for the paradigmatic KPZ equation as well as for other related kinetic equations. For the KPZ case, the knowledge of such a potential together with its numerical evaluation (in 1, 2 and 3 dimensions) allowed us to obtain information about the system's time dynamical behavior. Such an analysis opens new perspectives over possible relations between the NEP asymptotic and critical behaviors. In addition, a functional Taylor expansion admitted by the KPZ nonequilibrium potential, that results to be naturally truncated at third order offers some insight on the origin of a diffusive instability as well as on the asymptotic time behavior. This variational scheme is also exploited to inquire on the dynamical behavior of the KPZ equation through a path-integral approach. All these aspects offers novel points of view, shedding light on particular aspects of KPZ dynamics.

*Speaker

First-order Phase transition in a non-conserved one-dimensional stochastic process.

Somayeh Zeraati * [1], Farhad H. Jafarpour, Haye Hinrichsen

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It is believed that first-order phase transition in nonconserving systems with fluctuating domains is impossible in one dimension . However, we introduce an exactly solvable one-dimensional driven-diffusive model which involves two species of particles, with nonconserved dynamics. The dynamics of the model is determined by two parameters and which control transition rates. Then we show, analytically, the existence of a first-order phase transition at a particular point in the phase diagram. We provide a heuristic explanation to justify the first-order phase transition of our model. We arrive at the conclusion that first-order phase transitions in nonconserving one-dimensional systems with fluctuating domains are indeed possible in certain model with several particle species if one of the species is used for marking different types of minority islands.

*Speaker

Transport and fluctuations in quantum many-body systems

Marko Znidaric * [1]

[1] FMF, University of Ljubljana – Slovenia

I will present exact as well as numerical results about transport properties of one-dimensional many-body quantum systems. Using boundary-driven Lindblad equations one can study nonequilibrium steady states. Various interesting aspects will be discussed, like the role of integrability, interactions and disorder, that can all result in nonequilibrium phase transitions. Besides average properties, fluctuations calculated using large-deviation formalism also provide valuable information.

*Speaker

Topic 3: Quantum Fluids and Condensed Matter-Oral

Breakdown of superfluidity and extreme value statistics in a one dimensional Bose gas

Mathias Albert * [1], Cord Muller, Tobias Paul, Nicolas Pavloff, Patricio Leboeuf

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Phase coherence is a key ingredient of many characteristic quantum effects in transport phenomena, some of the most striking ones being superfluidity, conductance quantization, or the quantum Hall effect. In particular, interference effects have a prominent role in presence of disorder, resulting in weak or strong Anderson localization. In this talk I will discuss statistical properties of a one dimensional Bose-Einstein condensate at rest or moving through a disordered region of finite extent. I will focus on the superfluid fraction and the critical velocity and demonstrate their connections to extreme value statistics of the random environment.

*Speaker

Dual gauge field theory of quantum liquid crystals

Aron Beekman * [1], Jaakko Nissinen, Kai Wu, Ke Liu, Robert-Jan Slager, Zohar Nussinov, Vladimir Cvetkovic, Jan Zaanen

[1] Keio University – Japan

Liquid crystals are phases of matter where translational symmetry is (partially) unbroken but rotational symmetry is broken. In low-temperature condensed matter quantum analogues thereof with a similar symmetry breaking pattern can arise for instance when electronic ordering is disrupted by strong fluctuations near a phase transition. This goes under the name "quantum nematics", which are reported in iron and cuprate high-temperature superconductors. To understand the underlying principles of such quantum liquid crystals we consider on very generally the dislocation-mediated quantum melting of bosonic crystals in two dimensions. The space group of the original crystal dictates which particular smectic and nematic phases will be obtained. The machinery at work is a strong/weak duality mapping, akin to vortex-boson duality, where phonons are represented by gauge bosons that mediate elastic forces. Upon losing translational rigidity in the liquid crystal phase, the phonons obtain a mass gap due to the Anderson-Higgs mechanism. Using this methodology we can analytically calculate the full low-energy mode spectrum of the liquid crystal phases. We find that flawlessly: the longitudinal phonon turns into a pure compression mode of the liquid; the transverse shear phonon turns into a gapped mode; a massless Goldstone mode emerges as a result of rotational symmetry breaking. We also consider electrically charged matter and calculate the electromagnetic responses of quantum liquid crystals among which conductivity, electron energy loss and the Meissner effect. It turns out that the best chance to observe the presence of quantum nematic behaviour is to use finite-momentum longitudinal spectroscopy, such as EELS or RIXS. arXiv: 1603.04254

*Speaker

Fresh news from atomic Flatland

Jean Dalibard * [1]

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Most experimental studies with quantum gases are performed with atoms confined in a harmonic potential. This geometry is well suited for the investigation of some aspects of the equilibrium properties of the gas, but prevents one from addressing questions related to long-range correlations. This restriction is particularly significant for low dimensional systems, where these correlations evidence the emergence of novel phases of matter.
In this talk I will discuss recent experimental research on Bose gases confined in box-like potentials [1-3]. With an emphasis on the quasi two-dimensional geometry, I will address both the study of the gas for itself, and its use as a medium revealing novel features in the propagation of resonant light in a disordered environment.
This research is supported by ERC (UQUAM project) and IFRAF.

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*Speaker

Wave packet revivals at quantum phase transitions

Francisco De Los Santos * [1], Elvira Romera

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The time evolution of quantum wave packets may lead to interesting collapse and revival phenomena. Propagating wave packets initially evolve quasiclassically and oscillate with a classical period but eventually spread and collapse. At later times, multiples of a revival time Tr, wave packets regain their initial wave form and behave quasiclassically again. Additionally, at times that are rational fractions of Tr, the wave packet temporarily splits into a number of scaled copies called fractional revivals. Revivals and fractional revivals have attracted a great interest during the past decades. They have been investigated theoretically in nonlinear quantum systems, atoms and molecules (including Graphene), and observed experimentally in, among others, Rydberg atoms, molecular vibrational states or Bose-Einstein condensates. Recently, methods for isotope separation, number factorization as well as for wave packet control have been put forward that are based on revival phenomena. Here, the concept of quantum revivals is extended to many-body systems and the implications of traversing a quantum phase transition are explored. By analyzing three different models, the vibron model for the bending of polyatomic molecules, the Dicke model for a quantum radiation field interacting with a system of two-level atoms, and Lipkin-Meshkov-Glick model, we show evidence of revival behavior for wave packets centered around energy levels as low as the fundamental state. Away from criticality, revival times exhibit smooth, nonsingular behavior and are proportional o the system size. Upon approaching a quantum critical point, they diverge as power laws with associated critical exponents and scale with the system size, although the scaling is no longer linear. Excited states quantum phase transitions also influence the revival behavior of wave packets, but in this case revival times appear to show softer singularities. E. Romera and F. de los Santos, Phys. Rev. B 80, 165416 (2009) F. de los Santos and E. Romera, Phys. Rev. A 87, 013424 (2013) F. de los Santos, E. Romera and O. Castaños, Phys. Rev. A 91, 043409 (2015)

*Speaker

Strongly correlated systems with nearly flat bands

Oleg Derzhko * [1], Johannes Richter, Olesia Krupnitska, Taras Krokhmalskii, and Patrick Muller

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There are plenty of lattices in one, two, and three dimensions which support a completely dispersionless (flat) one-particle energy band. If the flat band happens to be the lowest-energy one, it is possible to construct and completely characterize a certain manifold of many-particle ground states even in the presence of strong interactions. These states determine the low-temperature properties of strongly correlated systems in a specific range of external parameters [1]. In this contribution, we discuss the effect of slight dispersion of a previously strictly flat band. We focus on the high-field low-temperature properties of some quantum Heisenberg antiferromagnets [2] and on the kinetic-energy-driven ground-state ferromagnetism in the standard Hubbard model at low electron densities [3]. We also discuss why our findings are useful in searching for experimental manifestation of flat-band effects in strongly correlated systems.

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*Speaker

Dynamical creation of entanglement in quantum many-body systems

Irénée Frérot * [1], Tommaso Roscilde

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Starting from a weakly entangled state, a quantum many-body system will generically evolve towards a highly entangled state through the dynamical formation of rich correlation patterns. To develop conceptual tools helping us to understand these patterns in relation with more traditional properties of these systems, like the structure of the excitations, is hence an important step towards the characterisation of the quantum thermalisation process. In this talk, we will study this question in both fermionic and bosonic systems thanks to a time-dependent Schwinger bosons representation of the quantum field, allowing us to reduce the problem to an effective quasi-particle Hamiltonian. We will show that the concept of entanglement contour provides an interesting insight into the dynamical propagation of entanglement in these systems.

*Speaker

Critical Casimir forces in the canonical ensemble

Markus Gross * [1], Oleg Vasilyev, Andrea Gambassi, Siegfried Dietrich

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If a near-critical fluid is geometrically confined it exerts a critical Casimir force on the boundaries. So far, critical Casimir forces have typically been considered in the grand canonical ensemble, where the confined fluid film can exchange particles with a bulk medium at the same chemical potential. Here, we investigate critical Casimir forces in the canonical ensemble, where the total order parameter of the fluid (e.g., the total number of particles) is fixed. Such a constraint on the order parameter naturally arises in a number of simulation methods such as molecular dynamics. Via field theory and Monte Carlo simulations of the three-dimensional Ising model we show that, depending on the boundary conditions, the order parameter constraint leads to a significantly different behaviour of the critical Casimir force. For instance, for ++ boundary conditions, i.e., when the fluid is adsorbed with similar strengths at the two walls confining the film, the canonical critical Casimir force is found to be repulsive and decays algebraically upon increasing film thickness. This is in strong contrast to the well-studied grand canonical case with ++ boundary conditions, for which the critical Casimir force is attractive and decays exponentially. We also discuss the effect of the constraint on the fluctuations of the order parameter.

*Speaker

Quantum Monte Carlo study of the Rabi-Hubbard model

Frédéric Hébert * [1], Thibaut Flottat, George Batrouni, Valéry Rousseau

[1] Université de Nice Sophia Antipolis – France

We study, using quantum Monte Carlo (QMC) simulations, the ground state properties of a one dimensional Rabi-Hubbard model. The model consists of many Rabi systems coupled by hopping of photons between different systems. The phase diagram comports only two phases: a coherent phase and an incoherent one. The Mott phases that are present in the Jaynes-Cummings model are not observed here, due to the presence of non-negligible counter rotating terms. We study further these two models and find that the two models are equivalent if the detuning is negative and large enough, or if the counter rotating terms are small enough.

*Speaker

The Casimir effect in near-critical systems

Fred Hucht * [1], Hendrik Hobrecht

[1] Faculty of Physics, University of Duisburg-Essen – Germany

The critical Casimir effect is caused by the spatial confinement of thermal fluctuations near the critical point of a continuous phase transition. The resulting critical Casimir force is long ranged and universal, depending only on the universality class of the fluctuating medium, on the geometry of the system and on the boundary conditions. This universality of the Casimir force scaling function was demonstrated in [1], where the results of Monte Carlo simulations of magnetic thin films were shown to quantitatively match the critical Casimir forces measured in liquid Helium films near the lambda transition [2]. Recently, critical Casimir forces were shown to have strong and tunable influences on the interactions of colloidal particles in binary liquid mixtures near the separation temperature [3]. We present an efficient cluster Monte Carlo method that directly simulates colloidal particles in a near-critical medium [4], and find strong many-body effects. The results are in agreement with an analytical calculation using conformal mappings. Finally we discuss the influence of corners in two-dimensional rectangular Ising systems on the critical Casimir effect.

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*Speaker

Apparent first-order wetting in the two-dimensional Ising model from exact solution

Joseph Indekeu * [1], Xintian T. Wu, Douglas B. Abraham

[1] KU Leuven – Belgium

The global phase diagram of wetting in the two-dimensional ($2d$) Ising model is obtained through exact calculation of the surface excess free energy [1,2]. Besides a surface field for inducing wetting, a surface-coupling enhancement is included. The wetting transition is critical (second order) for any finite ratio of surface coupling J_s to bulk coupling J, and turns first order in the limit $J_s/J \to \infty$. However, for $J_s/J \gg 1$ the critical region is exponentially small and practically invisible to numerical studies. A distinct pre-asymptotic regime exists in which the transition displays first-order character.

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*Speaker

A kagome map of spin liquids

Ludovic Jaubert * [1], Karim Essafi Owen Benton

[1] OIST – Japan

Despite its deceptive simplicity, few concepts have more fundamental implications than chirality. In condensed matter, frustration has proven able to stabilize extended phases where chirality could be encoded in the collective behaviour of spins. Kagome systems in particular are fertile soil for exotic spin textures and have attracted the attention of chemists, experimentalists and theorists alike. In this talk, we will present a unifying network of spin liquids with anisotropic and Dzyaloshinskii–Moriya interactions. This network revolves around a paragon of quantum disorder, namely the Ising antiferromagnet. We show that this quantum disorder spreads over an extended region of the phase diagram at linear order in spin wave theory, which overlaps with the parameter region of Herbertsmithite ZnCu3(OH)6Cl2. As for the celebrated Heisenberg and XXZ antiferromagnets, they now belong to a triad of equivalent quantum spin liquids for spins S = 1/2. At the extremity of this network emerges a classical chiral spin liquid, analogue to the three-colouring problem on the honeycomb lattice enhanced by a global O(3) invariance which can be spontaneously broken. We will conclude this talk by discussing the possible experimental realisations of our theory.

*Speaker

Nonequilibrium Physics of Quantum Spin Systems with Long-Range Interactions

Michael Kastner * [1]

[1] National Institute for Theoretical Physics – South Africa

Quantum spin models with long-range interactions have been realised in various synthetic quantum many-body systems, moving such long-range models into the focus of recent research efforts. In the first part of this talk I give a survey of analytical results, mostly in the form of Lieb-Robinson bounds, that highlight some of the unconventional and surprising dynamical properties of long-range quantum models. In the second part I present a numerical method applicable to long-range quantum spin models out of equilibrium in arbitrary lattice dimension. The method combines sampling of the Wigner function with evolution equations obtained from the Bogoliubov-Born-Green-Kirkwood-Yvon (BBGKY) hierarchy, bringing about highly accurate estimates of correlation functions and other quantities. As an application I discuss a frustrated two-dimensional lattice with antiferromagnetic power-law interactions and a transverse field, making predictions pertinent to future ion trap experiments.

*Speaker

Thermodynamics, contact and density profiles of the repulsive Gaudin-Yang model

A. Kluemper * [1], O. Patu

[1] Wuppertal University – Germany

We address the problem of computing the thermodynamic properties of the repulsive one-dimensional two-component Fermi gas with contact interaction (Gaudin-Yang model). We derive an exact system of only two non-linear integral equations for the thermodynamics of the homogeneous model. This system allows for an easy and extremely accurate calculation of thermodynamic properties circumventing the difficulties associated with the truncation of the thermodynamic Bethe ansatz system of equations. We present extensive results for the densities, polarization, magnetic susceptibility, specific heat, interaction energy, Tan contact and local correlation function of opposite spins. Our results show that at low and intermediate temperatures the experimentally accessible contact is a non-monotonic function of the coupling strength. As a function of the temperature the contact presents a pronounced local minimum in the Tonks-Girardeau regime which signals an abrupt change of the momentum distribution in a small interval of temperature. The density profiles of the system in the presence of a harmonic trapping potential are computed using the exact solution of the homogeneous model coupled with the local density approximation. At finite temperature the density profile presents a double shell structure (partially polarized centre and fully polarized wings) only when the polarization in the center of the trap is above a critical value.

*Speaker

Dimensional crossover from 1D to 3D: an illustration with ultracold atoms

Guillaume Lang * [1], Frank Hekking, Anna Minguzzi

[1] CNRS, LPMMC – France

Since the 1960's, one-dimensional (1D) many-body systems have been studied by mathematical physicists in the context of integrability, yet for a long time they were deemed as non-physical toy models. In the last decade, however, the situation evolved dramatically with the possibility to trap and confine ultracold atoms to various 1D geometries (straight wires, rings...), raising new questions regarding their dynamical behavior. Indeed, while phase transitions are often suppressed, quantum fluctuations are enhanced compared to higher dimensions. Theoretical tools, such as Bethe Ansatz techniques, conformal field theory and bosonization, have been developed to study 1D interacting systems. Nonetheless, for a wide class of transverse confinements, atomic gases are better modeled as quasi-1D or quasi-2D, meaning that transverse modes can be populated as well. Since multimode systems are ubiquitous in condensed matter, ultracold atoms provide a means to simulate them in a very controlled way. Dimensional crossovers can occur in at least two ways: - occupation of various energy modes in a tight confining trap: the transition to higher dimension is realized by gradually opening the trap, thereby increasing the number of populated modes in energy space - realization of a higher-dimensional structure by an ensemble of low-dimensional ones in real space, e.g. in an optical lattice. I will focus on the first one, yet the formalism I develop works in both cases. Since dimensional crossovers in interacting systems are deemed as one of the most difficult problems in condensed matter physics, I focus on a conceptually simple case: free fermions in a cubic box trap at zero temperature. The observable I study to illustrate the crossover is the dynamical structure factor, which characterizes the dynamical response of a fluid to a moving potential barrier or impurity [2]. It is measurable by Bragg scattering and depends on the dimension in a non-trivial way for fermions. First, I will show how the dynamical structure factor behaves in 1D, 2D and 3D. In particular, the 1D case shows striking features which make it special compared to higher dimensions [3]. They are interpreted in simple terms. I will also show the dynamical structure factor of a quasi-1D system and illustrate the crossover to 2D. It happens exactly for an infinite number of modes, but a striking feature is that only a few transverse modes are needed to recover higher-dimensional physics to a good approximation. To be closer to experiments, I then study the effect of a trap. In this simple system it appears that, for a harmonic trap, each added degree of confinement is equivalent, within a good approximation, to increasing the space dimension of one unit. Therefore, the physics in a 3D trap is equivalent to the physics in a 6D box. Since the dynamical structure factor becomes harder and harder to compute as dimension is increased, I find it by induction on space dimension. To finish with, I introduce a tool to study crossovers in interacting systems. In 2D and 3D systems, the framework of Landau liquids is often useful to study interactions, yet it fails if they are too strong and does not apply to bosons. In 1D, the Fermi liquid picture breaks down, but the formalism of the Tomonaga-Luttinger liquid (TLL) allows to treat interactions in a non-perturbative way for a wide class of systems and regardless of the quantum statistics, provided energy and temperature are low enough. Unfortunately, this formalism does not work in higher-dimensional systems. My idea is thus to apply the TLL to multi-component 1D systems, each of them being correctly accounted for, and use the dimensional crossover to describe higher-dimensional interacting systems. The free case is studied as a testbed for this technique. [1] G. Lang, F. Hekking, and A. Minguzzi , Phys. Rev. A 93, 013603 (2016) [2] G.E. Astrakharchik and L.P. Pitaevskii, Phys. Rev. A 70, 013608 (2004) [3] G. Lang, F. Hekking, and A. Minguzzi, Phys. Rev. A 91, 063619 (2015)

*Speaker

Properties of the random-singlet phase: from the disordered Heisenberg chain to an amorphous valence-bond solid

Yu-Cheng Lin * [1], Yu-Rong Shu, Dao-Xin Yao, Chih-Wei Ke, Anders W. Sandvik

[1]National Chengchi University – Taiwan

We use a strong-disorder renormalization group (SDRG) method and ground-state quantum Monte Carlo (QMC) simulations to study S=1/2 spin chains with random couplings, calculating disorder-averaged spin and dimer correlations. The QMC simulations demonstrate logarithmic corrections to the power-law decaying correlations obtained with the SDRG scheme. The same asymptotic forms apply both for the Heisenberg antiferromagnetic chain and for chains with multi-spin couplings leading to spontaneous dimerization in the clean system. In the latter case, in the presence of disorder, we demonstrate an amorphous valence-bond solid with alternating domains of the two different dimerization patterns separated by spin-carrying domain walls (spinons). This amorphous valence-bond solid is asymptotically a random-singlet state and only differs from the random-exchange Heisenberg chain in its short-distance properties.

*Speaker

Photon-mediated long range interactions in atomic systems

Giovanna Morigi * [1]

[1] Saarland University – Germany

We argue that the dynamics of self-organization of atoms in cavities offers a test bed for studying the statistical mechanics of long-range interacting systems.
The system we consider are atoms in optical resonators that are transversally driven by lasers. When the laser intensity exceeds a threshold value, the atoms can spontaneously form spatially ordered structures, which result from the mechanical forces on the atoms associated with superradiant scattering into the cavity mode. We treat the atomic motion semiclassically and show that, while the onset of spatial ordering depends on the intracavity-photon number, the asymptotic state of the atoms is a thermal state, whose temperature is solely controlled by the detuning between the laser and the cavity frequency and by the cavity loss rate. From this result we derive the free energy and show that in the thermodynamic limit self-organization is a second-order phase transition. The order parameter is the field inside the resonator to which one can associate a magnetization in analogy to ferromagnetism, the control field is the laser intensity, but the steady state is intrinsically out of equilibrium. In the symmetry-broken phase, quantum noise induces jumps of the spatial density between two ordered patterns: We characterize the statistical properties of this temporal behavior at steady state and show that the thermodynamic properties of the system can be extracted by detecting the light at the cavity output.
We then characterize the semiclassical dynamics after a sudden quench across the driven-dissipative second-order phase transition. The relaxation dynamics exhibits a long prethermalizing behaviour which is first solely dominated by coherent long-range forces, and then by their interplay with dissipation. Remarkably, this final stage is orders of magnitude slower and exhibits correlations which are established by spatially-correlated noise and which go beyond mean-field. This behaviour challenges the common understanding of the role of dissipation in the relaxation dynamics. It further implies that cavity cooling of an atomic ensemble into the selforganized phase can require longer time scales than the typical duration of an experiment.
We finally provide a short outlook of these dynamics in the ultracold regime, when quantum fluctuations become relevant.

*Speaker

Critical Casimir forces and Bose-Einstein condensation of an imperfect Bose gas

Marek Napiorkowski * [1], Pawel Jakubczyk, Jaroslaw Piasecki

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We consider the d-dimensional imperfect (mean-field) Bose gas confined in a slit-like geometry and subject to periodic boundary conditions. Within an exact analytical treatment we first discuss the bulk phase diagram and the critical properties of the system at Bose-Einstein condensation. The bulk universality class is identified to be the one of the classical d-dimensional spherical model. Subsequently we consider the imperfect Bose gas enclosed in a slit of width D and analyze the attractive Casimir force acting between the slit boundaries. Above the bulk condensation temperature ($T > T_c$) the Casimir force decays exponentially as a function of D. For $T \leq T_c$ its decay is algebraic. The magnitude of the Casimir forces at T_c and for $T4$ and $T \leq T_c$. We also identify a particular regime of temperatures and widths D in which the Casimir force becomes repulsive. Papers: - Casimir force induced by an imperfect Bose gas, M. Napiórkowski and J. Piasecki, Phys. Rev. E **84**, 061105 (2011). - The Bulk Correlation Length and the Range of Thermodynamic Casimir Forces at Bose-Einstein Condensation, M. Napiórkowski and J. Piasecki, J. Stat. Phys. **147**, 1145 (2012). - The imperfect Bose gas in d dimensions: critical behavior and Casimir forces, M.Napiórkowski, P. Jakubczyk and K. Nowak, J. Stat. Mech. P06015 (2013). - Quantum criticality of the imperfect Bose gas in d dimensions, P. Jakubczyk and M. Napiórkowski, J. Stat. Mech. P10019 (2013). - On the relation between Casimir forces and bulk correlations, M. Napiórkowski and J. Piasecki, J. Stat. Phys. **156**, 1136 (2014) - Repulsive Casimir forces at quantum criticality, P. Jakubczyk, M. Napiórkowski, and T. Sęk, Europhys. Letters **113**, 30006 (2016)

*Speaker

Fluctuation-induced (Casimir) forces in fluids subjected to a temperature gradient

Jose M. Ortiz De Zarate * [1], Jan V. Sengers, Ted. R. Kirkpatrick

[1] Universidad Complutense – Spain

It is known that long-range correlations can induce forces in confined condensed-matter systems, commonly known as Casimir forces. Examples are Casimir forces due to critical fluctuations, Goldstone modes, or inhomogeneous thermal noise. We have identified a new type of Casimir effect in confined liquids when subjected to a temperature gradient [1-3]. This new type of non-equilibrium Casimir force appears to be much larger than previously known Casimir forces in soft condensed-matter systems [4]. Suggestions for experimental verification are presented [5].

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*Speaker

Constructing Landau formalism for topological order: Quantum chains and ladders

Toplal Pandey

* [1], Gennady Chitov

[1]Laurentian University – Canada

We will present the analysis of quantum phase transitions in the antiferromagnetic dimerized spin-$\frac{1}{2}$ XY chain and two-leg ladders. These transitions are not accompanied by the local symmetry breaking and appearance/dissapperance of the conventional local order parameters. The gapped phases of those models possess distinct nonlocal string order parameters (SOPs) and the hidden symmetry breaking in each phase can be identified. After mapping of the original spin Hamiltonians onto the tight-binding models with Dirac or Majorana fermions and the mean-field approximation (for ladders), the essential physics of nonlocal ordering can be grasped analytically. By utilizing duality transformations the calculation of SOPs is mapped onto the local order problem in some dual representation and done without further approximations. The phases with hidden orders can also be distinguished by the topological Pontryagin (winding) numbers. The latter provide a complimentary description. The main result which will be emphasised mostly in the presentation, is the proposed general framework to treat nonlocal orders and hidden symmetries which unifies the key elements of the Landau paradigm with the new concept of topological order. We will explain how this unified framework can be straightforwardly applied for spin chain and ladders, topological insulators and superconductors. To give more examples, the most recent applications of this theory to n-leg spin ladders and tubes will be discussed in more detail.

*Speaker

Critical Casimir forces and the equation of state of quantum critical systems

A. Rancon * [1], T. Roscilde, P. Holdsworth, L.-P. Henry

[1] Ecole Normale Superieure de Lyon – France

Thermal fluctuations in classical systems give rise to effective forces reminiscent of the paradigmatic Casimir force induced by the fluctuations of the electromagnetic vacuum. These forces have been thoroughly studied numerically for varieties of boundary conditions relevant for experiments in classical statistical physics, as well as periodic boundary conditions, which were a priori theoretical curiosities. Using the well-known correspondence between finite temperature quantum statistical systems and classical statistical field theory on a torus, I will show that the equation of state of a quantum critical system can be described by the critical Casimir force induced by periodic boundary conditions. This universality will be shown to hold for a variety of systems, using different numerical approaches, and I will comment on possible experimental realizations.

*Speaker

Transport Processes and Sound Mode Decay in Dilute Bose-Einstein Condensates

Linda E. Reichl * [1], Erich D. Gust

[1] University of Texas at Austin – United States

Monatomic Bose-Einstein condensates (BECs) have six hydrodynamic modes, two are damped by viscous effect and the remaining four modes consist of first and second sound. Values for the shear viscosity, the speed of first and second sound, and the lifetimes of the sound modes are obtained using a kinetic equation based on Bogoliubov mean field theory. The two pairs of sound modes decay at very different rates, except in the neighborhood of an avoided crossing of the sound speeds, where the identity of the longest lived modes switches. The speed and lifetime of the longest living sound mode, predicted by the theory, are consistent with that observed in a recent experiment. This unusual behavior of the sound modes, at very low temperature, may provide may provide a means to determine the temperature of the BEC at extremely low temperatures. 1. E.D. Gust and L.E. Reichl, J. Low Temp. Phys., 170 43 (2013) 2. E.D. Gust and L.E. Reichl, Phys. Rev. E 87 042109 (2013) 3. L.E. Reichl and E.D. Gust, Phys. Rev. A 88 053603 (2013) 4. E.D. Gust and L.E. Reichl, Phys. Rev. A 90 043615 (2014) 5. E.D. Gust and L.E. Reichl, Phys. Scr. T165 014034 (2015)

*Speaker

How do you know when your fluctuations are quantum?

Tommaso Roscilde * [1], Irénée Frérot

[1] Ecole Normale Supérieure de Lyon – France

Quantum fluctuations - stemming from Heisenberg's uncertainty - are at the heart of most dramatic quantum phenomena, from the absence of solidification of Helium at ambient pressure, to the absence of magnetic order in special magnetic insulators, to cite a few examples. But fluctuations can have a more mundane, thermal origin, leading to potentially similar results: so how can one ascertain the quantum nature of fluctuations? And can one establish a quantitative relationship between quantum fluctuations and entanglement, expressing the entropy of quantum fluctuations? Here I will discuss a general framework which allows to single out (and measure) quantum fluctuations in a generic quantum system, and to investigate their peculiar spatial structure and scaling properties. The latter properties generalize to finite temperature the behavior exhibited by entanglement in many-body ground states. In particular I will point out how recent experiments in atomic physics are particularly well positioned to capture unambiguous signatures of quantum fluctuations in quantum many-body systems, from microscopic to macroscopic scales.

*Speaker

Quantum Spin Fluid of the S=1/2 Kagome-Lattice Antiferromagnet

Toru Sakai * [1], Hiroki Nakano

[1] University of Hyogo – Japan

The S=1/2 kagome-lattice antiferromagnet is one of interesting frustrated quantum spin systems. The system is supposed to exhibit the quantum spin fluid in the ground state, which was proposed as an origin of the high-temperature superconductivity. The spin gap is an important physical quantity to characterize the spin fluid behavior. Whether the S=1/2 kagome-lattice antiferromagnet is gapless or has a finite spin gap, is still unsolved issue. Because any recently developed numerical calculation methods are not enough to determine it in the thermodynamic limit. Our large-scale numerical diagonalization up to 42-spin clusters and a finite-size scaling analysis indicated that the S=1/2 kagome-lattice antiferromagnet is gapless in the thermodynamic limit[1]. It is consistent with the $U(1)$ Dirac spin fluid theory of the kagome-lattice antiferromagnet [2,3]. On the other hand, some density matrix renormalization group (DMRG) calculations supported the gapped Z_2 topological spin fluid theory[4,5]. The previous effective Hamiltonian approach indicated that the spin gap remains in the thermodynamic limit, while the number of the low-lying singlet states increases with the number of sites like 1.15^N [6]. Our recent numerical diagonalization analysis on the magnetization process of a distorted kagome-lattice antiferromagnet indicated that the perfect kagome-lattice system is just on a quantum critical point[7]. It would be a possible reason why it is difficult to determine whether the perfect kagome-lattice antiferromagnet is gapless or gapped. In this paper, we show another evidence to confirm the gapless behavior, based on the finite size scaling analysis of the field derivative of the magnetization[8]. [1]H. Nakano and T. Sakai: J. Phys. Soc. Jpn. 80 (2011) 053704. [2]Y. Ran, M. Hermele, P. A. Lee and X. -G. Wen: Phys. Rev. Lett. 98 (2007) 117205. [3]Y. Iqbal, F. Becca, S. Sorella and D. Poilblanc: Phys. Rev. B 87 (2013) 060405(R). [4]S. Yan, D. A. Huse and S. R. White: Science 332 (2011) 1173. [5]S. Nishimoto, N. Shibata and C. Hotta: Nat. Commun. 4 (2013) 2287. [6]F. Mila: Phys. Rev. Lett. 81 (1998) 2356. [7]H. Nakano and T. Sakai: J. Phys. Soc. Jpn. 83 (2014) 104710. [8]T. Sakai and H. Nakano in preparation.

*Speaker

A new spin liquid on the pyrochlore lattice

Nic Shannon * [1], Owen Benton, Han Yan, Ludovic Jaubert

[1] Okinawa Institute of Science and Technology Graduate University – Japan

Spin ice, a family of rare-earth pyrochlore magnets, offers perhaps the most celebrated example of a classical spin-liquid state, decribed by a U(1) gauge theory, complete with magnetic monopole excitations. This underlying gauge symmetry manifests itself in singular, "point-point" features in neutron scattering experiments. In this talk we present evidence for a new kind of spin liquid on the pyrochlore lattice [1]. This new spin liquid arises in a realistic model of anistotropic exchange on the pyrochlore lattice. It can be described by tensor field-theory with a continuous gauge symmetry, sharing a number of common features with (linearised) general relativity. And, just as the gauge structure of spin ice is visible through "point-points" in neutron scattering, so fluctuations in this new spin liquid lead to extended "pinch lines" - a prediction which can be tested directly in experiment. We discuss the application of these ideas to two pyrochlore magnets of current interest, Yb2Ti2O7 and Tb2Ti2O7. [1] O. Benton, L. Jaubert, H. Yan and N. Shannon, arXiv:1510.01007

*Speaker

The interplay between universal scaling laws and vortex clustering in two-dimensional quantum turbulence

Audun Skaugen * [1], Luiza Angheluta

[1] University of Oslo – Norway

The relationship between vortex dynamics and the turbulent energy spectrum is an active research topic in quantum turbulence of superfluids and Bose-Einstein condensates. The energy spectra in quantum turbulence exhibit a Kolmogorov -5/3 scaling law, analogous to classical turbulence. Recent developments show that in two-dimensional quantum flows, this energy spectrum corresponds to an inverse energy cascade, which is realized by clustering of like-signed quantized vortices. We investigate numerically the statistics of quantized vortices in two-dimensional quantum turbulence using the Gross-Pitaevskii equation. We find that a universal -5/3 scaling law in the turbulent energy spectrum is intimately connected with the vortex statistics, such as number fluctuations and velocity, which also show a similar scaling behavior. The -5/3 scaling law appearing in the power spectrum of the vortex number is consistent with a scenario of isolated vortices passively advected by a turbulent superfluid velocity, which is again generated by like-signed vortex clusters. The velocity probability distribution of clustered vortices is also sensitive to spatial correlations, and exhibits a power-law tail with a -5/3 exponent that we can predict analytically from the point vortex model.

*Speaker

Topological aspects of symmetry breaking in triangular-lattice Ising antiferromagnets

Andrew Smerald * [1], Frederic Mila Sergey Korshunov

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We investigate the triangular lattice Ising antiferromagnet with coupling beyond nearest neighbour, focussing in particular on the interplay between topology and symmetry. Using a specially designed Monte Carlo algorithm with directed loops, we show that a first order phase transition from a low-temperature, broken-symmetry stripe state to the paramagnet can be split, revealing an intermediate nematic phase. Furthermore, we demonstrate the emergence of several properties of a more topological nature, such as fractional edge excitations in the stripe state, the proliferation of double domain walls in the nematic phase and the coexistence of a broken symmetry and algebraically decaying spin correlations. Finally we investigate the nature of the second order phase transition between the stripe and nematic phases and demonstrate that it is of the Kasteleyn type and in the Pokrovsky-Talapov universality class.

*Speaker

Universality Class of Transition to Quantum Turbulence

Masahiro Takahashi * [1], Michikazu Kobayashi, Kazumasa A. Takeuchi

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Kolmogorov's law and the logarithmic law of the velocity field near the wall were found for developed turbulence in classical and quantum turbulences. The existence of these laws suggests that there is a universal behaviour in such fluctuating systems. In this point of view, we put one step farther to understand turbulence by revealing the universality class for a transition to vortex turbulence in quantum fluid systems. By numerically simulating a quantum fluid system to measure critical exponents, we found that the transition to vortex turbulence belongs to the directed percolation (DP) universality class. The DP class is a fundamental universality class for transitions into an absorbing state, which can be seen in various models describing, e.g., forest fire expansion and epidemic spreading. Our numerical simulation has been done by solving the Gross-Pitaevskii equation, which is known to reproduce various experiments on cold atom gases, with dissipation and spatio-temporal random potential of amplitude V. By increasing the potential amplitude V, we can observe the transition to quantum turbulence. The transition can be characterized by the vortex density ρ, which serves as an order parameter. We have numerically simulated steady states and quench dynamics. By these measurements, we have found three independent critical exponents, β, α, and d_{f} in agreement with those for the DP universality class. Hence we conclude that the non-equilibrium phase transition to vortex turbulence belongs to the DP universality class. In addition, we found another power-law decay of vortex density, $\rho \sim t^{-3/2}$, at short times in the quench simulations. This behaviour is believed to be seen when the Richardson cascade occurs and Kolmogorov's law lies behind. To confirm this, we calculated the energy spectrum and indeed identified Kolmogorov's -5/3 law in the early-time regime. In other words, the quench dynamics shows a two-step relaxation, first governed by Kolmogorov's law and then replaced by the DP critical decay.

*Speaker

Order from structural disorder in frustrated magnets

Mike Zhitomirsky * [1]

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A hallmark of geometrical magnetic frustration is degeneracy between multiple classical spin configurations that are not related by any underlying symmetry. Such a degeneracy can be lifted by thermal and quantum fluctuations via a so called order by disorder effect. I discuss the role of structural disorder, nonmagnetic vacancies and random exchange bonds, on degeneracy lifting in frustrated magnets. Analytic and numerical results show that structural disorder select a different subset of classical ground states compared to fluctuations. The effect of a quenched disorder can be roughly represented by an effective biquadratic exchange with positive sign. Competition between quenched and thermal disorder leads to appearance of interesting and complicated phase diagrams. We illustrate the above by showing numerical results for the effect of structural disorder on a Heisenberg triangular-lattice antiferromagnet in a magnetic field, diluted compass and eq orbital models, and for the anisotropic pyrochlore antiferromagnets.

*Speaker

Topic 4: Disordered and Glassy Systems-Oral

Shearing structurally disordered systems: revisiting mean-field descriptions

Elisabeth Agoritsas * [1], Eric Bertin, Ezequiel Ferrero, Kirsten Martens, Jean-Louis Barrat

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Shearing structurally disordered systems: revisiting mean-field descriptions Structurally disordered systems, when submitted to an external deformation such as a constant shear, are known to exhibit a nonlinear response, signature of an out-of-equilibrium phase transition. This highly nontrivial behaviour depends in fact crucially on the intensity of the external driving, which triggers randomly local plastic rearrangements throughout the system, thus constantly updating its local disordered energy landscape. Linking on the one hand the collective behaviour of these local plastic events, and on the other hand the macroscopic nonlinear response, represents a challenging issue from the statistical physics point of view of driven disordered systems. Indeed, it corresponds to characterising generalised stochastic processes with the following features: *(i)* a dynamical structural disorder; *(ii)* a self-generated and spatio-temporally correlated noise; *(iii)* a non-convex and long-range interaction fixed by the elastic propagation of stress in the system. Several *mean-field* 'elasto-plastic' models have been developed, at a mesoscopic scale defined by the typical size of individual plastic events. These mean-field descriptions have proven to be rather successful in reproducing certain features observed in sheared disordered systems, but not all at once; moreover, a consistent picture connecting them is still missing. Here we discuss the physical ingredients that are put in such mean-field models, in particular the assumptions underlying the effective stochastic process defining them. We focus on the steady-state response of athermal systems, when the velocity of the deformation (*i.e.* shear rate) is controlled, discussing specifically the so-called 'Hébraud-Lequeux' model [1] and its generalisations [2,3]. In particular, we find that, in the validity range of these mean-field models (that we specify), the exponents characterising the solid-liquid transition in these driven disordered systems are robust with respect to either a distribution of energy barriers for the system to overcome locally, or to a partial relaxation of the local stress after a plastic event. We discuss moreover the shear-rate dependence of the disorder dynamics and of the noise distribution. [1] P. Hébraud and F. Lequeux, *Phys. Rev. Lett.* **81**, 2934 (1998). [2] E. Agoritsas, E. Bertin, K. Martens, & J.-L. Barrat, Eur.Phys.J.E 38, 71 (2015). [3] E. Agoritsas & K. Martens, arXiv-1602.03484 [cond-mat.soft].

*Speaker

The interest of nonlinear responses to study the glass transition.

Samuel Albert * [1], F. Ladieu, P. Gadige, C. Wiertel-Gasquet, R. Tourbot

[1] CEA – France

Although structural glasses are everyday materials playing an increasing role in modern technological applications [1], the glass transition in itself remains a conundrum. Over the two past decades several experimental breakthroughs have deepened our understanding of glasses. Among them the nonlinear responses —-to which this talk is devoted– have played an important role: it will be argued that nonlinear responses give more insights that what had been originally anticipated in the late nineties. Time permitting, various kinds of experimental nonlinear responses will be compared [2,3,4], aiming at giving a unified physical picture both for equilibrium and for ageing experiments. **ACKNOWLEDGEMENTS**
We thank C. Alba-Simionesco, G. Biroli, J.-P. Bouchaud, P.M. Déjardin, and G. Tarjus for long-lasting help. We acknowledge extremely useful exchanges and discussions with A. Loidl, P. Lunkenheimer, T. Bauer, M. Michl and their collaborators of the Augsburg group. The support of the european grant "NPRGGLASS", of the RTRA (Triangle de la Physique), as well as the support of the Institut des Systemes Complexes de la Region Ile de France are warmly acknowledged.

[1] M. D. Ediger and P. Harrowell, *J. Chem. Phys.*, **137**, 080901 (2012).

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*Speaker

Real Space Renormalization Group Theory of spin glasses and disordered Models of Glasses

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We develop a real space renormalisation group analysis of spin glass in field (Phys. Rev. Lett. 114, 095701) and disordered models of glasses (to be published, submitted to PNAS), in particular of the spin models at the origin of the Random First Order Transition theory. For the glass models we find three fixed points respectively associated to the liquid state, to the critical behavior and to the glass state. The latter two are zero-temperature ones; this provides a natural explanation of the growth of effective activation energy scale and the concomitant huge increase of relaxation time approaching the glass transition. For the spin glass in field, in addition to the three fixed point associated to the liquid state, to the critical behaviour and to the spin-glass phase, there is an additional zero temperature fixed point, corresponding to the zero field spin glass phase, that becomes unstable adding an infinitesimal field. The lower critical dimension depends on the nature of the interacting degrees of freedom and is higher than three for all models. This does not prevent three dimensional systems from being glassy or spin-glass like. Indeed, we find that in three dimensions their renormalisation group flow is affected by the fixed points existing in higher dimension and in consequence is non-trivial. Within our theoretical framework the glass transition as well as the spin glass transition in field result to be avoided phase transitions.

*Speaker

Activated dynamic scaling in the random-field Ising model

Ivan Balog * [1], Gilles Tarjus

[1] Institute of Physics – Croatia

The random-field Ising model shows extreme critical slowdown described by activated dynamic scaling. The characteristic time for the relaxation to equilibrium diverges exponentially with the correlation length, $\ln \tau \sim \xi^{\psi}/T$, with ψ an *a priori* unknown barrier exponent. We extend a dynamical formalism, within the nonperturbative functional renormalization group, for problems with disorder to obtain the behavior of the barrier exponent for all spatial dimensions d, between upper critical ($d = 6$) an the lower critical ($d = 2$). For $d_{DR}0$ a new exponent related to the number of spanning avalanches. Below d_{DR}, we recover that $\psi = \theta$ with θ the temperature exponent near the zero-temperature fixed point that controls the critical behavior. A physical interpretation of the results in terms of collective events in real space, avalanches and droplets is going to be discussed.

*Speaker

Spinodals with Disorder: from Avalanches in Random Magnets to Glassy Dynamics

Giulio Biroli * [1], Saroj Nandi, Gilles Tarjus

[1] IPhT CEA Saclay – France

Motivated by the connection between the dynamical transition predicted by the mean-field theory of glass-forming liquids and the spinodal of an Ising model in a quenched random field (RFIM) beyond mean-field, we revisit the phenomenon of spinodals in the presence of quenched disorder and develop a complete theory for it. By working at zero temperature in the quasi-statically driven RFIM, thermal fluctuations are eliminated and one can give a rigorous content to the notion of spinodal. We show that the spinodal transition is due to the depinning and the subsequent expansion of rare droplets. We work out the critical behavior, which, in any finite dimension, is very different from the mean-field one: the characteristic length diverges exponentially and the thermodynamic quantities display very mild non-analyticities much like in a Griffith phenomenon. On the basis of our results we assess the physical content and the status of the dynamical transition predicted by the mean-field theory of glassy dynamics. Phenomenological implications concerning avalanches of motion and dynamic facilitation will be also discussed.

*Speaker

Different amorphous correlation length scales as the multiple facets of the glass transition

Chiara Cammarota * [1], Giulio Biroli, Giacomo Gradenigo, Gilles Tarjus, Marco Tarzia

[1] King's College London – United Kingdom

The development of a full-fledged theory of the Ideal Glass Transition in supercooled liquids has been hindered for long time by the lack of evidence for the existence of a static cooperative length scale significantly growing when the putative critical point is approached, and giving rise to the peculiar glass critical behaviour. After the first definition of the so called "point to set" correlation length scale, the first good candidate for such a static medium-range spatial correlation, in recent times many theoretical experimental and numerical studies on glass-formers have been distinguished by the discovery and characterisation of quite a number of different static correlation length scales: the pattern-repetition correlation length scale, the extent of correlation from blocked particles either randomly chosen, or arranged in a spherical boundary, in a single wall or double mirroring walls, with particles placed in the positions of an equilibrium configuration or a random template, besides other crossover length scales obtained from finite size scaling studies of several bulk properties. The detailed definitions of these correlation length scales and the assessment of their mutual differences or interconnections constitute a challenge and a validation ground for any theory of glass formation in the regime of temperature where these length scales are found to significantly deviate from the microscopic correlation length emerging in classical studies of the static structure factor. In the Random First Order Transition theory several of these cooperative lengths find a proper definition interestingly enlightening different aspects of the physics of glass-formers. In this talk I will present the results of my recent works [1-4] devoted to the development of a theory of the complementary but distinct cooperative phenomena at the origin of different cooperative length scales. I will talk about the consequences their discovery implies on our understanding of the ideal glass transition or in general on the phenomenon of glass formation. The theoretical predictions will be discussed in the light of some of their checks in recent numerical and experimental works. [1] Renormalization group analysis of the random first-order transition C Cammarota, G Biroli, M Tarzia, G Tarjus Physical review letters 106 (11), 115705 (2011) [2] Ideal glass transitions by random pinning C Cammarota, G Biroli Proceedings of the National Academy of Sciences 109 (23), 8850-8855 (2012) [3] Confinement as a tool to probe amorphous order C Cammarota, G Gradenigo, G Biroli Physical review letters 111 (10), 107801 (2013) [4] Fluctuations and Shape of Cooperative Rearranging Regions in Glass-Forming Liquids G Biroli, C Cammarota arXiv preprint arXiv:1411.4566 (2014)

*Speaker

Effective Hamiltonians of 2D Spin Glass Clusters

Colin Clement * [1], Danilo Liarte, A. Alan Middleton, James P. Sethna

[1] Cornell University – United States

Inspired by machine learning we have developed a method for computing effective Hamiltonians which describe interactions between the clusters which are thought to dominate the dynamics of spin glasses in two dimensions. The result is a kind of real-space renormalization that emerges naturally from the correlations of a given sample of disorder, and can be compared to results from Domain-Wall renormalization. We use samples from high-performance numerically exact Pfaffian methods to explore the flow of the distribution of couplings for different temperatures and system sizes. Recursively applying our procedure on the effective cluster Hamiltonian, we find that high-temperature effective Hamiltonians retain the low-temperature correlations present in their parent models.

*Speaker

Echoes of the glass transition in athermal soft spheres

Eric Corwin * [1], Peter Morse

[1] University of Oregon – United States

The glass transition and the athermal jamming transition are both transitions from one disordered state to another marked by a sudden increase in rigidity. Before the onset of rigidity, thermal hard spheres and athermal soft spheres both share the same configuration space. Is there a signature of the glass transition in the topology of the allowed configuration space, and is this same signature present for athermal spheres? I will answer these questions by introducing the concept of local rigidity, and in doing so, I will demonstrate the existence of a pre-jamming phase transition coinciding precisely with the thermal glass transition density.

*Speaker

Static sources of dynamical fluctuations in glass-formers

Daniele Coslovich * [1]

[1] Université de Montpellier – France

The dynamics of glass-forming liquids is heterogeneous and displays growing spatial correlations upon cooling. Whether such behavior arises from fluctuations in local structure or more complex forms of amorphous order is a highly debated question. To clarify this issue, we studied several model liquids within a coherent simulation framework based on the iso-configurational ensemble [1]. We found that the correlation between the preferred local structure and dynamic heterogeneity is system-dependent: it is pronounced in systems that deviate markedly from the mean-field picture of glassy dynamics and weak or absent in models that adhere to it to a good extent. I will review these results and then assess recent proposals to account for dynamic fluctuations using more generic measures of structure, such as overlap distributions and predictability analysis. Finally, I will characterize the structure of ultra-stable glassy samples of hard and soft spheres, which we recently equilibrated at large packing fractions using an optimized swap Monte Carlo algorithm [2]. [1] G. M. Hocky, D. Coslovich, A. Ikeda, D. R. Reichman, Phys. Rev. Lett. 113, 157801 (2014) [2] L. Berthier, D. Coslovich, A. Ninarello, M. Ozawa, arXiv:1511.06182 (2015)

*Speaker

Configurational Temperatures in Granular Materials

Karen Daniels * [1]

[1] North Carolina State University – United States

Because granular materials exhibit reproducible statistical distributions which depend in simple ways on macroscopic parameters such as volume and pressure, it is tempting to create a statistical mechanics of athermal materials. I will describe a suite of experiments which investigate to what extent these ideas are meaningful. In an apparatus designed to generate a large number of independent, jammed, two-dimensional configurations, we test whether or not various temperature-like variables are able to equilibrate between a subsystem and a bath. Each configuration consists of a single layer of photoelastic disks supported by a gentle layer of air blown through a microporous frit. New configurations are generated by alternately dilating and re-compacting the system through a series of boundary displacements, using overhead air jets to randomize the particles prior to each run. The use of photoelastic particles permits us to measure the vector forces at each inter-particle contact. One thermodynamic-like description, the force-moment ensemble [1], states that the distribution of particles and stresses within a system is controlled by a tensorial temperature-like variable known as angoricity. In the first experiment I will describe, we surround a subsystem of low-friction particles with a bath of higher-friction particles, and examine packings produced under biaxial compressive strains [2]. Using the overlapping histogram method, we find that the angoricity tensor successfully equilibrates between the subsystem and the bath. We observe that both the compression and shear components of the angoricity are linearly dependent on the hydrostatic pressure, in agreement with predictions from the force-moment ensemble. In a second experiment, we compare packings produced under different loading histories, and find that the tensorial angoricity is in fact sensitive to the choice of protocol.

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*Speaker

Experimental evidences of the Gardner phase in a granular glass

Olivier Dauchot * [1], Antoine Seguin

[1] CNRS, UMR Gulliver – France

Analyzing the dynamics of a vibrated bi-dimensional packing of bidispere granular discs below jamming, we provide evidences of a Gardner phase deep into the glass phase. To do so we perform several independent compression cycles within the same glass and show that the particles select different average vibrational positions at each cycle, while the neighborhood structure remains un- changed. We compute the mean square displacement as a function of the packing fraction and compare it with the average separation between the cages obtained for different compression cycles. Our results are fully compatible with recent numerical observations obtained for a model of mean field glass former. We also characterize the distribution of the cage order parameters. Here we note several differences with the numerical results, which can be attributed to activated processes and cage heterogeneities absent in the case of a mean field models.

*Speaker

Theory of the jamming transition at finite temperature

Eric Degiuli * [1], E. Lerner, M. Wyart

[1] Ecole Polytechnique Federale de Lausanne – Switzerland

A theory for the microscopic structure and the vibrational properties of soft sphere glass at finite temperature is presented. With an effective potential, derived here, the phase diagram and vibrational properties are worked out around the Maxwell critical point at zero temperature T and pressure p. Variational arguments and effective medium theory identically predict a non-trivial temperature scale $T^* \sim p^{1+1/(1-a)}$ with $a \approx 0.17$ such that low-energy vibrational properties are hard-sphere like for $T > T^*$ and zero-temperature soft-sphere like otherwise. However, due to crossovers in the equation of state relating T , p, and the packing fraction ϕ, these two regimes lead to four regions where scaling behaviors differ when expressed in terms of T and ϕ. Scaling predictions are presented for the mean-squared displacement, characteristic frequency, shear modulus, and characteristic elastic length in all regions of the phase diagram.

*Speaker

Localization and quantum creep in disordered quantum rotors

Andrei Fedorenko * [1], Alexei Andreanov

[1] ENS Lyon – France

Ability of the renormalization group (RG) methods based on ε - expansion to describe properly the activated dynamics of random field systems was questioned many years ago [1]. Even for the classical transition, the only available evidence comes from numerical simulations and experiments. We study the dynamics of a d-dimensional system of $O(N)$ quantum rotors in the presence of random fields using functional renormalization group (FRG). Below the lower critical dimension $d_{\rm lc} = 4$ the system exhibits a quasi-long-range order with a power-law decay of correlations that is controlled by a quasi-classical zero temperature fixed point. In real space renormalization group schemes one usually fixes the temperature and the Planck constant so that the renormalized disorder strength grows approaching an infinite-randomness fixed point. In our FRG scheme we fix the disorder strength near the fixed point but allow the temperature and the effective Planck constant to flow to zero. The both parameters turn out to be dangerously irrelevant like the temperature in the random field Ising model that drastically changes the dynamic scaling picture which one could expect from a naive RG treatment. This allows one to obtain the evidence for the activated scaling and calculate the corresponding critical exponents using ε-expansion. At zero temperature the spin-waves are localized at the length scale $L_{\rm loc}$ beyond which the quantum tunneling is exponentially suppressed $c \sim e^{-(L/L_{\rm loc})^{2(\theta+1)}}$. At finite temperature T the spin-waves propagate by thermal activation over energy barriers that scales as L^θ. Above $d_{\rm lc}$ the system undergoes an order-disorder phase transition with activated dynamics such that the relaxation time grows with the correlation length ξ as $\tau \sim e^{C\xi^\theta/T}$ at finite temperature and as $\tau \sim e^{C'\xi^{2(\theta+1)}/\hbar^2}$ in the vicinity of the quantum critical point. [1] T. Senthil, Phys. Rev. B 57, 8375 (1998).

*Speaker

Spatio-temporal patterns in ultra-slow creep dynamics of magnetic interfaces

Ezequiel Ferrero * [1], Laura Foini, Thierry Giamarchi, Alejandro Kolton, Alberto Rosso

[1] Université Grenoble Alpes – France

In presence of impurities or structural disorder, ferromagnetic domain walls advance only when a sufficiently large external field is applied. Close to this depinning threshold, the wall proceeds by abrupt jumps called avalanches; while, at much smaller fields, it can only creep assisted by thermal activation. In this work we develop a novel numerical technique that captures this ultra-slow creep regime over arbitrarily large time scales for the paradigmatic problem of an elastic interface moving in a random media. Our results can be summarized as follows:

1) We point out the existence of activated events that involve a collective reorganization of substantial portions of the system, with a cutoff size S_{opt} that diverges at vanishing applied field.
2) At variance with uncorrelated depinning avalanches, creep events display spatio-temporal patterns similar to the sequence of aftershocks observed after a large earthquake, they are highly correlated.
3) We show that events assembly in independent "clusters".

Remarkably, this clusters show a scale-free statistics identical to the depinning avalanches when clusters bigger than S_{opt} are considered and display a power-law distribution with an exponent proper of equilibrium for smaller clusters. This crossover, between an equilibrium behavior at small length scales and emergent properties of the depinning universality class at large length scales, is in agreement with Functional Renormalization Group expectations and is found to be self-consistent when analyzing the roughness of the interface at different scales. Our results are compatible with the celebrated creep law for the velocity of the interface below threshold, but on the other hand they challenge the commonly assumed scenario of uncorrelated creep events. We expect this spatio-temporal patterns to be experimentally accessible by magneto-optical imaging of ferromagnetic films and, for that, we provide realistic quantitative predictions.

*Speaker

Universal Spectrum of Normal Modes in Low-Temperature Glasses: an Exact Solution

Silvio Franz * [1], Giorgio Parisi, Pierfrancesco Urbani, Francesco Zamponi

[1] LPTMS – France

Packing of hard spheres is a non-convex, continuous optimization problem (COP) in presence of constraints. Jamming can be seen as the point where the system undergoes a phase transition from a SAT phase, where all the constraints that define the problem can be satisfied to an UNSAT phase where this is not possible. It turns out that the jamming phase transition is super-universal: (1) the critical exponents of hard spheres do not appear to depend on spacial dimension in numerical simulations, (2) COP models, in principle very different from sphere also have the same exponents. I will illustrate this universality, and show how it can be exploited to characterize and describe universal features of the spectrum of glassy systems close to jamming. I will report about an analytical study of the vibrational spectrum of the perceptron. This well known neural-network model turns out to be the "simplest model of jamming" and allows for an exact solution. Two distinct classes of soft modes can be identified. The first kind of modes are related to isostaticity and appear only in the close vicinity of the jamming transition. The second kind of modes instead are present everywhere in the glass phase and are related to the hierarchical structure of the potential energy landscape. These results highlight the universality of the spectrum of normal modes in disordered systems, and open the way towards a detailed analytical understanding of the vibrational spectrum of more realistic models of low-temperature glasses.

*Speaker

Essential difference in the dynamics between strong and fragile glass-formers

Akira Furukawa * [1], Hajime Tanaka

[1] University of Tokyo – Japan

The dynamics of a liquid slows down as it is cooled towards the glass transition. In terms of to what degree the temperature dependence of the viscosity (or relaxation time) deviates from Arrhenius behavior, liquids are classified into two types: strong glass-formers with nearly Arrhenius behavior and fragile glass-formers with super-Arrhenius behavior. Here we reveal an essential difference in the dynamics between strong and fragile glass-formers through molecular dynamics simulations. In strong glass-formers, the relaxation dynamics of density fluctuations is (quasi-)non-conservative, whereas that of fragile glass-formers exhibits conservative (diffusive) behavior. We demonstrate that this distinction is a direct consequence of the fundamental difference in the underlying elementary process between these two dynamical classes of glass-formers. For fragile glass-formers, a density-exchange process proceeds the density relaxation, which locally takes place in normal states but is increasingly cooperative and non-local as the temperature is lowered in supercooled states. On the other hand, in strong glass-formers, such an exchange process is absent. Our finding provides a novel insight into Angell's classification scheme from a hydrodynamic perspective.

*Speaker

Disentangling the role of facilitation and hopping on approaching the colloidal glass transition

Rajesh Ganapathy * [1], Shreyas Gokhale, Hima K Nagamanasa, A K Sood

[1] Jawaharlal Nehru Centre for Advanced Scientific Research – India

Despite extensive research, it remains to be established whether glass formation is a fundamentally thermodynamic or dynamic phenomenon. In particular, it is not yet clear whether structural relaxation is dominated by the correlated motion of localized excitations, as postulated by the dynamical facilitation (DF) theory, or by the collective hopping of groups of particles, as envisioned by various thermodynamic approaches. We developed a scheme based on a real space microscopic analysis of particle dynamics to ascertain the relevance of dynamical facilitation as a mechanism of structural relaxation in glass-forming liquids. By analyzing the spatial organization of localized excitations within clusters of mobile particles in a colloidal glass former and examining their partitioning into shell-like and corelike regions, we establish the existence of a crossover from a facilitation-dominated regime at low area fractions to a collective activated hopping-dominated one close to the glass transition.

*Speaker

Non-equilibrium quasi-long-range order of a driven random field O(N) model: Numerical and Renormalization group study

Taiki Haga * [1]

[1] Kyoto University – Japan

Thermodynamic systems in an ordered phase can exhibit remarkably complex behavior when they are driven by an external force. Well-studied examples include ferromagnetic systems and crystalline systems that are driven by steady shear and oscillating external fields. The driving forces can significantly change the nature of the phase transition. The ferromagnetic and crystalline phases are characterized by long-range order (LRO). As a qualitatively different behavior, the two-dimensional XY model exhibits quasi-long-range order (QLRO), wherein the order parameter remains zero but the spatial correlation decays in a power-law form. The transition between the QLRO phase and the disordered phase is called the Berezinskii-Kosterlitz-Thouless (BKT) transition. This peculiar type of phase transition has attracted considerable research attention. However, the possibility that a driving force causes the BKT transition has not been clearly discussed or established. Consequently, the question arises as to whether there is a system that does not exhibit the BKT transition in equilibrium, while it does exhibit the transition in the presence of a driving force. In this study, we consider three-dimensional O(N) spin models driven with a uniform velocity over a random field (Driven Random Field O(N) Model) as first examples of such systems. First, for the case that N=2 (XY model), we show that this model exhibits QLRO at low temperatures by using the spin-wave approximation. Furthermore, for the cases that N=2 and 3, we numerically demonstrate a non-equilibrium phase transition between the QLRO phase and the disordered phase, which turns out to resemble the BKT transition in the two-dimensional pure XY model in equilibrium. Finally, we develop a non-perturbative renormalization group approach for our Driven Random Field O(N) Model. This approach employs an exact renormalization group equation for the dynamical effective average action with a non-perturbative approximation scheme and it enables us to obtain a unified non-perturbative description of the (N, d) phase diagram, where d is the spatial dimension.

*Speaker

Rigidity and its Origin in Configurational Constraint

Peter Harrowell * [1], Shibu Saw

[1] University of Sydney – Australia

Mechanical rigidity is a consequence of a constraint of the sampling of the space of configurations. This constraint can be achieved by a variety of means: a phase transition into an ordered state, decreasing particle mobility by cooling or the pinning of a selection of particles. The possibility that a measure of the configurational constraint can provide an account of the shear modulus independent of how that constraint is imposed offers a number of benefits. In the case of an amorphous material, rigidity can be lost by raising the temperature or by applying a nonlinear shear strain. In this talk we shall demonstrate that the different physical explanations of these two phenomena, i.e. the glass transition and the occurrence of plastic yield events, respectively, can be described in terms of a common variable, the degree of configurational constraint.

*Speaker

Cross Correlations between Plasticity and Magnetism in Amorphous Solids

H.g.e Hentschel * [1], R Dasgupta, B Sengupta, I Procaccia

[1] Emory University – United States

We will report on new cross correlation phenomena involving plasticity and magnetism in amorphous solids. As an example of such a cross correlation effect we shall consider plasticity induced magnetic ordering in amorphous solids. Here amorphous magnetic solids, like metallic glasses, with no macroscopic magnetic order even in the presence of an applied field when not strained due to random locally favored orientations for individual spins can, nevertheless, exhibit the emergent growth of a macroscopic magnetic order when strained. The magnetic moment increases in mesoscopic steps whenever a plastic avalanche occurs. The plasticity acts as the effective noise driving the frustrated system towards equilibrium.

*Speaker

Dynamics and phase transition of a three-dimensional Potts glass model

Koji Hukushima * [1], Takashi Takahashi

[1] University of Tokyo – Japan

Mean-field theory of spin glasses has provided a number of novel concepts for understanding of a phase transition in disordered glassy systems. In particular, replica-symmetry breaking (RSB) plays an essential role in describing complex free-energy structure. It turns out that the pattern of RSB is clarified into two distinct classes, full RSB and one-step RSB. Despite extensive studies including large-scale numerical simulations, no conclusion has been reached about the issue whether the RSB concepts survive in short-ranged spin-glass models in finite dimensions. In recent years, some mean-field spin-glass models with the one-step RSB have attracted much attention of many researchers. These models are regarded as a prototype of a phenomenological picture of structural glass transition, called random first-order transition (RFOT), which is characterized by a thermodynamic transition with a discontinuous order parameter without latent heat. The advisability of the RSB picture in finite dimensional spin glass models comes to an issue again in the context of the structural glass transition. In this talk, we present some results of large-scale Monte Carlo simulations based on extended ensemble method for a Potts-glass model in three dimensions. Our findings for static quantities are fully compatible with those expected from the RFOT picture based on the one-step RSB. It is also found that a dynamical singularity observed by the four-point susceptibility occurs simultaneously at the static one-step RSB transition temperature.

*Speaker

Overlap fluctuations, phase transitions and stable glass melting in plaquette spin models

Robert Jack * [1], Juan P Garrahan

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Plaquette spin models are classical spin systems that have trivial thermodynamic properties, but nevertheless exhibit many glassy phenomena: super-Arrhenius growth of relaxation times, dynamical heterogeneity, and increasing length scales associated with point-to-set correlations. By biasing a three-dimensional plaquette model to be similar to a second (quenched, fixed) copy of the model, we recently observed a phase transition [1], whose order parameter is the overlap between the two copies of the system. (The bias to high overlap is applied via a field ϵ that couples the two copies.) The nature of this phase transition is consistent with the predictions of Franz and Parisi [2] for generic glassy systems, although in this three-dimensional setting, phase transitions only appear for finite values of the field ϵ. I will discuss theoretical consequences of this observation, particularly regarding similarities and differences between dynamical facilitation and mean-field theories of the glass transition. These results are also relevant for understanding the mechanisms by which stable glasses recover to equilibrium, on heating above their glass transitions [3]. [1] RL Jack and JP Garrahan, Phys. Rev. Lett. 116, 055702 (2016). [2] S Franz and G Parisi, Phys. Rev. Lett. 79, 2486 (1997). [3] RL Jack and L Berthier, arXiv:1603.05017.

*Speaker

Activity-induced aging in a topologically constrained glass

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It is well established that curved interfaces in soft matter underlie a rich variety of geometry- and topology-driven phenomena, but the role of curvature in the out-of-equilibrium dynamics of active matter has only recently started to attract interest. Here we present particle-resolved computer simulations of a simple active model system composed of self-motile, repulsive rods that are confined to a spherical manifold. We find that, depending on the rod length and packing density, the system can exhibit a variety of dynamical phases including swarming and distorted laning motion. Notably, for densely packed short rods, we find a novel self-spinning glass phase that is characterized by strong disorder and persistent collective rotation. By subsequently allowing the confining spherical manifold to swell and shrink, the active glass can be melted and revitrified through the effective increase and decrease of density, respectively. We find that this 'breathing' motion of the sphere gives rise to a new type of aging dynamics, in which the system solidifies into a different but more stable glass state after several breathing cycles. This is to be contrasted with the passive-glass scenario, which in our model system would remain completely unaffected by repeated swelling and shrinking. The aging behavior we observe is thus purely induced by the interplay between the geometry and activity of the system. Such activity-driven dynamics opens up new pathways for exploring and controlling the out-of-equilibrium behavior of topologically constrained active and glassy matter.

*Speaker

Bursty crystal plasticity: from jamming to pinning

Lasse Laurson * [1], Arttu Lehtinen, Markus Ovaska, Sanja Janicevic, Giulio Costantini, Stefano Zapperi, Mikko J. Alava

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Crystalline solids subject to an increasing stress undergo a transition from nearly-elastic behaviour to plastic flow mediated by collective, avalanche-like dislocation motion, observable as power-law distributed strain bursts in micron-scale samples, and as a similar, broad distribution of acoustic emission energies in bulk specimens. To address the question of the origin and nature of such intermittent and critical-like dynamics in crystal plasticity, we perform extensive two- and three-dimensional discrete dislocation dynamics (DDD) simulations, both with and without the presence of other defects (such as precipitates or solute atoms) giving rise to a random quenched or time-dependent pinning field interacting with the dislocations. Our results show that both two-dimensional [1] and three-dimensional [2] "pure" DDD models exhibit bursty plastic deformation with properties inconsistent with a depinning-type non-equilibrium phase transition critical point. Instead, these systems behave analogously to some glassy systems with an extended critical-like phase, here observable down to zero applied stresses [3]. We attribute this behaviour to dislocation jamming, i.e. dislocations getting stuck to other dislocations via formation of complex dislocation structures. When extending the parameter space of the models by considering a quenched pinning field of intermediate strength interacting with the dislocations and competing with the tendency of dislocations to jam, a depinning-like scaling picture of the dislocation avalanches is recovered [4]. Even stronger disorder is shown to lead to the absence of scale-free avalanche dynamics. We also discuss our recent DDD simulations with mobile impurities interacting with the dislocations [5]. [1] P. D. Ispanovity, L. Laurson, M. Zaiser, I. Groma, S. Zapperi, and M. J. Alava, Avalanches in 2D Dislocation Systems: Plastic Yielding Is Not Depinning, Phys. Rev. Lett. 112, 235501 (2014). [2] A. Lehtinen, G. Costantini, M. J. Alava, S. Zapperi, and L. Laurson, Glassy features of crystal plasticity, submitted for publication. [3] S. Janicevic, M. Ovaska, M. J. Alava, and L. Laurson, Avalanches in 2D dislocation systems without applied stresses, J. Stat. Mech. P07016 (2015). [4] M. Ovaska, L. Laurson, and M. J. Alava, Quenched pinning and collective dislocation dynamics, Sci. Rep. 5, 10580 (2015). [5] M. Ovaska, T. Paananen, L. Laurson, and M. J. Alava, Collective dynamics of dislocations interacting with mobile solute atoms, accepted for publication in J. Stat. Mech.

*Speaker

Structural relaxation is a scale-free process

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We propose that the relaxation of a supercooled liquid at rest results from a series of transitions that are akin to solid-solid transformations. This idea arises because, at low temperatures, liquids spend most of the time vibrating around local minima (inherent states) of their potential energy surface. Since inherent states are, by definition, mechanically stable, they are genuine elastic solids. Hence relaxation events are solid-solid transitions and should leave elastic imprints in the surrounding medium. We demonstrate that it is indeed so via a systematic analysis of the inherent stress field obtained from 2D and 3D numerical simulations of equilibrated liquids. Moreover, our study reveals two significant and unexpected facts. First, we find that the inherent stress field presents anisotropic and long-ranged (power-law) correlations, which are a clear mark of elasticity. Second, we find that the relaxation events occurring over finite time windows are also power-law correlated in space. It follows that the relaxation process is scale-free beyond a size of order a few particles, an observation which rules out the currently widely held belief that it would decorrelate beyond some finite length scale. Our work thus brings evidence that elasticity plays a quite non-trivial role in relaxation and must absolutely be taken into account in any theory.

*Speaker

Nonlinear plastic modes in disordered solids

Edan Lerner * [1]

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Understanding the yielding transition observed upon deforming a glass beyond its elastic limit requires the proper identification of the objects, akin to dislocations in crystals, that carry plastic flow. In my presentation I will introduce a theoretical framework within which a robust, micro-mechanical definition of precursors to plastic instabilities in glassy solids, often termed 'soft-spots', naturally emerges. They are shown to be collective displacements, referred to as 'plastic modes', that lead to transitions over energy barriers in the glass, and can be calculated by properly accounting for nonlinearities of the potential energy landscape. I will review some of the micro-mechanical properties of plastic modes, and argue for the usefulness of their density as an order parameter that governs the rate of plastic flow in deformed glasses.

*Speaker

Observing Replica Symmetry Breaking in Glassy Random Lasers

Luca Leuzzi * [1], Fabrizio Antenucci, Andrea Crisanti

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In the framework of theoretical modeling of optical systems in random media, a non-linear quenched-disordered phasor model has been recently introduced reproducing known properties of multimode laser emission regimes and predicting new ones. In particular, a parameter measuring the correlation between intensity fluctuations of light modes is introduced and analyzed in different physical regimes as the amount and kind of coupling disorder and non-linearity is varied. A one-to-one relationship of such Intensity Fluctuation Overlap (IFO) is established to the standard Parisi overlap order parameter in mean-field replica theory for spin-glasses. In the phasor spherical model, describing the onset and behavior of standard mode-locking and random lasers, replica symmetry breaking in the IFO is shown to occur at high intensity pumping or low temperature. This order parameter identifies the laser transition in random media and describes its glassy nature in terms of the only data so far accessible in random laser measurements: emission spectra. The theoretical analysis is, eventually, compared to recent IFO measurements demonstrating the validity of the theory and providing a straightforward interpretation of different spectral behaviors in different random lasers.

*Speaker

Population Annealing: Theory and Application to Glassy Systems

Jonathan Machta * [1]

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Population annealing is an efficient sequential Monte Carlo algorithm for simulating equilibrium states of systems with rough free energy landscapes. I will describe the algorithm and discuss its convergence to equilibrium. Results from large-scale simulations of the 3D Edwards-Anderson (Ising) spin glass will be presented and implications for the low temperature spin glass phase will be discussed. I will also present preliminary results from simulations of dense binary mixtures of hard spheres.

*Speaker

Solution of the dynamics of liquids and glasses in the large-dimensional limit

Thibaud Maimbourg * [1], Jorge Kurchan, Francesco Zamponi

[1] Ecole Normale Supérieure – France

The dynamics of liquids, viewed as strongly interacting classical particle systems, remains a field where theoretical descriptions are struggling. So far, there is no microscopic theory starting from first-principles and using controlled approximations. Hydrodynamics is a coarse-grained regime, and microscopic theories (such as Mode-Coupling Theory) lack a small parameter. At the thermodynamic level, static equilibrium properties are well understood for simple liquids; however if one goes to glassy regimes, the same problems are encountered. Here we derive, from first principles, the statics and dynamics of liquids and glasses using the limit of large spatial dimensions, which provides a well-defined approximation with a clear small parameter. We show that this mean-field solution to the structural glass problem verifies the Random First-Order Transition scenario, as conjectured thirty years ago, based on the solution of mean-field spin glasses. It allows also to show that some approximate scale invariances in the phase diagram, relevant to finite-dimensional experiments, are exactly verified in this limit.

*Speaker

Quantum versus Thermal annealing, the role of Temperature Chaos

Victor Martin-Mayor * [1], Itay Hen

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We report here the results of a experimental investigation of the D-wave Two quantum annealer (DW2) [1], inspired in recent theoretical results for spin-glasses. D-Wave chips are aimed to find low-energy states of (stylized models for) spin-glasses. DW2 chip solve problems with 512 qubits. Next generation chips will handle up to 1000 qubits. Interestingly, D-Wave Two performance turns out to be extremely sensitive to a physical effect known by spin-glass practitioners as "temperature chaos" [1]. Our understanding of these chaotic effects is still scant, but a theoretical picture is emerging [2]. Salient features include extreme statistical fluctuations and a weird problem-size evolution. In fact, temperature chaos is a real show-stopper for state-of-the-art classical computations [3]. However, temperature chaos may be a fairly elusive phenomenon: it is extremely rare on the small systems that DW2 solves. In fact, its importance was missed by previous attempts to assess the DW2 chip performance [4]. Drawing from our previous spin-glass experience, we use the dynamics of a Monte Carlo algorithm, namely Parallel Tempering, to spot those problem instances presenting strong temperature chaos. We introduce a meaningful parameter to describe the difficulty of the problem posed by each instance: the Parallel Tempering mixing time τ. We had to screen 80000 instances in order to have τ that spans four orders of magnitude. Surprisingly, we find that the classical free-energy landscape is also significant for the performance of DW2. The time to solution varies by seven-order of magnitudes when τ is varied. We show in a quantitative way that temperature chaos correlates strongly as well with DW2 sensitivity to errors/noise during the programming cycles. We also show that, contrary to previous expectations, the success probability in DW2 does vary with the (quantum) annealing time. However, only those instances presenting the strongest temperature chaos seem to benefit significantly from the increment of the annealing time. In conclusion, we have presented a quantitative methodology to check the performance of a quantum annealer. Any forthcoming machine claiming to yield a real quantum speed-up can now be confronted with a really significant standard. [1] V. Martin-Mayor and I. Hen, Scientific Reports 5, Article number: 15324 (2015). [2] L.A. Fernandez, V. Martin-Mayor, G. Parisi and B. Seoane, EPL 103 (2013) 67003. [3] Janus collaboration, J. Stat. Mech. (2010) P06026; J. Stat. Mech. (2014) P05014. [4] W. Ronnow et al., Science 345, 420 (2014); S. Boixo et al., Nat. Phys. 10, 218 (2014).

*Speaker

Turning intractable counting into sampling: Computing the configurational entropy of three-dimensional jammed packings

Stefano Martiniani * [1], Julian Schrenk, Jacob D. Stevenson, David J. Wales, Daan Frenkel

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Many problems in physics can be framed in such a way that the states of interest are extrema, or solutions, of a high dimensional function. Enumerating and characterising the distribution of these states is a classical problem, be it the study of random Gaussian and polynomial fields, or spin and structural glasses in statistical physics, or the search for new exotic materials in condensed matter physics, or even the study of the possible configurations of a neural network in machine learning. The physical significance of this area may even go further and could have implications for string theory or cosmology. We have shown that, in the context of high-dimensional landscapes, questions such as, "how many solutions are there?" or "how likely is it to observe a certain state?" can, in general, be answered. The answer boils down to measuring the volume of the basin of attraction for a particular state or for a number of them, depending on the question at hand. In this talk we present the first numerical calculation of the total number of disordered jammed configurations Ω of N repulsive, three-dimensional soft spheres in a fixed volume V. To make these calculations tractable, we increase the computational efficiency of the approach of Xu et al. [Phys. Rev. Lett. 106, 245502 (2011)] and Asenjo et al. [Phys. Rev. Lett. 112, 098002 (2014)] and we extend the method to allow the computation of the configurational entropy as a function of pressure. The approach that we use computes the configurational entropy by sampling the absolute volume of basins of attraction of the stable packings in the potential energy landscape. We find a surprisingly strong correlation between the pressure of a configuration and the volume of its basin of attraction in the potential energy landscape. Related unpublished results will also be discussed.

*Speaker

Event-chain paradigm for Monte Carlo methods: Infinitesimal, irreversible and rejection-free Markov chains.

Manon Michel * [1]

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Monte Carlo methods, by sampling high-dimensional integrals through random walks, have revolutionized the understanding of complex systems. The traditional Metropolis local random walks induce however a high rate of rejections, making any simulations around a phase transition point too expensive. I explain how a consistent interpretation of the mathematical lifting concept and the factorized Metropolis filter yield a new paradigm of irreversible algorithms [1]. This new class of rejection-free algorithms indeed break detailed balance yet fulfill the global one and display moves that are infinitesimal, instead of finite random local moves.

As an application, I exhibit how event-chain algorithms bring considerable speed-ups for general particles systems [1], but also for classical continuous spin model, including the notoriously difficult problem of spin glasses [2, 3]. In particular, recent work on Heisenberg spins system shows a qualitative reduction of the dynamical scaling exponent, leading to an infinite speed-up [3]. The powerful event-chain algorithm is general yet easy to implement. Its infinite number of samples provide direct access to observables that could not be obtained directly and complex interactions can be factorized into simple components [1].

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*Speaker

Configuration Memory in Patchwork Dynamics for Low-dimensional Spin Glasses

A. Alan Middleton (syracuse University) * [1], Jie Yang

[1] Syracuse University – United States

A patchwork dynamics method is used to study the loss and recovery of configurations in spin glass models in dimensions $d = 1$ and $d = 2$. This method is used as a heuristic to accelerate the dynamics and to investigate how these models might reproduce the remarkable memory effects seen in experiment. Starting from a ground state configuration at one choice of couplings, a sample is aged up to a given scale under an independent choice of couplings, leading to the partial erasure of the original state. The memory of the original ground state is then computed when the couplings are reset to the original choice and coarsening is applied. Recovery of the original ground state with coarsening is found for two-dimensional Ising spin glasses and one-dimensional Potts models. It can be proven that one-dimensional Ising glasses neither lose nor gain overlap with coarsening. The recovery curves are consistent with scaling relations that define a coarsening recovery scale in terms of the aging scale.

*Speaker

Beating by order the amorphous lower limit of thermal conductivity

Stefano Mossa * [1], Hideyuki Mizuno, Jean-Louis Barrat

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The way in which ordered and disordered structural organizations impact properties of materials with identical chemical composition at the same external thermodynamic conditions is a key issue. Consider heat transfer, a process of paramount importance in physics and material science. The value measured in the amorphous glassy structure is considered as a lower limit for the thermal conductivity of any material. Indeed, in this case phonons strongly interact with disorder, and their lifetimes reach the minimum time scale allowed by thermal fluctuations at the given temperature. Smart design at the nano-scale, however, is known to allow reducing the thermal conductivity even below the amorphous limit, as demonstrated in recent breakthrough experiments. The mechanisms contributing to these observations still have not been completely rationalized in a coherent picture. In this talk I will address this point. We have studied by classical Molecular Dynamics computer simulation model systems, formed by binary mixtures of soft spheres with different masses, for a few values of the mass heterogeneity[1]. The vibrational spectra and the low temperature thermal conductivity have been investigated in the two cases where the masses are distributed at random positions (glass) or organized in fully ordered intercalated structures (super-lattices). I will show that, by controlling the width of the ordered domains in the latter case, the thermal conductivity in the direction of the replication pattern can be tuned to reach a value lower than that associated to the completely disordered structure. In this case, the different domains act as filters in complementary non-overlapping regions of the vibrational spectrum, therefore significantly suppressing the total phonons transport in the direction of the replication pattern. I will elucidate the critical role played by the interfaces, and show how to directly modify these latter to tune heat transfer even further. [1] "Beating the amorphous limit in thermal conductivity by super-lattices design" Hideyuki Mizuno, Stefano Mossa, and Jean-Louis Barrat Scientific Reports 5, 14116 (2015) - doi:10.1038/srep14116

*Speaker

The role of polydispersity and softness in equilibrating glasses at unprecedently low temperatures

Andrea Ninarello * [1], Daniele Coslovich, Ludovic Berthier

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The role of polydispersity and softness in equilibrating glasses at unprecedently low temperatures One striking challenge of glass science is to reveal properties of systems at very low temperatures, due to the intervention of the dynamical arrest during the cooling process that causes a tremendous increase of relaxation times. At present, computational studies of atomic glassy models have been able to reach temperatures of the order of the mode-coupling crossover, which are much higher than that of the experimental glass transition. In this contribution we perform Monte-Carlo simulations of atomic glass-formers implementing an effective algorithm which allow us to equilibrate the system well beyond the mode-coupling crossover. We systematically test different polydisperse systems reporting the role that polydispersity and particle softness play in avoiding cristallization and efficiently reach previously unexplored regimes. In this framework we can study properties of the potential energy landscape at unprecedently low temperatures, such as inherent structures energy, saddle points behaviour and soft vibrational modes. At the same time, dealing with athermal polydisperse systems, we can investigate the relation between glass and jamming transitions at extremely high packings [1]. This work also paves the way to numerous novel investigations of soft-potential atomic glass-formers at large degree of supercooling, such as mesures of configurational entropy, plastic properties and, possibly, the ultimate behaviour of glass-formers very close to the ideal glass transition. [1] Berthier L., Coslovich D., Ninarello A., Ozawa M., arXiv:1511.06182, (2016)

*Speaker

Fat diagrams: a topological expansion for lattice models

Giorgio Parisi * [1], Carlo Lucibello, Federico Ricci , Tommaso Rizzo

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In this talk I will study the expansion around mean field for short-range lattice models, i.e. the so-called loop expansion. I will show how to construct in a systematic way the loop expansion using as zero'th order approximation the exact solution of the model on the Bethe Lattice. I am interested to study this expansion near to the critical point where the correlation distance diverges.
This expansion can be formulated in term of "fat diagrams"; it is particularly interesting in cases where a phase transition is absent in the usual mean field theory, but a transition is present in the Bethe approximation.

*Speaker

Connecting local yield stresses with plastic activity in a model amorphous solid

Sylvain Patinet * [1], Damien Vandembroucq, Michael L. Falk

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A long-standing problem in modeling of mechanical response of amorphous solids is the absence of clear relations between structure and plastic activity. Here we directly probe local regions of a model atomic glass by measuring the local yield stress of glasses produced via differing quench protocols. A strong correlation is established between the local low shear stress thresholds and the plastic rearrangements generated during remote loading. This purely local yield stress field shows a better prediction power of the plastic activity location in comparison with more conventional structural properties. Most importantly, the soft zones thus defined are shown to be persistent with the plastic deformation, i.e. after several plastic rearrangements. This direct and non-perturbative approach gives access to explicit physical quantities characterizing the stability of amorphous solids from atomistic simulations. Our results reinforce the relevance of modeling plasticity in amorphous solids based on a gradually evolving population of discrete and local zones pre-existing in the structure.

*Speaker

Disordered Contact Networks in Jammed Packings of Frictionless Disks

Kabir Ramola * [1], Bulbul Chakraborty

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We analyse properties of contact networks formed in packings of soft frictionless disks near the unjamming transition. We construct polygonal tilings and triangulations of the contact network that partitions space into convex regions which are either covered or uncovered. This allows us to characterize the *local* spatial structure of the packing near the transition using well-defined geometric objects. We construct bounds on the number of polygons and triangulation vectors that appear in such packings. We study these networks using simulations of bidispersed disks interacting via a one-sided linear spring potential. We find that several underlying geometric distributions are reproducible and display self averaging properties. We find that the total covered area is a reliable real space parameter that can serve as a substitute for the packing fraction. We find that the unjamming transition occurs at a fraction of covered area $A_G^* = 0.446(1)$. We determine scaling exponents of the covered area as the energy of the system approaches zero $E_G \to 0^+$, and the coordination number Z approaches its isostatic value. We find $\Delta A_G \sim \Delta {E_G}^{0.25(2)}$ and $\Delta A_G \sim \Delta Z^{1.00(1)}$, representing new structural critical exponents. We use the distribution functions of local areas to study the underlying geometric disorder in the packings. We find that a finite fraction of order $\psi_O^* = 0.369(1)$ persists as the transition is approached.

*Speaker

Dynamical Field Theory of the Glass Crossover

Tommaso Rizzo * [1], Thomas Voigtmann

[1] Institute for Complex Systems (CNR) and Sapienza University – Italy

Many theoretical approaches to supercooled liquids, including notably Mode-Coupling-Theory (MCT), predict a sharp transition where there is instead a dynamical crossover from power-law to exponential growth of the relaxation time. In spite of this shortcoming MCT is quantitatively successfull in describing the early stages of the relaxation and there have been continuous efforts to modify it in order to describe the crossover. Most of the attempts so far have been based on the *ad hoc* introduction of activated process but at present no such proposal is considered fully satisfactory. An alternative way to tackle the problem is based on the theory of critical phenomena. The sharp transition has indeed the features of a critical point, characterised by diverging fluctuations and correlation length. Furthermore it has intrinsically a mean-field nature, being the outcome of an approximate closure of the exact dynamical equations. The modern theory of critical phenomena tells us that mean-fields results should be always tested under the effect of long-wavelength fluctuations that can be studied by means of an appropriate Landau theory. The analysis of the Landau theory in the case of the glass crossover is technically more complex compared, say, to the classic example of the ferromagnetic transition in the Ising model. This is because one should study a dynamical theory (given that there is no actual stable glass state) and also because the avoided nature of the transition cannot be detected by conventional perturbative field-theoretical loop expansions. In spite of these technical difficulties this program is essentially completed for the β-regime, that is the time-scale where the dynamics develops a plateau and the system appears to be a glass. The results are rewarding: one can show the existence of an exact mapping between the dynamical Landau theory and a dynamical theory with quenched disorder (*T. Rizzo, arXiv:1603.02925*). Then the mean-field approximation made *before* disorder averaging leads to a rather simple and intuitive dynamical model called Stochastic-Beta-Relaxation (SBR) *T. Rizzo, EPL 106 (2014) 56003* that can be studied non-perturbatively unveiling the avoided nature of the transition. According to SBR dynamical fluctuations in the β regime are determined by quenched local fluctuations of the critical temperature. This mechanism destabilises the glassy phase implying that the β regime must eventually end into the so-called α regime where ergodicity is restored even below the crossover temperature. The quenched nature of the temperature fluctuations can only be valid on the time-scale of the β regime, that is large but well separated from the larger α scale, nevertheless one can to a certain extent obtain also information on the α regime. Ongoing studies of the solution of SBR *T. Rizzo and T. Voigtmann, EPL 111, 56008 (2015) and arXiv:1504.06263* display a rather rich phenomenology common to most super-cooled liquids. In its simplest version SBR naturally explains two prominent features of the dynamical crossover: the change from a power-law to exponential increase in the structural relaxation time and the violation of the Stokes-Einstein relation between diffusion and viscosity. The solution in three dimensions unveils a qualitative change at the crossover in the structure of dynamical fluctuations from a regime characterised by power-law increases of their amplitude and size to a regime dominated by strong Dynamical Heterogeneities (DH): rare regions where dynamics is relatively much faster than in the rest of the system. While the relaxation time changes by orders of magnitude, the size of DH's does not change significantly and actually decreases below the crossover temperature. The theory of the α regime remains to be developed. However, based on the description of the β regime provided by SBR, an interesting possibility is that below the crossover ergodicity is restored by non-conventional activated dynamics characterised by elementary events of a collective nature with intrinsic time and length scales of an unusual large (but not necessarily increasing) size (mesoscopic vs. microscopic). While mean-field methods are currently applied to many problems related or inspired by the physics of supercooled liquids, the set of results we have presented should be acknowledged between the few significant advances obtained beyond mean-field. Furthermore they provide a detailed and falsifiable scenario for the physics of the glass crossover in a time where numerical simulations are beginning to access systematically this temperature region and could finally set the question of the relevance of the research line, to which SBR belong, connecting structural glasses and spin glasses.

*Speaker

Experimental Evidence for a Non-equilibrium Phase Transition in Trajectory Space

C. Patrick Royall * [1], Rattachai Pinchaipat, Francesco Turci, James E. Hallett, Matteo Campo, Thomas Speck

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The glass transition is one of the longstanding challenges in condensed matter. In particular, one seeks to understand how solidity emerges with little apparent change in structure [1]. In recent years, it has become possible to identify structural changes in a range of glassformers through the identification of certain geometric motifs which minimise the local free energy, so-called locally favoured structures (LFS) [2]. However, demonstrating a causal link between these and dynamical properties of the system has met with some success [3], but in general appears challenging [4]. Among the key achievements has been to identify a non-equilibrium phase transition in trajectory space. This transition bears many of the hallmarks of a conventional transition, but, rather than through their configurations, the two phases are distinguished through the properties of their trajectories, of length a few structural relaxation times. In particular, this transition reveals phase coexistence between the normal supercooled liquid and a phase rich in locally favoured structures [5]. Until now, such transitions have been exclusively confined to numerical and theoretical studies, but here we present evidence that such a transition occurs in experiment. Specifically, we identify trajectories in a model glassformer, colloidal hard spheres, using particle-resolved studies (confocal microscopy). We analyse the trajectories and find a characteristic large deviation behaviour, a non-Gaussian distribution in their population of LFS. That is to say, the population of LFS-rich trajectories is much larger than is expected, which we interpret as evidence of an LFS-rich glass phase. Reweighting the trajectories provides evidence of two distinct populations, normal liquid and LFS-rich glass, consistent with a first-order phase transition in trajectory space. We confirm our results with computer simulations. This work provides an experimental perspective by which differing theories of the glass transition such as dynamic facilitation (which incorporates such non-equilibrium phase transitions) and theories which place an emphasis on structure, such as random first order transition theory and geometric frustration, may be related to one another.

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*Speaker

Role of fluctuations in glassy transitions of plaquette spin models of glasses

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We study the role of fluctuations in plaquette spin models of glasses. The slow dynamics of such models are known to be be well described in terms of rare defects and kinetic constraints. Yet it has also recently been shown that in the presence of a constraining field these models display thermodynamic phase transitions associated with an overlap order parameter, similarly to what is expected from the random first-order transition approach based on the mean-field theory of the glass transition.[1] By comparing the models on Bethe lattices of different local connectivity we can assess the influence of short-scale fluctuations, which is found to be crucial. Such effects can be disentangled from those of large-scale fluctuations that can be understood from a comparison with the models on Euclidean lattices and the derivation of effective theories. We discuss the implications for the connection between the mean-field theory of the glass transition and the defect picture put forward by the dynamical-facilitation approach [2]. [1] R. L. Jack and J. P. Garrahan, Phys. Rev. Lett. **116**, 055702 (2016). R. M. Turner, R. L. Jack, and J. P. Garrahan, Phys. Rev. E **92**, 022115 (2015). [2] G. Biroli *et al.*, arXiv:1512.04720 ; C. Rulquin, G. Biroli, G. Tarjus, and M. Tarzia, in preparation.

*Speaker

Disentangling the role of shear induced structure formation and friction in shear jamming

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Amorphous packings of spheres have been intensely investigated in order to understand the mechanical and flow behaviour of dense granular matter, and to explore universal aspects of the transition from fluid to structurally arrested or jammed states. Packings of frictionless spheres jam at the random close packing density, of about 64% in volume fraction. However, in the presence of friction, jamming can occur over a broad range of densities, down to the so called random loose packing limit, of 55% in volume fraction. This range also corresponds to interesting phenomena in granular and colloidal suspensions. Recent investigations have focussed on anisotropic packings of frictional grains generated by shear deformation leading to shear jamming, which occurs over a range of densities below the density at which frictionless spheres jam. With the aim of disentangling the role of structures induced by shear deformation and friction in generating shear jamming, we study sheared assemblies of frictionless spheres computationally, over a wide range of densities, extending far below their jamming point. We demonstrate the emergence of a variety of geometric features characteristic of jammed packings with the increase of shear strain. We thus argue that shear deformation alone is able to generate the necessary structures for shear jamming, while friction is instrumental in stabilising packings over a range of densities below the isotropic jamming point. We substantiate this claim by showing that configurations generated by shear deformation of frictionless sphere jam with no structural change upon the introduction of frictional forces. We also investigate aspects of percolation that are relevant to shear jamming and show that the percolation of six-coordinated spheres corresponds to the shear jamming transition, either as a function of applied strain or density in the sheared steady states. References: H. A. Vinutha and S. Sastry "Disentangling the role of structure and friction in shear jamming" Nature Physics (2016) doi:10.1038/nphys3658 H. A. Vinutha and S. Sastry "Geometric aspects of shear jamming induced by deformation of frictionless sphere packings" JSTAT (submitted)

*Speaker

Shear Softening above Jamming

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We investigate experimentally the mechanical response of a monolayer of frictional grains to an inhomogeneous shear perturbation across the jamming transition. We inflate an intruder inside the packing and use photo-elasticity and tracking techniques to measure the induced shear strain and stresses at the grain scale. We quantify experimentally the constitutive relations for strain amplitudes as low as 10^{-3} and for a range of packing fractions within 2% variation around the jamming transition. At the transition strong nonlinear effects set in. The dependencies of the critical strain and the associated critical stresses on the distance from jamming are extracted via scaling analysis. We check that the constitutive laws, when applied to the equations governing mechanical equilibrium, lead to the observed stress and strain profiles. These profiles exhibit a spatial crossover between an effective linear regime close to the inflater and a truly nonlinear regime away from it. The crossover length diverges at the jamming transition. We will compare these results with recent findings about the existence of a Gardner phase deep into the glass phase.

*Speaker

The Gardner threshold: a border between two glasses

Beatriz Seoane * [1], Ludovic Berthier, Patrick Charbonneau, Yuliang Jin, Giorgio Parisi, Corrado Rainone, Francesco Zamponi

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Glasses (aka amorphous solids) exhibit various anomalies when compared with crystals (aka ordered solids): they display enhanced transport, activated slow dynamics across energy barriers, excess vibrational modes with respect to Debye's theory (the so-called Boson Peak), and respond drastically to very small mechanical deformations. In these works, we identify the common, universal origin to these anomalies first in a mean-field model for glasses [2] and finally in a realistic, three-dimensional model of glasses [1]. We show that in highly packed hard spheres, vibrations become highly correlated in space and time at a sharply defined threshold, which we call "Gardner threshold". This work is deeply related with the last developments in the analytical theory of glasses, where the glass problem has been finally solved exactly in the artificial limit of infinite spatial dimensions. The analytical solution predicts the existence of a genuine phase transition (a Gardner phase transition) within the glass, separating the glass and the jamming transitions. In this work we, not only establish the relevance of the (remanent of the) Gardner transition for real glasses, but also characterize it using well-defined observables, including time-dependent quantities and spatial correlations, that should be experimentally measurable.
[1] arXiv:1511.04201 [2] Phys. Rev. E 92, 012316 (2015).

*Speaker

RG scaling with marginal variables: Universal scaling functions and nonlinear invariant combinations extracted from normal form theory for bifurcations

James P Sethna * [1], Archishman Raju, Lorien Hayden, Danilo Liarte

[1] Cornell University – United States

The renormalization group predicts that observables like magnetization and susceptibility are universal scaling functions of invariant combinations of variables. Traditional invariant combinations fail to capture the behavior at the upper and lower critical dimension where the RG flows pass through a bifurcation. While the presence of logarithms is well known, a systematic analysis of the scaling form is needed to develop universal scaling functions and test scaling collapses. We analyze the RG flows of a system using normal form theory. We derive nonlinear invariant combinations which allow good scaling collapses, using the Ising model and the random field Ising model as examples. We also point out consequences for finite size scaling analyses.

*Speaker

Spectral Statistics of Disordered System with Goldstone symmetry

Pragya Shukla * [1]

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The Goldstone symmetry represents the invariance of a linear operator, say Hamiltonian, under a uniform shift in a local configuration variable and its breaking is associated with appearance of low-energy excitations in a system. The symmetry manifests itself through specific constraints on the column/row sum of the matrix elements of its Hermitian operators which are also randomized if disorder exists. Systems with such constraints exist in diverse areas e.g bosonic Hamiltonians such as phonons, and spin-waves in Heisenberg and XY ferromagnets, antiferromagnets, and spin-glasses, Euclidean random matrices, random reactance networks, financial systems and Internet related Google matrix etc. This motivates us to analyze the statistical properties of random matrices with column row constraints . The presence of additional constraints besides real-symmetric nature leads to new correlations among their eigenfunctions, hinders a complete delocalization of dynamics and affects the eigenvalues too. The statistical analysis of the latter indicates the presence of a new universality class analogous to that of a special type of Brownian ensemble appearing between Poisson and Gaussian orthogonal ensemble. Ref: [1] Random matrix ensembles with column/ row constraints: IP. Shukla and S. Sadhukhan, J. Phys A, 48, 415002, (2015). [2] Random matrix ensembles with column/ row constraints: II S. Sadhukhan and P. Shukla, J. Phys A, 48, 415003, (2015).

*Speaker

Mechanical Yield in Amorphous Solids: A First-Order Phase Transition

Murari Singh * [1], Prabhat K. Jaiswal, Itamar Procaccia, Corrado Rainone

[1] Weizmann Institute of Science – Israel

Amorphous solids yield at a critical value of the strain (in strain-controlled experiments); for larger strains, the average stress can no longer increase - the system displays an elastoplastic steady state. A long-standing riddle in the materials community is what the difference is between the microscopic states of the material before and after yield. Explanations in the literature are material specific, but the universality of the phenomenon begs a universal answer. We argue here that there is no fundamental difference in the states of matter before and after yield, but the yield is a bona fide first-order phase transition between a highly restricted set of possible configurations residing in a small region of phase space to a vastly rich set of configurations which include many marginally stable ones. To show this, we employ an order parameter of universal applicability, independent of the microscopic interactions, that is successful in quantifying the transition in an unambiguous manner.

*Speaker

Fundamental differences between glassy dynamics in two and three dimensions

Grzegorz Szamel * [1], Elijah Flenner

[1] Colorado State University – United States

The two-dimensional freezing transition is very different from its three-dimensional counterpart. In contrast, the glass transition is usually assumed to have similar characteristics in two and three dimensions. Using computer simulations, we show that glassy dynamics in supercooled two- and three-dimensional fluids are fundamentally different. Specifically, transient localization of particles upon approaching the glass transition is absent in two dimensions, whereas it is very pronounced in three dimensions. Moreover, the temperature dependence of the relaxation time of orientational correlations is decoupled from that of the translational relaxation time in two dimensions but not in three dimensions. Lastly, the relationships between the characteristic size of dynamically heterogeneous regions and the relaxation time are very different in two and three dimensions. These results strongly suggest that the glass transition in two dimensions is different than in three dimensions.

*Speaker

Marginality and criticality in low-temperature glasses

Francesco Zamponi * [1]

[1]ENS Paris – France

While amorphous solids constitute most of the solid matter found in Nature, their understanding is much poorer than for crystalline solids, at the point that most solid state textbooks are entirely focused on crystals. The reason underlying this uncomfortable situation is that amorphous solids display all kind of anomalies with respect to a simple description in terms of phonon excitations around a perfect lattice. In particular, they show an excess of low-frequency vibrational modes, their thermodynamic and transport coefficients behave differently from crystals, they respond non-linearly to arbitrarily small strains, and have highly cooperative dynamics. I will discuss a new approach to the problem, based on the exact solution in the limit on large spatial dimensions. The solution predicts the existence of a new phase transition, the Gardner transition, separating a high-temperature "normal" solid phase from a low-temperature "marginally stable" solid phase. The marginally stable phase offers, potentially, a unified explanation of the anomalies of amorphous solids. As a side product, we obtain exact results for the critical exponents associated to the jamming transition of granular materials.

*Speaker

Statistical Physics of Fracture and Plasticity

Stefano Zapperi * [1]

[1] University of Milan – Italy

Understanding how materials respond to external mechanical perturbation is a central problem of science and engineering. While for most practical purposes it is useful to idealize the mechanical response of a material as a deterministic function of the externally applied perturbation, disorder and fluctuations are unavoidable, leading to sample-to-sample variations and non-trivial size effects. The size dependence of strength is a well known but still unresolved issue in the fracture of materials and structures. The difficulty in addressing this problem stems from the complex interplay between microstructual heterogeneity and long-range elastic interactions. Furthermore, in micro and nanoscale samples, the plastic yield strength displays size effects and strain bursts, features that are not present in macroscopic samples where plasticity is a smooth process. Large fluctuations both in fracture processes and in microscale plasticity make the use of conventional continuum mechanics problematic and calls instead for a statistically based approach. In this talk, I will review recent results obtained from idelized models of disordered fracture and from more realistic simulations of defected graphene. Finally, I will discuss the size dependence of strain burst statistics as revealed by atomistic and mesoscale models for crystal and amorphous plasticity.

*Speaker

Topic 5: Biological Physics-Oral

Intracellular transport of cargos by multiple teams of motors

Cecile Appert-Rolland * [1], Sarah Klein, Ludger Santen

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It is an open question why inside cells, cargos (vesicles, organelles..) are often transported by teams of motors pulling in opposite directions - a solution which may appear quite inefficient a priori. In order to characterize the stochastic dynamics of such a system, and propose some hypotheses why it can nevertheless be a relevant choice for intracellular transport, we have modeled the cargo-motors complex by taking explicitly into account the dynamics and position of each motor along the microtubule [1,2]. We first show that the resulting complex exhibits anomalous diffusion (subdiffusive at short times, superdiffusive at intermediate time scales), in good agreement with several experimental observations [3]. We illustrate how this property can be helpful when traveling in a crowded environment. We are also able to reproduce some observed relaxation events in the cargo position that would be related to the release of some elastic energy. Thanks to the asymmetry of motor team properties, it turns out also that the dynamics of such a cargo-motors complex is easily controllable. Indeed, we show that it is possible to monitor and even reverse the drift of the cargo motors complex by tuning a single external parameter, such as the ATP concentration, or the viscous force exerted on the cargo [1]. In particular we find the counterintuitive result that decreasing ATP concentration or increasing viscosity can speed up the complex. In a cell, obstacles could play a role similar to such an effective viscosity. All these predictions could be tested in *in vitro* experiments. [1] Klein, Appert-Rolland, Santen, EPL 107 (2014) 18004 [2] Klein, Appert-Rolland, Santen, EPL 111 (2015) 68005 [3] Klein, Appert-Rolland, Santen, Eur. Phys. J. Special Topics 223 (2014) 3215

*Speaker

Weak synchronization and large-scale collective oscillations in dense bacterial suspensions

Hugues Chaté * [1], Chong Chen Song Liu Xiaqing Shi Yilin Wu

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Collective oscillatory behavior is ubiquitous in nature and it plays a vital role in many biological processes, including embryogenesis, organ development, and pace-making in neuron networks or in cardiac tissues. Elucidating the mechanisms that give rise to collective oscillations is essential to the understanding of biological self-organization. In this talk, I report the discovery of striking very large-scale collective oscillations in a quasi-two-dimensional dense suspension of swimming E coli bacteria. This system was studied before but the phenomenon we observed was overlooked due to its elusive nature: individual trajectories and movies do not show the weak synchronization of cell trajectories. But passive particles floating on the surface or mesoscale averaging of the cell's velocities reveal regular oscillatory behavior organized over centimeter scales. I will then present a self-propelled particle model which demonstrates that this spectacular phenomenon can arise without long-range interactions. These findings expand our knowledge of biological self-organization as well as reveal a new type of long-range order in active matter systems.

*Speaker

Trade-off conditions for evolutionary punctuated equilibrium: a thermodynamic-like characterization

M. G. E. Da Luz * [1], M. E. Wosniack, L. S. Schulman

[1] UFPR – Brazil

The interactions between species, the resources available from the environment, and occasional genetic mutations control the microevolution dynamics at short and intermediate times (order of generations). On the other hand, for an ecosystem as a whole, macroevolution determines (at much longer times) the distribution of species regarding their formation, extinction, and diversification. Empirically, data sources for macroevolution are basically provided by fossil records, fundamental to link modern taxa behavior to ancient evolutionary mechanisms. Nonetheless, the connection between macroevolution and microevolution is far from being totally understood. For instance, fossil records do not support a smooth and gradual transition of the species along time, something which should be expected from the natural selection rules at individuals scales. In fact, the creation and annihilation of species is not a steady (or even stable) process. Data seem to indicate that long term evolution is characterized by bursts of high evolutionary activity followed by metastable configurations. Such intermittency is known as *punctuated equilibrium*, with the punctuation corresponding to high activity phases followed by periods of stasis. The mechanisms for punctuated equilibria are topics of intense debate. But it is generally accepted that the interaction network is a fundamental factor, accounting for the correlations driven the coevolution of species (e.g., on smaller time scales it is related to the stability of communities). Unfortunately, the actual portrayal of these networks is quite demanding due to the high number of elements and the difficulty to quantify their interaction strengths. Also, surveillance of extensive food webs data have revealed small world properties, like high clustering and also a power-law scaling. It makes the general characterization of all the connections along the network very laborious. In this work we discuss essential ingredients for the intrinsic emergence of punctuated equilibrium, examining conditions influencing rapid recover once in a state of low diversity. With this aim, we consider the quite plastic Tangled Nature (TN) model in evolutionary ecology. The general and simple way it handles networks – naturally allowing the links to change during the ecosystem evolution – is one of the model highlights and very relevant for our purposes. We study the behavior of emergent patterns assuming different web interaction features and look for configurations yielding punctuated equilibrium. Since it is known that a key component to maintain quasi-static periods is mutualistic cooperation, we calculate the number of possible combinations of mutualistic pairs in the TN interaction matrix and show that the system performs an exhaustive search for 'harmonious' pairs during a hectic period. The searching may not succeed if the interaction network is weak and no quasi-static phases of large diversity can emerge. On the opposite, too strongly correlated networks result just in quasi-static phases of very short periods. As a consequence, long term stable ecosystems can be maintained only as a balanced compromise between the strength of interspecies correlations. These findings agree with both, empirical results pointing to a necessity of diversity for the distribution of interactions for community stability, and analysis demonstrating the key role played by the network architecture. Finally, to vet if indeed punctuated equilibrium can be typified as a collective process, we explore the parallels between micro/macro evolution and mechanics statistics/thermodynamics. But for so we must recall that evolution is not an equilibrium phenomenon, being close related to the concept of complex systems. Hence, we shall borrow ideas and methods from thermodynamics, still not using its standard formulation. So, we first consider properly adapted definitions (so not usual thermodynamics) of 'macroscopic' energy-like, entropy-like and temperature-like quantities, which are non-extensive and non-intensive. We examine their behavior and verify that they are able to identify the hectic phases, qualitatively differentiating the bursts from the metastable periods. We argue this is an evidence of punctuated equilibrium as a composite dynamics, hence typical of complex systems.

*Speaker

Mechanics and constrained Growth of dense branched actin networks followed by a new magnetic colloids technique.

Olivia Du Roure * [1], Pierre Bauër, Joseph Tavacoli, Jessica Planade, Alphée Michelot, Audrey Guillotin, Julien Heuvingh

[1] PMMH, CNRS/ESPCI – France

Cell mechanics is fundamental in many cellular processes both in physiological and pathological situations. The actin cytoskeleton is responsible for the main part of this mechanics. In cells, actin filaments are very dynamic polymers spatially organized by many different partners. Rheological studies have been devoted to the understandings of the mechanical properties of actin gels assembled in solutions. We recently developed a new approach to study more biologically relevant system; this approach is based on magnetic particles and the use of the biochemical machinery at play in the leading edge of a cell. The idea is to use dipolar attractive forces that develops between superparamagnetic micro-sized objects to deform in a controlled way dense branched actin networks grown from the surface of the particles. The main advantage of this technique in the context of biophysics is its high throughput that allows reliable measurements to be performed. We carried out a first study which established the link between elastic properties of these networks and their architecture in dense branched actin networks assembled from a mix of purified proteins. We are now studying more biological context by the use of yeast extracts from wild type or mutants. In a new version of the technique, we also developed new particles with flat surfaces that allow non linear measurements to be done and growth under constraints to be followed. These new developments open the ways to study cell mechanics at the scale of isolated cells and even at the scale of a tissue.

*Speaker

From chromosome crumpling to the interacting randomly branched polymers

Ralf Everaers * [1], Angelo Rosa

[1] Laboratoire de Physique, ENS de Lyon – France

The conformational statistics of ring polymers in melts or dense solutions is strongly affected by their quenched microscopic topological state. The effect is particularly strong for non-concatenated unknotted rings, which are known to crumple and segregate and which have been implicated as models for the generic behavior of interphase chromosomes. In [1] we have used a computationally efficient multi-scale approach to identify the subtle physics underlying their behavior, where we combine massive Molecular Dynamics simulations on the fiber level with Monte Carlo simulations of a wide range of lattice models for the large scale structure. This allowed us to show that ring melts can be *quantitatively* mapped to coarse-grained melts of *interacting* randomly branched primitive paths. To elucidate the behavior of interacting branched polymers, we use a combination of scaling arguments and computer simulations[2]. The simulations are carried out for different statistical ensembles: ideal randomly branching polymers, melts of interacting randomly branching polymers, and self-avoiding trees with annealed and quenched connectivities. In all cases, we perform a detailed analysis of the tree connectivities and conformations. We find that the scaling behaviour of average properties is very well described by the Flory theory of Gutin et al. [Macromolecules 26, 1293 (1993)]. A detailed study of the corresponding distribution functions allows us to propose a coherent framework of the behavior of interacting trees, including generalised Fisher-Pincus relationships and the detailed analysis of contacts statistics. [1] Ring Polymers in the Melt State: The Physics of Crumpling, Angelo Rosa and Ralf Everaers, Phys. Rev. Lett. 112, 118302 (2014) [2] Conformations of randomly branching polymers with volume interactions, Angelo Rosa, A.Y. Grosberg, M. Rubinstein and Ralf Everaers, in preparation.

*Speaker

Injection, dissipation, efficiency of motor activity in a living cell

Étienne Fodor * [1], Wylie W. Ahmed, Maria Almonacid, Matthias Bussonnier, Nir S. Gov, Marie-Hélène Verlhac, Timo Betz, Paolo Visco, Frédéric van Wijland

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Following a tracer embedded in a living oocyte can be revealing both biology and physics-wise. For the nonequilibrium physicist, the challenge is to identify the injection and dissipation channels that lead to anomalous fluctuations that are a trademark of living matter, as observed in a variety of systems raging from cells to reconstituted actin gels. We combine an active Brownian motion model with the techniques of stochastic thermodynamics to access and quantify the energy fluxes induced by the motors' activity, along with their efficiency in powering the tracer's motion.

*Speaker

Stochastic approaches for receptor clustering and receptor time correlation functions

Bertrand Fourcade * [1], Olivier Destaing, Corinne Albigès-Rizzo, Antoine Delon

[1] University Grenoble-Alpes – France

In recent years, several stochastic reaction-diffusion algorithms have been introduced for modeling in cellular biology. The optimal choice of a stochastic reaction diffusion algorithm depends on the particular biological which is modeled. In this contribution, we concentrate on receptor dynamics for cell-substrate adhesion. Using a compartment-based method, we investigate how receptor can dynamically cluster upon activation via intracellular signals. Generalizing standard algorithms for modeling molecular diffusion with chemical reactions, we first show that receptor can form stable or metastable clusters when their activation/deactivation cycle is coupled to composition changes in the membrane. As a second point, we show that this method can be used in parallel with recent fluorescence correlation spectroscopy experiments probing the local fluctuations of a small number of particles. In this context, time correlation functions for different reaction-diffusion of models will be given.

*Speaker

Collective swings in biological groups

Irene Giardina * [1]

[1] Sapienza University of Rome – Italy

Many biological systems display ordered patterns on the large scale. Flocks of birds are a paradigmatic example of such behavior, where thousands of individuals move in unison and perform extraordinary maneuvers while retaining full coherence. These biological groups exhibit some distinctive features: they are extremely polarized but frequently switch direction, either spontaneously or in response to external disturbances. The occurrence of spontaneous collective turns indicate that flocks combine strong order with a large sensitivity to noise. In this talk, I will discuss some possible mechanisms underlying this behavior. I will show that there are two crucial ingredients that enhance the effect of noise in ordered networks, leading to collective changes of state: the non-symmetric nature of interactions between individuals, and the presence of local heterogeneities in the topology of the interaction network. The consequences of these features can be larger the larger the system size leading to a localization of the fluctuation modes and a relaxation time that remains finite in the thermodynamic limit.
The system keeps changing its global state in time, being constantly driven out of equilibrium by spontaneous fluctuations. Our results explain what is observed in several living and social systems and are consistent with recent experimental data on bird flocks and other animal groups.

*Speaker

Upside Down and Inside Out: The Biomechanics of Cell Sheet Folding

Raymond E. Goldstein * [1]

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Deformations of cell sheets are ubiquitous in early animal development, often arising from a complex and poorly understood interplay of cell shape changes, division, and migration. In this talk I will describe an approach to understanding such problems based on perhaps the simplest example of cell sheet folding: the "inversion" process of the algal genus Volvox, during which spherical embryos literally turn themselves inside out through a process hypothesized to arise from cell shape changes alone. Through a combination of light sheet microscopy and elasticity theory a quantitative understanding of this process is now emerging.

*Speaker

Role of Motor-Motor Coupling in Multi-Motor Driven Cargos with Applications to Drug Delivery by Nano-Carriers

Rony Granek * [1], Itay Peker, Ohad Cohen

[1] Ben-Gurion University of the Negev – Israel

Motor proteins constitute an essential part of the cellular machinery. They have been the subject of intensive studies in the past two decades. Yet, when several motors simultaneously carry a single cargo, the effect of motor-motor coupling, such as mutual stalling and jamming, remains unclear. We commence by constructing a general model for single motor motion [1]. The model correctly predicts the motor step size distribution and its dependence on load, as recently measured in single molecule experiments. We then use our proposed model to predict transport properties of multi-motor complexes [1], with particular attention to linear cargos with variable flexibility, motor density and number of motors: (i) a chain of motors connected by springs, a recently studied construction of a pair, and (ii) an array of motors all connected by identical springs to a stiff rod, which is essentially a mirror image of standard gliding motility assays. In both systems, and for any number of carrying motors, we find that, while low flexibility results in a strongly damped velocity, increased flexibility render an almost single motor velocity. Comparing our model based simulations to recent gliding assays we find remarkable qualitative agreement. We also demonstrate consistency with other multi-motor motility assays. In all cases, the characteristic spring constant, that controls the crossover behavior between high and low velocity regimes, is found to be the stalling force divided by the mean step size. We conjecture that this characteristic spring constant can serve as a tool for engineering multi-motor complexes for drug delivery applications. In particular, we revisit our recently suggested construct for a spherical particle [2], in which the particle surface is grafted with polymer spacers, each ending with a dynein associating molecule, for example, nuclear localization signal peptide. We show that the spacer polymer molecular weight can be adjusted to significantly increase the mean carrier run length. This should lead to appreciable enhancement of active transport of the nano-carrier, and consequently drug delivery, to the nucleus. References: [1] I. Peker and R. Granek, "Multi-Motor Driven Cargos: From Single Motor under Load to the Role of Motor-Motor Coupling", submitted for publication (2016). [2] O. Cohen and R. Granek, "Nucleus Targeted Drug Delivery: Theoretical Optimization of Nano-Particles Decoration for Enhanced Intracellular Active Transport", Nano Letters 14, 2515 (2014).

*Speaker

Synaptic domains as diffusion-controlled structures.

V Hakim * [1], J. Ranft, LG Almeida, P. Rodriguez, A. Triller

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Synapses allow the transfer of information between two neurons and they are thought to be the physical locus of memory. Their formation and stability is a thus a key question in neuroscience. Post-synaptic domains have been classically conceived as formed by local insertion of proteins at the synapse. Advances in single-molecule imaging have challenged this view and have suggested that proteins are primarily inserted extrasynaptically. We review these results and report our quantitative investigation of this scenario which we have analyzed by building upon studies of diffusion-controlled growth in statistical mechanics. Protein multi-merization in the neuron membrane allied to protein recycling in the neuron cytoplasm give rise to a non-equilibrium steady state with a continuous distribution of protein-cluster sizes that we have analyzed with the help of rate equations and computer simulations. This has led us to predict the existence of extrasynaptic clusters with a characteristic size distribution which depends on the turnover rate of scaffold molecules in a domain and also depends on how the diffusive mobility of clusters varies with their sizes. We present new super-resolution microscopy data for the inhibitory synapse scaffold protein gephyrin which establish the existence of extrasynaptic gephyrin clusters. Quantitative analysis shows that the experimental data is consistent with predictions in a range of model parameters. Finally, we show that the proposed model has important consequences for size fluctuations of synaptic domains and discuss them in the light of recent experiments.

*Speaker

Active matter models for cell sheets

Silke Henkes * [1], Rastko Sknepnek, Daniel Matoz-Fernandez, Kirsten Martens, Eric Bertin, Daniel Barton

[1] University of Aberdeen – United Kingdom

Understanding the physical properties of epithelial cell sheets is one of the central questions in cell and developmental biology, and a number of recent in-vitro studies have probed their mechanical and dynamical properties in depth. Here we focus on two approaches: First, we perform a detailed study of individual active driving mechanisms including death and division, and separately polar motility, in a simplified system of soft active particles. We find that both fluidise the system. Dividing system achieve this through local strain events, and division patterns akin to fate mapping in biology, while purely non-aligning motile systems show long-range velocity correlations due to preferential coupling to low-energy modes. Our full description is based on a self-propelled Voronoi model, and includes all active drivers (division, ingression, motility, and cortical tensions). We implement free cell boundaries allowing us to model the edges of epithelial cell layers growing on a substrate. Our model reproduces experimental results including T1 transitions and overall cell sheet tension.

*Speaker

Statistical model of collective transport by ants: facing an obstacle

Jonathan Ron * [1], Itay Pinkoviezki, Nir Gov Aviram Gelblum, Ehud Fonio, Ofer Feinerman

[1] Weizmann institute of science – Israel

To cooperatively carry food, orders of magnitude larger than their own size and weight, single ants conform efforts and coordinate their motion to reach their collective goal. In this study we look at the dynamics of collective transport when the ants motion is frustrated by an obstacle. We compare analytical description of the ant-load system to computer based stochastic simulations. The results show how changes in internal interactions and information fluxes yield different bi-stable dynamical phases, and demonstrate how internal noise sources affect the dynamics. The results display agreement with recent experiments and observations.

*Speaker

Physical biology of chromatin dynamics: functional coupling between chromatin organization and epigenome

Daniel Jost * [1], Noelle Haddad, Cédric Vaillant, Surya Ghosh

[1] CNRS, TIMC-IMAG – France

Cellular differentiation occurs during the development of multicellular organisms and leads to the formation of many different tissues where gene expression is modulated without modification of the genetic information. These modulations are in part encoded by chromatin-associated proteins or biochemical tags that are set down at the chromatin level directly on DNA or on histone tails. These markers are directly or indirectly involved in the local organization and structure of the chromatin fiber, and therefore may modulate the accessibility of DNA to transcription factors or enzymatic complexes, playing a fundamental role in the transcriptional regulation of gene expression. Statistical analysis of the repartition of this epigenomic information along the chromosomes have shown that genomes of higher eukaryotes are linearly partitioned into domains of functionally distinct chromatin states. In particular, experimental evidence has shown that the pattern of chromatin markers along chromosomes is strongly correlated with the 3D chromatin organization inside the nucleus. This suggests a coupling between epigenomic information and large-scale chromatin structure that could be statistically quantified. Recently, using polymer physics and numerical simulations, we showed that attractive interactions between loci of the same chromatin state might be the driving forces of the folding of chromatin inside the nucleus. In this study, we assumed that the epigenomic information pre-exists to the 3D organization. However, increasing number of experimental results suggests that chromatin marks are themselves highly dynamic during cell cycle or developmental stages and that 3D organization of chromatin might play a key role in the stabilization and function of chromatin markers. We will describe our efforts to better understand the dynamical crosstalk between the epigenome and the 3D organization and we will illustrate the modularity of our framework in several biological contexts. In particular, we show that epigenomic-driven contacts and the formation of interacting compartments coupled to a reader-writer mechanism of epigenetic maintenance lead to a better and more robust control of epigenome, suggesting that 3D organization of chromosome plays a functional role at the epigenetic regulation level.

*Speaker

Physical mechanism of selective gating functions of nuclear pore complexes

Yong Woon Kim * [1], Seongjin Kim, Juyeon Yi

[1]Korea Advanced Institute of Science and Technology – South Korea

As a highly selective gateway, nuclear pore complex (NPC) regulates the molecular transports between the nucleus and cytoplasm in eukaryotic cells. Despite critical importance of nucleo-cytoplasmic trafficking in cell functioning, how a NPC carries out the selective gating remains largely unknown because of natively disordered nature of nucleoporins distributed along the central channel of a nuclear pore. Here we report that the biological gating function is accomplished by a physical phase transition between distinctively different conformations of disordered nucleoporins with phenylalanine-glycine residues, triggered by a binding of cargo-transport protein complexes. Using hyperparallel tempering Monte Carlo simulations and extensive Brownian dynamics simulations with salient features of amino acid sequences of nucleoporins implemented, we also show that the facilitated cargo transports are orchestrated by multiple physical interactions with charged or hydrophobic amino acids. This provides a prominent example where physical notions such as cooperativity and structural phase transition serve to understand selectivity and specificity in biological transports.

*Speaker

Fluctuation relations of fitness and information in population dynamics

Tetsuya J. Kobayashi * [1], Yuki Sughiyama

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A variety of cells and organisms can change their phenotypes and, in some cases, genotypes randomly and adaptively in order to survive in unpredictably changing environment. Even if such type-switching is completely stochastic, it could benefit the population of cells and organisms by increasing the average fitness (average long-term population growth) of the population. In addition, if cells and organisms can actively sense the environment and choose adaptive types based on the sensed information, the cells and organisms could have additional gain of fitness. Because the fitness is the fundamental quantity that characterizes the evolutionary properties of the population, understanding the relations between the fitness of a population and the information obtained by sensing is as important as understanding the relation between entropy and information in information thermodynamics. In this work, we derive such relations between fitness and information by employing a path-integral formulation of population dynamics. By describing the dynamics in a path-wise manner, we can easily see that the problem of fitness and information shares quite similar mathematical structure as that of entropy and information in stochastic and information thermodynamics. By focusing on this similarity, we derive a series of fluctuation relations of fitness and information and related variational properties. The implications of the relations are discussed from the viewpoint of evolutionary and systems biology. The relations may serve as a link that connect thermodynamics and biology.

*Speaker

A minimal model for the generation of F-actin waves

Thomas Le Goff * [1], Benno Liebchen, Davide Marenduzzo

[1] University of Edinburgh – United Kingdom

F-Actin is a polymer existing in the cytoskeleton of cells and which is involved in cell motility, cell division or cell signaling. These polymers form a network which can exhibit very interesting dynamics. Particularly, actin waves usually following formation of spots were observed experimentally [1]. We propose a simple physical model based on a minimum number of ingredients to describe the appearance of these waves :(i) treadmilling - i.e. the simultaneous growth and shrinkage at the two ends of the actin fiber, (ii) polymerisation and (iii) a nematic interaction term causing fiber alignment for large concentration of F-actin. With this simple model we obtain very rich dynamics, in particular we can observe formation of spots and waves resembling the dynamics seen experimentally. Our model also allows us to make definite predictions on the mechanism underlying wave formation in vivo. [1]T. Bretschneider, K. Anderson, M. Ecke, A. Müller-Taubenberger, B. Schroth-Diez, H. C. Ishikawa-Ankerhold, G. Gerisch, Biophys. J. **96**, 2888 (2009).

*Speaker

Disordered actomyosin contracts in unexpected ways

Martin Lenz * [1]

[1] LPTMS - CNRS and U. Paris-Sud – France

The motion of living cells is in large part due to the interaction of semi-flexible actin filaments (F-actin) and myosin molecular motors, which induce the relative sliding of F-actin. It is often assumed that this simple sliding is sufficient to account for all actomyosin-based motion. While this is correct in our highly organized striated muscle, we question the application of this dogma to less ordered actomyosin systems, thus reexamining a cornerstone of our understanding of cellular motion.

*Speaker

Cross scale dynamics and the evolutionary emergence of infectious diseases

Claude Loverdo * [1], Sebastian J. Schreiber, Ruian Ke, Miran Park, Prianna Ahsan and James O. Lloyd-Smith

[1] LPTMC / CNRS – France

Recent data have highlighted the potential for evolutionary emergence of novel pathogens. Emerging pathogens encounter new environments, such as new host species, and if they are poorly adapted then they must evolve to escape extinction. A rich body of theory addresses this 'evolutionary escape' problem, but it has not kept pace with empirical findings about pathogen evolutionary dynamics. Pathogens experience selection on traits at multiple scales, including replication rates within host individuals and transmissibility between individuals; these scales are coupled by strong transmission bottlenecks. We present the first fully multi-scale analysis of evolutionary emergence, with a stochastic model linking pathogen growth and competition within individuals to transmission between individuals. We identify a new factor governing pathogen emergence: the mutant replacement number, which determines the rate at which the mutant strain increases in frequency in the infected population. This quantity combines with viral mutation rates, reproductive numbers, and transmission bottleneck width to determine how emergence risk is influenced by pathogen life history and selective forces at multiple scales, including possible cross-scale conflicts. We delineate conditions controlling whether emergence occurs, and whether evolution occurs swiftly or gradually within chains of transmission. Wider transmission bottlenecks always help the emergence of pathogens with short-term infections, but can help or hinder emergence of pathogens with longer infectious periods. We analyze the impact of mutant strains present in the initial inoculum, and propose guidelines for genetic surveillance of zoonotic reservoirs. This work lays the foundation for a new generation of evidence-based risk assessment of emergence threats.

*Speaker

Glassy and heterogeneous dynamics in biological tissues

M. Lisa Manning * [1]

[1] Syracuse University – United States

Biological tissues involved in important processes such as embryonic development, lung function, wound healing, and cancer progression have recently been shown to be close to a liquid-to-solid transition. In many non-biological materials, a disordered liquid-to-solid transition occurs when the temperature decreases or the packing density of objects increases past a critical threshold. Over the past 20 years physicists have made great progress in understanding the universal nature of these glass and jamming transitions. However, existing theories cannot explain observations of jamming transitions in confluent biological tissues, where there are no gaps between cells and the packing density is always unity. I will discuss a new theoretical framework for predicting rates of cell migration in biological tissues, and show that this model predicts a novel type of critical rigidity transition, which takes place at constant packing density and depends only on single cell properties such as the number of adhesion molecules expressed. Next, we take into account the fact that cells are motile and tend to move persistently, and develop a phase diagram that includes cell speed and persistence. We show that the rigidity transition controls a surface of glass transitions in this higher dimensional phase space. Finally, I will show that our a priori theoretical predictions with no fit parameters are precisely realized in cell cultures from human patients with asthma, and discuss how these ideas might also be applied to heterogeneous cell populations to understand processes in embryonic development and cancer progression.

*Speaker

Modeling swimmers with the key physics and statistical ingredients for controlling micro-confined transport

Verónica I. Marconi * [1]

[1] Universidad Nacional de Córdoba and IFEG-CONICET – Argentina

In this talk i will summarize our numerical and experimental interdisciplinary contributions to the field of self propelled cells under micro-confinement and its applications: E.Coli [1,2] and soil bacteria [3], human spermatozoa [4,5] and choanoflagellates [6]. I will show you how crucial is to succeed first in getting a good physical model of the micro-swimmers dynamics and statistics in order to be able to contribute to the design and optimization of real applications. We aimed to fabricate micro-devices for studying, directing, guiding, trapping, controlling and sorting cells in biomedicine, ecology, agronomy and evolutionary biology. These aims were possible to be achieved thanks to a reach feedback among physicists, molecular biologists, biotechnologists and bioengineers. I hope to convince you how important is the contribution of physicists to this field, showing the physics vs biology difficulties of the problems, the open questions and present challenges. [1] I. Berdakin *et. al.*, PRE (2013); [2] I. Berdakin *et. al.* CEJP (2013); [3] J. E. Quelas *et al*, Sci. Rep. (2016), [4] H. A. Guidobaldi *et. al.*, PRE (2014); [5] H. A. Guidobaldi *et. al.* Biomicrofluidics (2015); [6] J. Sparacino *et. al.* and G. Miño *et. al.*, preprints 2016.

*Speaker

Stochastic wound closure dynamics

Philippe Marcq * [1], Vincent Nier, Maxime Deforet, Guillaume Duclos, Hannah Yevick, Olivier Cochet-Escartin, Pascal Silberzan

[1] Physico-Chimie Curie – France

Epithelization, the process whereby an epithelium actively covers a cell-free surface, is central to wound healing but also pivotal in embryonic morphogenesis, regeneration, and cancer. We study experimentally and theoretically the closure of a large number of well-controlled circular apertures within an epithelial monolayer over a non-adhesive substrate. We formulate a simple stochastic model that includes purse-string contractility, tissue fluctuations, and effective friction to qualitatively and quantitatively account for the dynamics of closure. We show that monolayers can cover well-controlled mesoscopic nonadherent areas much larger than a cell size by purse-string closure and that active epithelial fluctuations are required for this process.

*Speaker

Wild swarms of midges linger at the edge of an ordering transition

Stefania Melillo * [1], A.Attanasi, A.Cavagna, L. Del Castello, I. Giardina, S.Melillo, O.Phol, L.Parisi, B.Rossaro, E.Shen, E. Silvestri, M.Viale

[1] CNR - Institute for Complex Systems - UOS Sapienza University of Rome - Department of Physics – Italy

Insect swarms are the paradigmatic examples of disordered and cohesive biological systems. Swarms are generally made of individuals moving in an erratic way, apparently without interacting with each other, but only with a common landmark. We experimentally studied swarms of midges in their natural environment, collecting data in the field and reconstructing 3D-trajectories of each individual in the swarm. Our analysis reveals that, despite the lack of order, swarms exhibit strong correlations of the velocity fluctuations. Such correlations are not compatible with models of non interacting particles and indicate that individuals are able to influence each other's behavioral changes on a group scale. More surprisingly, we found that swarms tune their control parameter, namely the density, in order to maximize their correlation. Swarms are quite far from the far from thermodynamic limit, so that the value of the control parameter at which correlation and susceptibility peak depends on size. As a consequence, correlation length and susceptibility scale with the system's size and swarms exhibit a near-maximal degree of correlation at all sizes.

*Speaker

Nuclear Architecture and Active Matter

Gautam I Menon * [1], Ankit Agrawal, Nirmalendu Ganai, Surajit Sengupta

[1] The Institute of Mathematical Sciences – India

Our genetic information resides in several long molecules of DNA, packaged into individual chromosomes within the nuclei of each of our cells. Chromosomes in human cells are now known to be organised territorially between cell divisions. Such chromosome territories are positioned probabilistically, although non-randomly, with the nucleus. I will present physical arguments, a biophysical model and computer simulations for these and related features of nuclear architecture, showing how they can be understood as a generic consequence of inhomogeneous non-equilibrium active processes acting on chromosomes. The simulations accurately describe a number of central features of nuclear architecture, including distribution functions of gene density and centre of mass for individual chromosomes, the shapes and other geometrical attributes of chromosome territories and the spatial organization of gene-rich and gene-poor chromatin. The approach described here underlines the importance of non-equilibrium processes for the large-scale architecture of the cell nucleus, while providing a precise quantitative framework to model and understand their consequences.

*Speaker

Birdsong in motor coordinates

Gabriel Mindlin * [1]

[1] Universidad de Buenos Aires – Argentina

Fundamental unresolved problems of motor coding and sensorimotor integration include what information about behavior is represented at different levels of the motor pathway. Insight into this issue is essential for understanding complex learned behaviors such as speech or birdsong. A major challenge in motor coding has been to identify an appropriate framework for characterizing behavior. In this talk we discuss a novel approach linking biomechanics and neurophysiology to explore motor control of songbirds. We developed a model of song based on gestures that can be related to physiological parameters the birds can control. This physical model for the vocal structures allowed a reduction in the dimensionality of the singing behavior. This is a powerful approach for studying sensorimotor integration and represents a significant methodological advantage. Our results also show how dynamical systems models can provide insight into neurophysiological analysis of vocal motor control. It also illustrates the turbulent relationship between physics and biology...

*Speaker

Transport through the nuclear pore complex: crowding and plasticity

Fabien Montel * [1], Thomas Auger, Cyndélia Guillaume, Orestis Faklaris, May Penrad-Mobayed, Jean-Marc Di Meglio,Loïc Auvray

[1] Laboratoire de Physique - Ens de Lyon – France

The nuclear pore complex is the unique gateway between the nucleus and the cytoplasm of the cells. It ensures both directional and selective transport of nucleic acids and proteins. Its detailed mechanism is still highly debated and in particular its ability to react to very different environments. Using two different single molecule techniques we studied the influence of external control parameters (molecular crowding and development stage) on its structure and dynamics. We used a near field optics technique (Zero-Mode Waveguide for nanopores, [1]) to quantify the effect of the molecular crowding of the pore on the transport through native and mimetic pores. De Gennes- Brochard model for polymer injection is extended and the critical pressure for cargo translocation is measured to extract the free energy of translocation in different conditions. Our results obtained using optical super-resolution (dSTORM) indicates that development impacts the internal diameter of the nuclear pore complex. This effect can be recapitulated by a change in transcriptional activity. We also observe and quantify a 2D phase transition from a dense and amorphous structure to the large scale crystallization of the pores on a square lattice during development. [1] Zero-mode waveguide detection of flow-driven DNA translocation through nanopores. Auger T, Mathé J, Viasnoff V, Charron G, Di Meglio JM, Auvray L, Montel F. Phys Rev Lett. 2014 Jul 11;113(2):028302.

*Speaker

The effect of self-propelled micro-swimmers on macro-scale characteristics of flow

Hossein Nili * [1], Ali Fahimniya, Ali Naji

[1] Institute for Research in Fundamental Sciences (IPM) – Iran

A quantitative phenomenological study is made on the effect of the presence of micro-swimmers at a dilute volume fraction on an otherwise standard flow through a micro-channel. The study is based on a continuum model of active swimming within a flow, which extends the standard Navier-Stokes equations to account for a new source term, namely an active stress tensor. The continuum model serves to provide prediction power as to what to expect from active flow within micro-channels that could be microfluidic or physiological pathways. The established behaviour of swimmer migration towards channel walls is quantified in this work, and the effects of background flow and active parameters on it analysed; a new parameter is defined to quantitatively specify the details of swimmer migration towards walls. The focus of attention in this work is on puller swimmers, i.e. those driven from the front such as Chlamydomonas that, unlike pushers, give rise to a stable flow regime. In this regime, macro-scale characteristics of flow such as flow patter (qualitative) and drag (quantitative; comprising of conventional drag and active drag) are conveniently compared between a standard pressure-driven flow and the same flow with micro-swimmers present. The comparison shows the pronounced effect of the self-propulsion of swimmers, albeit at a dilute rate, on flow characteristics.

*Speaker

Effective diffusion and gradients of transcription factors. The case of Bicoid.

Silvina Ponce Dawson * [1], Emiliano Perez Ipina

[1] Universidad de Buenos Aires – Argentina

During early development, the establishment of gradients of transcription factors determines the patterning of cell fates. The case of Bicoid (Bcd) in *Drosophila melanogaster* embryos is well documented and studied, yet there are still controversies on which are the mechanisms that explain all the characteristics of its gradient. The *SDD* model, in which Bcd is *Synthesized* at one end and then *Diffuses* and is *Degraded*, has been introduced long ago. The *SDD* model, however, predicts that the gradient formation takes much longer than the time observed experimentally if estimates of the Bcd diffusion coefficient derived from optical experiments are used. A recent analysis of these optical experiments has shown that they estimate *effective* diffusion coefficients which rule the net transport that results from diffusion and reactions. This analysis prescribes the free diffusion coefficient of Bcd to be between one and two orders of magnitude faster than the ones estimated using Fluorescence Recovery After Photobleaching (FRAP). Bcd, being a transcription factor, does bind to regulatory sites on DNA. It has been documented that it also interacts with mRNA. In this talk I will present an *SDID* model which includes the *Interaction* of Bcd with binding sites. I will present an analysis of how the time and length scales of the gradient are associated to the biophysical parameters of the problem and in which way the latter should be related to the experimental observation of the Bcd distribution obtained in embryos that express Bcd-GFP. I will also show that the model prescribes the formation of the gradient within the time determined experimentally if the observations are interpreted within the context of the *SDID* model.

*Speaker

Dynamics in steady state in-vitro acto-myosin networks

Yael Roichman * [1], Adar Sonn-Segev, Anne Groswasser-Bernheim

[1] Tel Aviv University – Israel

Active gels inspired from the cell's skeleton are a paradigmatic model to understand the complex mechanisms governing key cellular operations/processes such as motion and mechanics. Well-studied examples of such materials are networks constructed by the structural protein actin and its associated molecular motors myosin II. We study the dynamical processes taking place in such active slightly crosslinked networks by tracking tracer particles embedded within them. We identify a range of protein concentrations in which these gels remain at steady state, which enables us to study the effect of myosin motor concentration and size on the structural and dynamical characteristics of the gel. We find a sharp transition to irreversibility of gel dynamics as the myosin concentration increases. We find that the mechanical properties and the reorganization dynamics of active cytoskeleton gels exhibit the same dependence on motor protein concentration regardless of the scale of their features. However, the statistics and type of motor induced active events depends significantly on their feature size.

*Speaker

Dynamically adaptive transport networks on a growing medium

Henrik Ronellenfitsch * [1], Eleni Katifori

[1] Physics and Astronomy, University of Pennsylvania – United States

Many transport networks in nature are able to dynamically adapt to changes in the load, strengthening highly used transport lines and removing unused ones. This type of dynamically adaptive network can be found for instance in the mammalian vasculature or in slime molds. Inspired by models of leaf vasculature development, we couple the dynamics of such networks to growth of an underlying tissue matrix and show that growth acts as an effective decaying source term in the dynamical adaptation equation. We demonstrate that the system exhibits a transition between less efficient network topologies that develop without growth, and efficient, hierarchically organized network topologies that develop with growth. These topologies can be seen as an effect of tissue growth driving the dynamics towards a particularly symmetric steady state in a self-organized fashion that can not be reached easily otherwise.

*Speaker

Chromosome organization and the Physics of crumpled polymers

Angelo Rosa * [1], Ralf Everaers, Ana-Maria Florescu, Manon Valet

[1] Scuola Internazionale Superiore di Studi Avanzati (SISSA) – Italy

Chromosome structure and dynamics make the objects of considerable experimental investigation. In the latest years, this approach has been paralleled by computer simulations of polymer models [1] which provide a remarkable accurate description of chromosome behavior under various conditions and over wide ranges of length- and time-scales. In this talk, I will discuss the analogy between chromosome conformations and the Physics of crumpled polymers in entangled solutions [2-4]. In particular, I will show how one can exploit this analogy (1) to explain the essential observed behavior of chromosomes in cell nuclei during interphase [2,5,6] and (2) to design a fast computational scheme for building model conformations of large chromosomes with different degrees of resolution [3,7]. References: [1] A. Rosa, C. Zimmer – International Review of Cell and Molecular Biology 307, 275 (2014). [2] A. Rosa, R. Everaers – Plos Computational Biology 4, e1000153 (2008). [3] A. Rosa, R. Everaers – Physical Review Letters 112, 118302 (2014). [4] A. Rosa et al. – In preparation (2016). [5] A. Rosa, N. B. Becker, R. Everaers – Biophysical Journal 98, 2410 (2010). [6] M. Valet, A. Rosa – Journal of Chemical Physics 141, 245101 (2014). [7] A.-M. Florescu, A. Rosa – Submitted (2016).

*Speaker

Microfluidic analysis of collective cell migration in Dictyostelium.

Satoshi Sawai * [1], Taihei Fujimori, Akihiko Nakajima

[1] Graduate School of Arts and Sciences, University of Tokyo – France

Sensing of chemoattractant gradient in crawling eukaryotic cells such as Dictyostelium and neutrophils is thought to be mediated by a reaction-diffusion type mechanism of local activation and global inhibition. We have recently demonstrated that such a mechanism explains not only the spatial sensing of Dictyiostelium chemotaxis but also its temporal sensing aspect [1]. Here, we address a related problem in collective migration were cells not only make use of diffusive signals but also local contact guidance. In the late stage of Dicytostelium aggregation, cells chain up in head-to-tail manner in the so-called ?contact following' motion that is so far poorly characterized. Here, we carried out single-cell based quantitative imaging analysis of shape and motion of mutually attached cells migrating under quasi-2D spatial constriction in a microfluidic chamber. We will discuss the results and suggest how local signals guided by both the chemoattractant and cell-cell contact promotes cell polarity. We will discuss the implications of the present findings to cell migration in other systems.

[1] A. Nakajima, S. Ishihara, D. Imoto and S. Sawai (2014) Rectified directional sensing in long-range cell migration. Nat. Commun. 5, 5367.

*Speaker

Mechanical Limits to Transcriptional Noise

Stuart A. Sevier * [1], David A. Kessler, Herbert Levine

[1] Rice University – United States

Over the last several decades it has been increasingly recognized that stochastic processes play a central role in transcription. Though many stochastic effects have been explained, the source of transcriptional bursting (one of the most well-known sources of stochasticity) has continued to evade understanding. Recent results have pointed to mechanical feedback as the source of transcriptional bursting but a reconciliation of this perspective with preexisting views of transcriptional regulation is lacking. In this letter we present a simple phenomenological model which is able to incorporate the traditional view of gene expression within a framework with mechanical limits to transcription. Our model explains the emergence of universal properties of gene expression, wherein the lower limit of intrinsic noise necessarily rises with mean expression level.

*Speaker

Growth and Division of Active Droplets: A Model for Protocells

Rabea Seyboldt * [1], David Zwicker, Christoph A. Weber, Anthony A. Hyman, Frank Jülicher

[1] Max Planck Institute for the Physics of Complex Systems – Germany

It has been proposed that during the early steps in the origin of life, small droplets could have formed by phase separation from a surrounding complex mixture. These droplets could have provided chemical reaction centers to generate and evolve organic molecules. However, whether these droplets could divide and propagate is unclear. Here we study the dynamics of such droplets by combining the physics of phase separation with chemical reactions that are maintained away from thermodynamic equilibrium by an external supply of energy. Outside the droplets, these reactions turn precursors into droplet material, which then gets incorporated into droplets, where it is eventually converted into a waste product that leaves the droplet. Surprisingly, our theoretical study shows that the resulting chemically driven fluxes can lead to shape instabilities that trigger division of droplets into two smaller daughters, which can then grow again. Therefore, chemically active droplets can exhibit cycles of growth and division that resemble the proliferation of living cells. Dividing active droplets could serve as a model for prebiotic protocells, where chemical reactions in the droplet play the role of a prebiotic metabolism.

*Speaker

RNA polymerase II transcription through dinucleosome

Jaeoh Shin * [1], Veronika Fitz, Stephan Grill, Vasily Zaburdaev

[1] Max Planck Institutes für Physik komplexer Systeme – Germany

RNA polymerase II (Pol II) is an enzyme that catalyses messenger RNA from DNA templates as the first step in gene expression. In eukaryotic cells, a large fraction of the DNA molecules is wrapped around nucleosomes which are connected by linker DNA. Here we study Pol II transcription along a DNA template with two nucleosomes by using the optical tweezer setup. Our goal is to understand the role of the neighbouring nucleosome on the Pol II transcription. We found that the Pol II transcription through the first nucleosome depends on the length of the linker DNA in a non-monotonous way. We suggest that this effect results from the relative angle between the nucleosomes. To better understand the experimental results, we develop a stochastic model accounting the nucleosomal barrier, backtracking, and the assisting force acting on Pol II. The model reproduces the dynamics of Pol II transcription in agreement with the experimental data without any fitting parameter. Our model shows that the relative strength of the nucleosomal barrier and the assisting force dramatically change the elongation dynamics. We also discuss how the second nucleosome affects the stability of the first nucleosome.

*Speaker

Fluctuation theorem for vibrant reaction networks in live cells

Jaeyoung Sung * [1], Yu Rim Lim, Ji-Hyun Kim, Seong Jun Park, Gil-Suk Yang, Sanggeun Song, Nam Ki Lee

[1] Chung-Ang University – South Korea

For quantitative understanding of probabilistic behaviors of living cells, it is essential to construct a correct mathematical description of intracellular networks interacting with complex cell environment, which has been a formidable task. Here, we present a novel model and stochastic kinetics for a vibrant intracellular network interacting with hidden cell environment, employing a complete description of cell state dynamics and its coupling to the system network. Our analysis reveals that various environmental effects on the product number fluctuation of vibrant reaction networks can be collectively characterized by Laplace transform of the time correlation function of the product creation rate fluctuation with the Laplace variable being the product decay rate. On the basis of the latter discovery, we propose an efficient method for quantitative analysis of the chemical fluctuation of intracellular networks coupled to hidden cell environment. By applying the present approach to the gene expression network, we obtain simple analytic results for the gene expression variability and the environment-induced correlations between the expression levels of mutually non-interacting genes. The theoretical results compose a unified framework for quantitative understanding of various gene expression statistics observed across a number of different systems with small number of adjustable parameters with clear physical meanings[1,2]. Ref. [1] Y. R. Lim et al., Phys. Rev. X 5, 031014 (2015) [2] S. Yang et al., Nat. Commun.5761 (2014)

*Speaker

Polymer physics approach to chromosome dynamics

Mikhail Tamm * [1]

[1] Physics Department, Moscow State University – Russia

In recent years there have been a significant progress in the study of spatial organization and in vivo dynamics of chromosome matter both in procaryotic and eucaryotic cells. Understanding the various experimental results obtained in this field is closely related, from theoretical physics point of view, with the study of the dense but unenentangled states of polymer chains, such as melts of nonconcatenated polymer rings, and the so-called fractal globule state of polymer chains, as well as the study of polymer chain dynamics surrounded by active and/or viscoelastic media. I present some novel results in the field, in particular I will discuss the generalization of classical Rouse model of polymer dynamics for fractal unentangled polymer conformations with spatial fractal exponent d_f different from 2 (in particular, $d_f = 3$ for the fractal globule). Also, I show how this model can be generalized for a polymer in a viscoelastic medium where probe particle undergoes a fractal Brownian motion with a given Hurst exponent H. A scaling theory for spatial-temporal correlation functions of such polymer conformations will be also presented, and the possible comparisons with available and future experimental data will be discussed.

*Speaker

Growth behavior of microbes on mixed carbon sources: Monod's problem revisited

Chao Tang * [1]

[1] Peking University – China

About 75 years ago, Jacques Monod discovered that bacteria display two types of growth behavior when fed with two sugars: in some cases the bacteria eat one sugar first and start to eat the second only after the first one is exhausted (diauxie); in other cases the bacteria consume the two sugars simultaneously (co-utilization). Monod's quest for the molecular mechanism of diauxie led to his discovery of the lac operon and eventually a Nobel Prize on gene regulation. These growth phenomena have since become one of the most studied subjects in biology. However, why bacteria would bother to have the two distinct eating strategies remained a mystery. In this talk, I will present a model to make sense of this.

*Speaker

Sequential pattern formation as a front instability problem

Lei-Han Tang * [1], Moritz Zehl, Min Tang

[1] Beijing Computational Science Research Center – China

Pattern formation is a fundamental process in embryogenesis and development. In his seminal paper half a century ago, Turing proposed a mechanism for spontaneous pattern formation in biological systems that involve the diffusion of two types of morphogens ("activator" and "inhibitor") whose interaction stimulates their own synthesis. Starting from random initial perturbations, the Turing model typically generates patterns via the development of finite-wavelength dynamical instabilities in confined geometries. Recently, a collaboration led by Terry Hwa at UCSD and Jiandong Huang at HKU conducted experiments of pattern formation in open geometry through control of the synthetic chemotactic circuit of bacteria[1]. A key feature of the system is a concentration-dependent diffusivity of the active species which can be tuned in the experiment through control of gene expression. Theoretical analysis of the traveling wave solution reveals key parameters that span the phase diagram of the system[2]. Very recently, we carried out linear stability analysis of the traveling wave which yields a localized mode. Depending on the sharpness of the motility variation in space, either a Hopf bifurcation or a first order transition to a pulsating front solution can be observed[3]. The autonomous diffusion control together with the open, expanding geometries offered by growing biological systems, give rise to novel strategies to generate well-defined patterns in space and time. [1] Chenli Liu et al., Science 334, 238 (2011). [2] Xiongfei Fu et al., Phys. Rev. Lett. 108, 198102 (2012). [3] Moritz Zehl, Min Tang and Lei-Han Tang, in preparation.

*Speaker

Defect-mediated morphologies in growing cell colonies

Julia M Yeomans * [1], Amin Doostmohammadi Sumesh P Thampi

[1] University of Oxford – United Kingdom

Morphological trends in growing colonies of living cells are at the core of physiological and evolutionary processes. Using active gel equations with a recently developed model of cell division, we show that shape changes during the growth can be regulated by the dynamics of topological defects in the orientation of cells. The friction between the dividing cells and underlying substrate drives anisotropic colony shapes toward more isotropic morphologies, by mediating the number density and velocity of topological defects. We show that the defects interact with the interface at a specific interaction range, set by the vorticity length scale of flows within the colony, and that the cells predominantly reorient parallel to the interface due to division-induced active stresses.

*Speaker

Receptor arrays optimized for sensing natural odors

David Zwicker * [1], Arvind Murugan, Michael P. Brenner

[1] Harvard University – United States

Natural odors typically consist of many molecules at different concentrations, which together determine the odor identity. This information is encoded in the collective response of olfactory receptors, which is then interpreted by the brain to reconstruct the odor. However, it is unclear how the composition of the odor and the concentrations of its constituents are encoded together. I will discuss a simple theoretical model of receptor arrays from which we derive design principles for optimally communicating the odor information. These principles can be summarized as two possibly conflicting goals: (i) each receptor should respond to half of all odor mixtures; (ii) activity patterns of different receptors should be uncorrelated. We show that there is a family of receptor arrays that meet these conditions and thus transfer the odor information near-optimally. Within this family, we can tune the receptor array for either measuring concentrations accurately or for discriminating mixtures well. Our model links microscopic measurements of the interaction of receptors and odorants to psycho-physical measurements. It can thus be used to study natural olfactory receptors and to improve artificial sensor arrays.

*Speaker

Topic 6: Soft Matter-Oral

A new scenario in phase transitions: Inverting the energy landscape

Ricard Alert * [1], Pietro Tierno, Jaume Casademunt

[1] University of Barcelona – Spain

Colloidal systems are excellent experimental models to study countless aspects of condensed matter physics. In particular, we study structural phase transitions in a magnetic colloidal crystal. In contrast to usual transitions, the energy landscape of the crystal completely inverts when a magnetic field is applied [1]. This opens a new scenario in phase transitions that entails a number of unprecedented features. Upon a quench to low magnetic fields, metastable domains are formed by spinodal decomposition and subsequently eliminated by front propagation. For the quench to high magnetic fields, we reveal the possibility that two coexisting equilibrium phases are connected by two physically different interfaces [2]. Finally, we show the landscape-inversion transition to be discontinuous yet feature critical properties.

[1] R. Alert, J. Casademunt, and P. Tierno. Landscape-Inversion Phase Transition in Dipolar Colloids: Tuning the Structure and Dynamics of 2D Crystals. Phys. Rev. Lett. 113, 198301 (2014)

[2] R. Alert, P. Tierno, and J. Casademunt. Formation of metastable phases by spinodal decomposition. Submitted to Nat. Phys.

*Speaker

Coupling of isotropic and directional interactions in self-assembling patchy particles

Debra J. Audus * [1], Francis W. Starr, Jack F. Douglas

[1]National Institute of Standards and Technology – United States

Patchy particles, composed of hard spheres decorated with a configuration of attractive patches, have been used as models of both globular proteins and synthesized particles having anisotropic interactions. We extend this canonical patchy particle model to include a short-ranged isotropic attraction and examine the effect of this additional interaction on the phase separation and self-assembly using Monte Carlo simulations and an analytic Wertheim based mean-field theory. We find that the introduction of an isotropic interaction decreases the region of self-assembly due to the increase in the region of phase separation, but that the nature of self-assembly is unmodified. Specifically, for particles with more than two patches, the resulting self-assembled structures are analogous to dynamic, branched polymers under good solvent conditions, while for the case of two patches, the analogous polymers are linear. The mass size distributions of the self-assembled structures are well described by Flory-Stockmayer theory, despite its mean-field nature, and these mass size distributions, when combined with the Wertheim based description of the association thermodynamics, allow for the prediction of a master curve for the average mass of the self-assembled structures; this result is dependent on the number of patches providing a framework for using experimental data to parameterize patchy particle models.

*Speaker

Orientational hopping of a magnetically confined colloidal Janus-rod

Andrew Kaan Balin * [1], Yongxiang Gao, Roel P.A. Dullens, Julia M. Yeomans, Dirk G.A.L. Aarts

[1] University of Oxford – United Kingdom

A 'hopping' transition is experimentally observed in the orientational state of a ferromagnetic micro-rod: In the presence of a static external magnetic field, a sedimented rod randomly flips between horizontal and vertical states relative to the surface it rests on. Normally, this kind of behaviour at equilibrium is indicative of a double-well potential energy landscape; however, the configuration of the field is such that the energy of the rod monotonically increases as a function of its inclination relative to the surface. We provide a theoretical analysis of this phenomenon and derive an exact probability distribution over inclination angles which matches the experimental data with no free parameters. The probability distribution exhibits a barrier between the metastable vertical state and the horizontal ground state. This barrier does not come from the monotonic potential energy; instead we show it is entropic in origin and entirely generic to orientationally confined systems. [Reference: Y. Gao*, A.K. Balin*, R.P.A. Dullens, J.M. Yeomans, D.G.A.L. Aarts, Physical Review Letters, 115, 248301 (2015) *Joint-first author]

*Speaker

Sodium Chloride, NaCl/ ϵ : New Force Field

Marcia C Barbosa * [1], J. R. Bordin, R. Fuentes-Azcatl

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A new computational model for sodium chloride, the NaCl/ϵ is proposed. The force field employed for the description of the NaCl is based on a set of radial particle-particle pair potentials involving Lennard-Jones (LJ) and Coulombic forces. The parametrization is obtained by fitting the density of the crystal and the density and the dielectric constant of the mixture of the salt with water at a diluted solution. Our model shows a better agreement with the experimental values than the other atomistic models for the density and for the surface tension of the pure system and for the density, the viscosity, the diffusion, and the dielectric constant for the mixture with water at various molal concentrations. The NaCl/ϵ together with the water TIP4P/ϵ model provide a good approximation for studying electrolyte solutions. The dielectric constant of the mixture is also tested in confinement in a nanotube, showing the presence of layering and of oscillations in value the dielectric constant at different distances from the confined surface. Reference: Raul Fuentes and Marcia C. Barbosa, J. Phys. Chem. B 120 2460 (2016)

*Speaker

Elastoplastic models of plasticity in disordered systems

Jean-Louis Barrat * [1]

[1] Université Grenoble Alpes – France

I will describe part of the ongoing effort to describe amorphous plasticity in terms of simple elastoplastic models. After introducing the physical rationals that motivate these models, I will discuss their mean field analysis, the possibility to observe strain localisation, and the statistical features of avalanches and fluctuations as a function of strain rate.

*Speaker

Metastability, a fresh look on an old problem: predetermined and temporally controlled supercooling in lipid-based particles

Roy Beck * [1], Guy Jacoby

[1] Tel Aviv University – Israel

Metastable-to-stable phase transition is an uncontrolled spontaneous process, highly sensitive to microscopic details. It is often assumed that this transition occurs by overcoming an activation barrier through a stochastic process. However, for the case of self-assembled lipid suspensions that exhibit such phase-transition, the driving mechanisms and dynamics are not well understood. Using cryogenic TEM and solution x-ray scattering we studied the phase transition dynamics of supercooled lipid-based particles and found a unique metastable phase transition from liquid-crystalline to stable crystalline state [1]. Unlike conventional supercooling phase transitions, upon cooling from 60^o C to 37^oC, recrystallization is delayed by tens of hours in a robust, predetermined and temporally controlled manner. Our results suggest that a non-stochastic physical mechanism is responsible for the delayed recrystallization, involving several rate-affecting processes. A qualitative model will be presented to describe the structural reorganization during the metastable phase transition. [1] G. Jacoby, K. Cohen, K. Barkan, Y. Talmon, D. Peer, R. Beck, Predetermined and controlled metastable phase transition in lipid-based particles. Scientific Reports 5, 9481 (2015)

*Speaker

Demixing transitions in Bicontinuous Cubic Phases close to the critical point

Jorge Benet * [1], Halim Kusumaatmaja Fabien Paillusson

[1] Durham University – United Kingdom

Self-assembled amphiphilic interfaces can adopt an astonishing range of complex shapes and morphologies, from single bilayer structures to stacks and convoluted periodic structures, and with length scales spanning from nanometers to microns. Their relevance in biological systems is exceptional, being the scaffold of many organelles including synaptic vesicles, endoplasmatic reticulum and Golgi apparatus. They also possess an incredibly wide range of exciting properties that can be exploited in biotechnology and biomedicine, as well as in detergency and foodstuff industries. In this work we employ computer simulations to probe composition fluctuations close to the critical point, which has received much attention in the literature due to the lipid raft hypothesis. It has been proposed that biological membranes work at a temperature very close to a demixing critical point, [1] where the small free energy differences between clustered and unclustered states might ease the control of patterning in living cell membranes. Interestingly, careful experimental studies on giant unilamellar vesicles strongly suggest that the nature of the critical point closely follow that of two-dimensional Ising universality class. [2] However, as alluded above, many organelles have complex shapes beyond spherical-like geometries, and BCPs are among them. Apart from differences in curvature and topology, BCPs also have a characteristic length scale given by size of the unit cell, which is not present in the standard 2D Ising model. Thus, in this work we investigate how these geometrical features affect the behaviour close to the critical point, and shed light on two fundamental questions: Do the critical exponents still follow 2D Ising model? Is there a crossover in the critical exponents that signifies the three-dimensional nature of BCPs? [1] Veatch, S. L. et al. Critical Fluctuations in Plasma Membrane Vesicles. ACS Chemical Biology 3, 287–293 (2008) [2] Honerkamp-Smith, A. R. et al. Line Tensions, Correlation Lengths, and Critical Exponents in Lipid Membranes Near Critical Points. Biophysical Journal 95, 236–246 (2008)

*Speaker

Plastic Events in Soft Glasses

Roberto Benzi * [1]

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Many materials around us respond elastically to small applied stresses, but flow once a threshold stress (the yield stress) is exceeded. This is the case for food products, powders, cosmetics, foams, etc... It turns out that understanding the yield stress transition in these materials, often called soft glasses, is a challenging question. Similar to structural glasses, soft glasses exhibit aging and complex dynamics. Also, the size of the elementary building block of a soft glass is usually ranging from 1 micron to 1mm, ruling out the possibility to investigate the problem by molecular dynamics.
Recently, a new approach has been proposed: using a mesoscopic formulation of the system, the dynamics of relative simple soft glasses, like foams or micro emulsions, has been investigated. Numerical simulations allow the computation of several important properties of the systems, such as the yield stress transition. In this talk, I will review the new approach and explain how the complexity of soft glass dynamics may be disentangled in a systematic way.

*Speaker

Non-equilibrium interfaces in fluids

Markus Bier * [1]

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The concept of non-equilibrium interfacial tension, defined via the work required to deform the system such that the interfacial area is changed while the volume is conserved, is discussed in the context of non-equilibrium fluid-fluid interfaces and of the relaxation of an initial perturbation of fluids towards the equilibrium state. For the former case it is shown that the interfacial structure between fluid phases not at coexistence relaxes towards that of the equilibrium interface at the same temperature long before the bulk phases have been equilibrated. For the latter case it is shown that the non-equilibrium interfacial tension is not necessarily positive and that negative non-equilibrium interfacial tensions are consistent with strictly positive equilibrium interfacial tensions.

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[2] M. Bier, Phys. Rev. E **92**, 042128 (2015).

*Speaker

Nanofluidics insights into the water carbon interface

Lyderic Bocquet * [1]

[1] Ecole Normale Supérieure – France

Nanofluidics is the frontier where the continuum picture of fluid mechanics confronts the atomic nature of matter. Recent experiments reported exceptional transport properties of water when confined in carbon nanopores. This has stimulated interest in carbon-based membranes for desalination, nano-filtration, and energy harvesting. But these works raised fundamental questions on the specificity of the water-carbon interface at the molecular scale, its structure, reactivity and dynamics.

We tackle this question by exploring the transport across individual carbon nanotubes (CNT), which allows to address systematically the fundamental properties at the nanoscales. To this end, we have developed new methods based on the manipulation of nano-scale building blocks which allow to fabricate original fluidic and mechanical systems involving single nanotubes.

I will first discuss an experimental study of ionic transport and current fluctuations inside individual CNTs. Experiments highlight some anomalous scalings of ionic transport at low salinity. This behavior is rationalized in terms of hydroxide adsorption at the (hydrophobic) carbon surface, providing new insights into the water-carbon surface.

Then, I will report experimental study of the water friction at the CNT interface. This is done experimentaly by exploring nanoscale water jets emerging from single CNT. The jets' peculiar hydrodynamics enable us to passively measure pressure-driven flow rates with unprecedented sensitivity and without dyes. Our experiments reveal diameter-dependent surface slippage in carbon nanotubes, with giant flow enhancements in the smallest tubes. In contrast, their boron-nitride analogues, which have the same crystalinity as CNT, exhibit no slippage. This shows that water-solid friction and interfacial slippage originates in subtle and even sub-atomic details of the solid-liquid interface.

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Scaling behavior for ionic transport and its fluctuations in individual carbon nanotubes, E. Secchi, A. Niguès, L. Jubin, A. Siria, L. Bocquet, Phys. Rev. Lett. 116, 154501 (2016). Nanoscale water jets emerging from single carbon nanotubes reveal giant diameter-dependent surface slippage, E. Secchi, S. Marbach, A. Niguès, D. Stein, A. Siria, L. Bocquet, in preparation (2016).

*Speaker

Curvature-dependence of the surface tension in nucleation experiments

Nicolas Bruot * [1], Frédéric Caupin

[1] The University of Tokyo – France

The liquid-vapor surface tension is a quantity that is well characterized in macroscopic systems. At the nanoscale, its dependency with the curvature R of the interface is however still largely unknown. The understanding of the evolution of the surface tension with the radius of curvature R is critical to accurately describe cavitation and condensation, as it may contribute to the failure of the classical nucleation theory (CNT) in representing the small nuclei. It is also relevant to problems of nanopores filling or emptying. We present here acoustic cavitation experiments in heptane and ethanol where the pressure is measured by a fiber optic probe hydrophone. We compare the results with CNT to investigate different models for the curvature dependence of the surface tension. Since CNT can also be applied to the converse phenomenon, the condensation of a liquid from its supersaturated vapor, we have analyzed our cavitation experiments together with corresponding condensation measurements by other groups to span a wide range of parameters and test the possible symmetry between cavitation and condensation. We show that the most commonly used model of a surface tension depending to the first order in $1/R$ (the Tolman equation) cannot account for all the experiments together. A second order dependence provides a more consistent description of the data. Formulas are given to deduce the nucleation rate for any conditions as a function of two parameters that we have obtained empirically and that only depend on the temperature.

*Speaker

Adhesion, delamination and wrinkle formation in thin films on patterned substrates

Zoe Budrikis * [1], Alessandro L. Sellerio, Zsolt Bertalan, Stefano Zapperi

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Partial adhesion of thin films on substrates is a source of a rich variety of patterns, such as 'telephone cord' buckles, wrinkles, and labyrinth domains, as well as being important to understand for technological applications. We report numerical simulations of graphene deposited on patterned substrates and trenches, focusing on the complex interplay between substrate geometry and mechanics of the sheet. We uncover a previously-overlooked universal phenomenon in which pairs of wrinkles form avoiding pairs – behaviour which is visible not only in graphene but in macroscopic systems such as geomembranes – and characterize how it depends on stress fields in the sheet and friction with the substrate. [1] We also show how adhesion of a sheet to the sidewalls of a trench depends on substrate interaction, temperature, and curvature of the edge of the trench, a dependence which we capture in a one-dimensional model for the sheet configuration. [2] [1] Zoe Budrikis, Alessandro L. Sellerio, Zsolt Bertalan, Stefano Zapperi. "Wrinkle Motifs in Thin Films". Scientific Reports 5, 8938 (2015). [2] Zoe Budrikis and Stefano Zapperi. "Temperature-dependent adhesion of graphene suspended on a trench". Nano Letters 16, 387–391 (2016).

*Speaker

Two-state interpretation of thermodynamic and dynamic properties of water and water-like models

Frédéric Caupin * [1], John W. Biddle, Miguel A. Gonzalez, Lokendra P. Singh, Amine Dehaoui, Chantal Valeriani, José L. F. Abascal, Rakesh Singh, Pablo G. Debenedetti, Bruno Issenmann, Mikhail A. Anisimov

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One particularly successful hypothesis explaining the thermodynamic anomalies of supercooled water proposes a liquid-liquid transition deep in the supercooled region, just out of the reach of experiment, obstructed by homogeneous ice formation. An equation of state based on the idea of the existence of two inter-convertible structures in cold water resulting in a liquid-liquid transition (the two-structure equation of state or TSEOS) has shown excellent agreement with experimental data throughout the supercooled and cold-stable region from atmospheric pressure up to 400 MPa, and has been adopted as the basis for the most recent formulation for supercooled water endorsed by The International Association for the Properties of Water and Steam. Previous applications of the TSEOS have also shown excellent agreement with both the ST2 and the TIP4P/2005 water models, including data in the vicinity of the liquid-liquid critical point that terminates the hypothesized liquid-liquid transition. New experimental data on the equation of state of water at negative pressure and viscosity of supercooled water under pressure was recently measured. Negative pressure experiments reveal behaviour that is not well accounted for by the TSEOS in its original form. This experimental data is as yet too sparse to be the basis of a quantitative equation of state, but TIP4P/2005 and ST2 show similar overall pictures of the phase diagram from the liquid-liquid critical point to extreme negative pressures, in particular the behaviour of lines of maxima and minima in the thermodynamic properties. By incorporating a liquid-vapour spinodal at negative pressure into the TSEOS, we give a comprehensive account of the thermodynamic behaviour of TIP4P/2005 at negative pressures, while maintaining the quality of the description in the liquid-liquid critical region achieved in previous work. In particular, the specific pattern of the loci of extrema in thermodynamic functions is reproduced. This pattern is strikingly similar to that obtained with ST2, suggesting that the observed global thermodynamic behaviour could be generic for realistic water models and thus may be expected in real water. To gain more insight, we also study a two-state modification of two standard thermodynamic models: van der Waals and lattice gas. Finally, we also extend the two-state formalism to dynamic properties, achieving a quantitative description of available experimental data for translational and rotational diffusion, as well as of our new viscosity data.

*Speaker

Supracolloidal reconfigurable polyhedra via hierarchical self-assembly

Dwaipayan Chakrabarti * [1], Daniel Morphew

[1] University of Birmingham – United Kingdom

Enclosed three-dimensional structures with hollow interiors have been attractive targets for self-assembly of building blocks across different length scales [1-3]. Colloidal self-assembly, in particular, has enormous potential as a bottom-up means of structure fabrication exploiting a priori designed building blocks because of the scope for tuning interparticle interactions [4]. Here we use computer simulation study to demonstrate self-assembly of designer charge-stabilized magnetic particles into a series of supracolloidal polyhedra, showing remarkable structural hierarchies [5-6]. The particles can be designed such that the polyhedra exhibit very different morphologies: hollow spherical or tubular structures. We optimize the design rule to satisfy competing thermodynamic and kinetic criteria that the task of programming self-assembly faces. The dominant pathways for self-assembly reveal two distinct mechanisms: one is staged or hierarchical, observed for spherical shells and the other involves a growth mechanism observed for tubular structures. These supracolloidal architectures open up in response to an external magnetic field and exhibit controllable porosity. The ability to reconfigure such hollow structures is critical to the design of responsive cages that can encapsulate guests and release them on demand. References: [1] L. R.MacGillivray and J. L.Atwood, Ang. Chem. Int. Ed. 38, 1018 (1999). [2] A. D. Dinsmore, M. F. Hsu, M. G. Nikolaides, M. Marquez, A. R. Bausch and D. A. Weitz, Science 298, 1006 (2002). [3] Y. He, T. Ye, M. Su, C. Zhang, A. E. Ribbe, W. Jiang and C. Mao, Nature 452, 198 (2008). [4] L. Cademartiri and K. J. M. Bishop, Nature Mater. 14, 2 (2015). [5] D. Morphew and D. Chakrabarti, Nanoscale 7, 8343 (2015). [6] D. Morphew and D. Chakrabarti, Unpublsihed (2016).

*Speaker

Phase-transition oscillations induced by a strongly focused laser beam

Sergio Ciliberto * [1]

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We report the observation of a surprising phenomenon consisting in a oscillating phase transition which appears in a binary mixture when this is enlightened by a strongly focused infrared laser beam. The mixture is PMMA/3-octanone, which has an Upper Critical Solution Temperature (UCST) at $T_c = 306.6K$ and volume fraction $\phi_c = 12.8$ [Crauste *et al., ArXiv*1310.6720, 2012]. In this talk we first describe the birth, growth, and decrease of droplets of rich PMMA phase in a poor PMMA homogeneous phase. We then analyze the dynamical properties of the oscillations and discuss the effects which may compete to produce them. Three main phenomena have to be considered: the local accumulation of PMMA induced by the laser beam, thermophoresis and non-linear diffusion. We finally show that the main properties of these oscillations can be reproduced using the Landau theory for binary mixtures in which a local driving mechanism, simulating the laser beam, is introduced. [Devailly *et al.*,PRE, **92**,052312 (2015)].

*Speaker

Bacteria swimming in High Molecular-weight polymer: lambda-DNA

Clémence Devailly * [1], Vincent Martinez, Angela Dawson, Jana Schwarz-Linek, Jochen Arlt, Wilson Poon

[1] University of Edinburgh – United Kingdom

Escherichia coli (E.coli) has become a model swimmer in the active matter field (e.g. [1]). Numerous studies focus on the swimming in water but bacteria as E.coli often live in viscoelastic media such as mucus in intestine tract. Mucus is a strong viscoelastic material with shear-thinning properties containing long polymer chains as proteins and DNA. It has been suggested recently [2] that in a solution of PolyVinylPirrolidone (PVP) of molecular weight 360kDa, small and fast rotating flagella (40nm thickness rotating at 100Hz) create a local high shear rate ($\sim 10^4 s^{-1}$) resulting in a polymer free channel from its surrounding, while the slow rotating body (1 μm $\times$2 μm rotating at 20 Hz) of the bacterium observe the viscosity of the polymer solution. Thus, bacteria body and flagella observe two different environments. Here, we investigate the swimming of E.coli in solution containing larger polymer coils, i.e. lambda-DNA (Mw=33.103 kDa) with a radius of gyration $Rg \sim 0.6$ μm of similar size than the body bacterium itself. By using Differential Dynamic Microscopy (DDM) and Dark Field Microscopy (DFM), we measure the swimming speed V and the body rotational speed Ω, averaged over $\sim 10^4$ cells. Surprisingly, we found that V and Ω are only weakly modified by increasing DNA concentration while the bulk viscosity increases by a factor of 20. We show by labelling the DNA with a fluorescent dye, that polymer coils do not act as hard sphere colloids between which the bacteria can swim. On the contrary, macrorheology measurements at high shear-rate (20 s^{-1}) as well as relaxation time of polymer coils are compatible with a local shear-thinning of the polymer by the swimming bacteria. These phenomena are particular to active particles such as flagellated bacteria, as Brownian diffusion of non-swimming bacteria is dependent on bulk viscosity. [1] J. Schwarz-Linek, J. Arlt, A. Jepson, A. Dawson, T. Vissers, D. Miroli, T. Pilizota, VA Martinez, WCK Poon. Colloids Surf B Biointerfaces, 137, 2-16 (2016). [2] VA Martinez, J. Schwarz-Linek, M. Reufer, L.G. Wilson, A.N. Morozov, W.C.K. Poon. PNAS, 111 (50),17771-17776 (2014).

*Speaker

Nanoparticle Organization in Polymer Layers

Jure Dobnikar * [1], Tine Curk, Francisco Martinez Veracoechea, Daan Frenkel

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The organization of nanoparticles inside grafted polymer layers is governed by the interplay of polymer-induced entropic interactions and the action of externally applied fields. The competition between the tendency for macro-phase separation of colloids and polymers and the action of the external forces pulling the colloids into the layers and causing elastic-like deformations of it can drive the formation of internally ordered, columnar colloidal structures spanning the polymer layer. We further show that external fields are not essential to obtain such colloidal patterns: we report Monte Carlo and molecular dynamics simulations that demonstrate that ordered structures can be achieved by compressing a "sandwich" of two grafted polymer layers, or by squeezing a coated nanotube, with nanoparticles in between. We derive an approximate equation of state for such "nanosandwiches" and show that the pattern formation can be efficiently controlled by the applied pressure, while the characteristic length-scale, that is, the typical width of the patterns, is sensitive to the length of the polymers. The rich morphology of the observed patterns opens up new routes for the design of thin structured films and applications in the area of physico-chemical sensing.

*Speaker

A quantitative measure of confinement effect for fluids adsorbed in random porous media

Wei Dong * [1], C.Z. Qiao, S.L. Zhao, H.L. Liu

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Although many investigations have been devoted to study fluids confined in random porous media since 1988 when Madden and Glandt proposed the first quench-annealed mixture model for fluids confined in random porous media [1-21], no precise measure has ever been proposed to describe quantitatively the quench effect for the adsorption of a fluid in a random porous material. We propose to measure such a confinement effect by the difference of free energy to insert a fluid particle into a quench-annealed system or into an equilibrium binary mixture. We determined this measure numerically either by grand-canonic-ensemble Monte Carlo simulation or scaled particle theory [17-21]. Our results reveal that the confinement effect is most strong for highly divided porous systems. The insights gained from this study will be certainly very useful for design new functionalized porous materials, e.g., for high-capacity gas adsorbents etc. [1] W. G. Madden and E. D. Glandt, J. Stat. Phys. 51, 537 (1988). [2] C. Vega, R.D. Kaminsky and P.A. Monson, J. Chem. Phys. 99, 3003 (1993). [3] A. Meroni, D. Levesque and J.J. Weis, J. Chem. Phys. 105, 1101 (1996). [4] L.D. Gelb, K. E. Gubbins, R. Radhakrishnan and M. Sliwinska-Bartkowiak, Rep. Prog. Phys. 62, 1573 (1999). [5] M. Schmidt, J. Phys.: Condens. Matter 17, S3481 (2005). [6] L. Sarkisov, P. R. Van Tassel, J. Phys.: Condens. Matter 20, 333101 (2008). [7] W. Dong, J. Chem. Phys. 102, 6570, (1995). [8] J.K. Brennan and W. Dong, J. Chem. Phys. 116, 8948, (2002). [9] J.K. Brennan and W. Dong, Phys. Rev. E 67, 031505, (2003). [10] W. Dong, X. S. Chen and W. M. Zheng, Phys. Rev. E 72, 012201, (2005). [11] S.L. Zhao, W. Dong and Q.H. Liu, J. Chem. Phys. 125, 244703, (2006). [12] S.L. Zhao, W. Dong and Q.H. Liu, J. Chem. Phys. 127, 144701, (2007). [13] E.V. Vakarin, W. Dong and J.P. Badiali, Physica A 379, 389, (2007). [14] W. Dong, V. Krakoviack and S.L. Zhao, J. Phys. Chem. C 111, 15910, (2007). [15] S.L. Zhao, W. Dong and Q.H. Liu, J. Mol. Liq. 136, 241, (2007). [16] W. Dong, Condensed Matter Physics 10, 509, (2007). [17] M. Holovko and W. Dong, J. Phys. Chme. B 113, 6360 and 16091, (2009). [18] W. Chen, W. Dong, M. Holovko and X. S. Chen, J. Phys. Chme. B 114, 1225, (2010). [19] T. Patsahan, M. Holovko and W. Dong, J. Chem. Phys. 134, 074503 (2011). [20] M. Holovko, T. Patsahan and W. Dong, Pure Appl. Chem. 85, 115 (2013). [21] W. Chen, S.L. Zhao, M. Holovko, X.S. Chen and W. Dong, J. Phys. Chem. B (submitted).

*Speaker

Tubular Crystals and Glass Formation: the Role of Soft Interactions

Ian Douglass * [1], Peter Harrowell, Toby Hudson

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The small density difference between glass and crystal phases that is associated with good glass forming ability in metal alloys is shown, using simulations, to be reproduced by particles interacting with soft repulsive interactions. The improved glass forming ability is shown to arise from the depression of the freezing point associated with the small density difference. Using the same model, novel crystals corresponding to ordered stackings of tubular structures are stabilized when the attractive interaction range is extended in asymmetric binary mixtures.

*Speaker

Statistical physics of cellular systems

Marc Durand * [1]

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Foams and cellular materials are interesting both as out-of-equilibrium systems with well-defined metastable states, and as models for more complex systems such as biological tissues. In the low liquid fraction ("dry" foams), foam structure is disordered but not disorganized: in two-dimensional foams, films are circular arcs that meet at three-fold junctions with 120° angles. One can define a topological disorder, associated with the distribution of number-of-sides per bubble, and a geometrical disorder, associated with the distribution of bubble size. There are evidence that these two disorders are correlated: in a monodisperse foam (1 bubble size), most of the bubbles are 6-sided. In a polydisperse foam, the larger bubbles have statistically more sides than the smaller ones. Bubble size distribution and packing (or "topology") are crucial in determining *e.g.* rheological properties or coarsening rate. When a foam is shuffled (either mechanically or thermally), bubbles undergo "T1" neighbour changes, which induce a random exploration of the foam configurations. We explore the relations between the geometrical and topological properties of a shuffled foam by using Monte-Carlo simulations . The observations are compared with a statistical model which takes into account the physical ingredients specific to foams [1,2]. [1] M. Durand et al., Physical Review Letters, 107, 168304 (2011) . [2] M. Durand, European Physical Journal E 38(12), 137 (2015).

*Speaker

Microscopic theory of non-Brownian suspension flows close to the Jamming point.

Gustavo During * [1], Edan Lerner, Matthieu Wyart

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While the rheology of athermal suspensions in the dilute regime is well-understood, their behavior in the dense limit remains unclear. As the packing fraction of particles is increased, particle motion becomes more collective, leading to a growing length scale and scaling properties in the rheology close to the jamming transition where flow stops. In my talk I will present a microscopic theory for the rheology of dense non-Brownian suspensions. The theory provides predictions for the scaling laws connecting macroscopic observables such as the pressure and viscosity with microscopic observables such as the coordination. The non-trivial critical exponent characterizing the scaling laws will be shown to stem from the existence of two different force scales between particles in contact close to the jamming point. The first force scale is proportional to the macroscopic pressure, while the second force scale is shown to be determined by the force between colliding particles. The microscopic theory will be then derived from the proper balance between these force scales which is necessary to reach a statistically stationary flow.

*Speaker

Evidence for the existence of the liquid?liquid critical point in tin tetraiodide

Kazuhiro Fuchizaki * [1], Nozomu Hamaya, Ayako Ohmura, Akio Suzuki, Keisuke Nishida, Hiroyuki Saitoh

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We present firm evidence for the existence of the second critical point in the fluid region of tin tetraiodide. This could be established by *in situ* synchrotron x-ray absorption measurement under pressure [1]. An abrupt change in absorptivity (transmissivity) by liquid tin tetraiodide at around 1.5 GPa was detected upon compression at 950 K whereas no abrupt change but only gradual increase of absorptivity with increasing pressure at 1200 K was confirmed. These observations clearly indicate that the density of liquid tin tetraiodide varies discontinuously along the 950 K isotherm but it exhibits continuous increase along the 1200 K isotherm, implying that the critical point is located between the two temperatures. The location is consistent with the prediction of the mean-field theory [2]. It should be emphasized that the measuring region is thus experimentally accessible without much difficulty. That is, the critical region will never be a "no-man's land" [3] for liquid tin tetraiodide. [1] K. Fuchizaki *et al.*, J. Phys. Soc. Jpn. **82**, 033003 (2013). [2] K. Fuchizaki *et al.*, J. Chem. Phys. **135**, 091101 (2011). [3] O. Misihima and H. E. Stanley, Nature **396**, 329 (1998).

*Speaker

Active microrheology in a colloidal glass: Comparison of mode coupling theory and molecular dynamics simulations

Matthias Fuchs * [1], Markus Gruber, Gustavo Abade, Antonio M. Puertas

[1] University of Konstanz – Germany

The force-induced motion of a probe particle provides important insights into the microscopic structural and transport properties in complex fluids far from equilibrium. We investigate a quintessential set up for the technique of 'active microrheology' in a soft solid: The behaviour of a colloidal probe subject to a constant force in a colloidal glass of hard spheres. Microscopic mode-coupling theory (MCT) (extending an older approach [1]) and molecular dynamics simulations (MDS) reveal the existence of a critical force, above which the tracer delocalizes. At this delocalization transition we find anomalous dynamics in both MCT and MDS. A scaling law description of the breaking of local cages will be presented, which rationalizes the decay seen in the simulated intermediate scattering functions. Furthermore, we observe heterogeneous dynamics of the tracer motion, which manifests itself in exponential tails in the van Hove function. Single trajectories of MDS show both mobile and localized behaviour. [1] I. Gazuz, A.M. Puertas, T. Voigtmann and M. Fuchs, Phys. Rev. Lett. 102, 248302 (2009)

*Speaker

Granular compaction by fluidization

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How to arrange a packing of spheres is a scientific question that aroused many fundamental works since a long time from Kepler's conjecture to Edward's theory [1], where the role traditionally played by the energy in the statical mechanics of thermal systems is replaced by the volume for athermal grains. In the last years, the compaction dynamics of granular packings by successive taps has received much attention [2, 3]. We are here interested in the possible experimental compaction of a granular bed by an upward flow [4]. An initial fluidized bed leads to well reproduced initial loose packing by the settling of grains when the high enough continuous upward flow is turned off. When the upward flow is then turned on again, we record the dynamical evolution of the bed packing. For a low enough continuous upward flow, below the critical velocity of fluidization, a slow compaction dynamics is observed. Strikingly, a slow compaction can be also observed in case of "fluidization taps" with bursts of fluid velocity higher than the critical fluidization velocity. The different compaction dynamics will be discussed when varying the different control parameters of these "fluidization taps". References [1] S. F. Edwards and R.B.S Oakeshott. Theory of powders. Physica A, 157 :1080–1090, 1989. [2] J. B. Knight, C. G. Fandrich, C. N. Lau, H. M. Jaeger, and S. R. Nagel. Density relaxation in a vibrated granular material. Phys. Rev. E, 51 :3957–3963, May 1995. [3] J. A. Dijksman and M. van Hecke. The role of tap duration for the steady-state density of vibrated granular media. EPL (Europhysics Letters), 88(4) :44001, 2009. [4] M. Schr´oter, D. I. Goldman, and H. L. Swinney. Stationary state volume fluctuations in a granular medium. Phys. Rev. E, 71 :030301, Mar 2005.

*Oral

Reconfigurable self-assembly of colloidal rods – attraction and chirality

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Nature excels at building complex functional materials. We however are far from understanding the structure and mechanism involved and even further from being able to replicate equivalent materials. Here, we use stiff monodisperse colloidal rods (filamentrous viruses) as minimalist building blocks to mimic biological structures such as membranes. The colloidal nature of the building blocks allows up-scaling the size and slowing the dynamics of the resulting self-assembled structure for better visualization and manipulation. Thanks to synthetic biology, we engineer libraries of colloidal-rods with control over their aspect ratio, stiffness, and chirality. We show that aqueous mixtures of polymers and rods self-assemble in a myriad of structures, including isotropic and nematic droplets [1] and colloidal membranes, a monolayer of aligned rods that behave on a coarse grained level like lipid bilayers. We tackle issues related to chirality like its interplay with interfacial tension, the transition toward twisted ribbons [2,3], chiral coalescence [4] and also membrane rafts [5].

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*Speaker

Response of flocks to external perturbations

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Flocking is a ubiquitous emergent phenomenon that occurs in many living and synthetic systems over a wide range of scales. Examples range from fish schools and bird flocks to bacteria colonies and cellular migrations, down to subcellular molecular motors and biopolymers. While our knowledge of collective motion in unperturbed systems greatly advanced in recent years, little is known concerning the response of moving groups to perturbations. This is a fundamental problem in non-equilibrium statistical physics but it also has important consequences for animal group behavior (e.g., response to external threats) and for controlling flocking systems, either biological or artificial. Here, we address the asymptotic linear response of active polar fluids ("flocks") to small external aligning fields and compute for the first time the susceptibility of polar ordered liquids, by making use of hydrodynamic theory and dynamic renormalization group techniques. Our results are valid in any dimension greater than or equal to two, and we also address finite size effects. In particular, below the upper critical dimension ($d_c = 4$), we obtain a diverging longitudinal susceptibility for vanishing fields in the thermodynamic limit. Our results may be compared with classic field-theoretic calculations for equilibrium ferromagnets to highlight the far-from-equlibrium effects typical of active matter flocks. Numerical simulations of a Vicsek model in two and three dimensions confirm our theoretical results. In the last part of this talk, we will finally discuss a more realistic set-up, in which finite flocks interact with the external world only via the flock own boundary.

*Speaker

Beyond classical depletion: how to induce "long-range" effective potentials in soft matter

Nicoletta Gnan * [1], Emanuela Zaccarelli, Francesco Sciortino, Alberto Parola, Lorenzo Rovigatti

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Effective forces can deeply modify the phase diagram of colloidal particles. This often happens in the presence of depletion forces, i.e. effective forces that originate from the presence of a co-solute (polymers, surfactants) in the suspension. Although the depletion force has been theoretically described more than 60 years ago by Asakura and Oosawa [1] and the number of works on the topic is huge, little effort has been dedicated to give a unified understanding on how such force can be influenced by the interacting properties of the solution. This is crucial to correctly predict colloidal stability in several situations and to interpret experimental results. In the talk I will discuss some cases in which, besides standard "short-range" depletion, it is possible to observe long-range depletion forces if the colloid-cosolute interaction is modified. For instance a non-trivial behavior occurs when colloid-cosolute hard-core interaction is replaced by a soft repulsion: depending on the colloid-cosolute size ratio the range of the effective interaction becomes longer compared to standard depletion [2], with consequences on the thermodynamic phase behavior . Also cosolute-cosolute interactions can give rise to long-range effective forces, even if the mechanism is different from depletion: the most famous example is that of the critical Casimir force, which arises when two colloids are immersed in a solvent close to its critical point. In such a case, the confinement of the density critical fluctuations between the colloids surfaces give rise to a long-range force[3], that can be controlled through a tiny variation of the temperature close to the critical point. Analogous to the critical point, a sol close to percolation induces a long-range effective force on colloidal particles with a range that can be controlled by the distance from the percolation threshold [4]. This effect is in analogy with the Casimir effect, but the mechanism giving rise to the effective force can be assimilated to a depletion effect as I will show theoretically and numerically during the talk. [1]S. Asakura and F. Oosawa, J. Pol. Sci. 33, 183 (1958). [2]L. Rovigatti, N. Gnan, A. Parola and E. Zaccarelli, Soft Matter 11,692 (2015). [3] M.E. Fisher, P.G. de Gennes. C. R. Acad. Sc. Paris B 287, 207 (1978). [4] N. Gnan, E. Z., F. Sciortino, Nat. Comm. 5,3267 (2014).

*Speaker

Dynamics of self-propelled Janus particles in viscoelastic fluids

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We experimentally investigate active motion of spherical Janus colloidal particles in a viscoelastic fluid. Self-propulsion is achieved by a local concentration gradient of a critical polymer mixture, which is induced by laser illumination. Even in the regime where the fluid's viscosity is independent from the deformation rate induced by the particle, we find a remarkable increase of up to two orders of magnitude of the rotational diffusion with increasing particle velocity, which can be phenomenologically described by an effective rotational diffusion coefficient dependent on the Weissenberg number. We show that this effect gives rise to a highly anisotropic response of microswimmers in viscoelastic media to external forces, e.g. gravity, depending on its orientation.

*Speaker

Direct measurement of ballistic to diffusive crossover in freely moving colloidal particles

Andrew P. Hammond * [1], Eric I. Corwin

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Einstein's description of Brownian motion provided proof for the atomic theory by demonstrating the presence of a microscopic scale for fluid systems, even if this scale was far beyond the abilities of contemporary measurement techniques. Recent advances in microscopy and high speed imaging have made it possible to experimentally measure the crossover from ballistic to diffusive motion, first in rarefied gasses and later in fluids by using particles trapped inside an optical trap. Soon after Einstein's work, Ornstein and Furth independently derived a generalized function for the mean square displacement (MSD) of a free floating particle undergoing Brownian motion in an ideal gas, a system that is experimentally close to rarefied gasses. Later, Clercx and Schram extended the expression for MSD to liquids by taking into account the cooperative and inertial effects that become non-trivial in a liquid. Existing measurements, however, are unable to show the full transition between ballistic and diffusive motion because of the spatial and temporal cutoff imposed by the optical trap at times comparable to the ballistic-diffusive crossover. We present a measurement of the MSD of a free colloid in water. This measurement shows the full transition between ballistic and diffusive motion with the precision necessary to distinguish between predictions for ideal gasses and dense fluids. Further, by measuring the ballistic regime we provide a direct, local measurement of temperature. We discuss future measurements of this system as a probe to explore nonlinear dynamics of non-Newtonian fluids.

*Speaker

Statistical mechanical approach to rheology of dense sheared granular flow: shear thickening and divergence of viscosity

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[1] Yukawa Institute for Theoretical Physics, Kyoto University – Japan

In the first part, a theory for jammed granular materials is developed with the aid of a nonequilibrium steady-state distribution function. The approximate nonequilibrium steady-state distribution function is explicitly given in the weak dissipation regime by means of the relaxation time. The theory quantitatively agrees with the results of the molecular dynamics simulation on the critical behavior of the viscosity below the jamming point without introducing any fitting parameter[1]. In the second part, we apply the above formulation to granular particles with attractive interaction to demonstrate the existence of shear thickening and to explain the mechanism the shear thickening. Reference: [1] K. Suzuki and H. Hayakawa, Phys. Rev. Lett. 115, 098001 (2015).

*Speaker

Influence of the permittivity gradient on static and dynamic properties of charged macromolecules

Christian Holm * [1]

[1] Institute for Computational Physics – Germany

Dissolved ions can alter the local permittivity of water, nevertheless most theories and simulations ignore this fact. We present a novel algorithm for treating spatial and temporal variations in the permittivity, and show several examples where this leads to large qualitative and quantitative differences. A dynamic example is the equivalent conductivity of a salt-free polyelectrolyte solution. Our new approach quantitatively reproduces experimental results unlike simulations with a constant permittivity that even qualitatively fail to describe the data. We can relate this success to a change in the ion distribution close to the polymer due to the built-up of a permittivity gradient. F. Fahrenberger, O.A. Hickey, J. Smiatek, C. Holm, "The influence of charged-induced variations in the local permittivity on the static and dynamic properties of polyelectrolyte solutions". J. Chem. Phys. 143, 243140, (2015). F. Fahrenberger, O.A. Hickey, J. Smiatek, C. Holm, "Importance of Varying Permittivity on the Conductivity of Polyelectrolyte Solutions", Phys. Rev. Lett.115, 118301 (2015). F. Fahrenberger, C. Holm,"Computing the Coulomb interaction in inhomogeneous dielectric media via a local electrostatics lattice algorithm" Phys. Rev. E 90, 063304, (2014). F. Fahrenberger, Z. Xu, C. Holm,"Simulation of electric double layers around charged colloids in aqueous solution of variable permittivity", J. Chem. Phys. 141 064902 (2014)

*Speaker

Ordering on a Sphere via Brazovskii Transitions

Eric M. Horsley * [1], Maxim O. Lavrentovich, Asja Radja, Alison M. Sweeney, Randall D. Kamien

[1] University of Pennsylvania – United States

The Brazovskii transition has been recognized as a mechanism for ordering in a variety systems such as diblock copolymers, cholesteric liquid crystals, and Rayleigh-Bénard convection. We extend the analysis of the instability, using analytic methods, to the 2-dimensional sphere. Furthermore, we discuss a novel application of the theory to the patterning of pollen. An analogy between pollen structures during development and a microscopic model first introduced by Leibler and Andelman [1] is drawn.

With the interaction of curvature and defects and recent work by Gómez *et al.* [2] on nucleation on curved surfaces in mind, we discuss the possibilities for future work intertwining these two ideas via the Brazovskii transition. To end, we pose a few open questions regarding what happens to ordering on a sphere in the large radius limit.

[1] S. Leibler, D. Andelman, *Ordered and curved meso-structures in membranes and amphiphilic films.* Journal de Physique 48, pp. 2013–2018 (1987)

[2] L. R. Gómez, N. A. García, V. Vitelli, J. Lorenzana, D. A. Vega, *Phase nucleation in curved space.* Nature Communications 6: 6856 (2015)

*Speaker

Melting in 2D and a Fresh Perspective on Monte Carlo

Sebastian Kapfer * [1]

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The melting transition of two-dimensional solids has been the subject of continued research for more than fifty years, with the prevalent scenarios being the KTHNY theory of defect unbinding and a conventional first-order liquid/solid transition. For hard disks, the KTHNY scenario has recently been essentially confirmed, even though the liquid-hexatic step is of first order [1]. A key problem in these simulations are the large correlation lengths, which we tackle using a new rejection-free global-balance Monte Carlo algorithm [2]. We show that the hard disk result transfers to soft interactions with inverse power-law or Yukawa potentials [3]. The order of the liquid-hexatic step can be tuned from first-order to continuous by softening the potential. We show that there is always a hexatic phase separating the liquid and solid phases, and identify two regimes of the hexatic with vastly different correlation lengths. The new algorithm is very versatile, and could also be applied to spin systems, polymers, path integral problems, etc. It can be augmented to treat long-range force laws such as Coulomb without any artificial truncation. [1] E. P. Bernard, W. Krauth, Phys. Rev. Lett. 107, 155704 (2011). [2] M. Michel et al., J. Chem. Phys. 140, 054116 (2014). [3] S. C. Kapfer, W. Krauth, Phys. Rev. Lett. 114, 035702 (2015).

*Speaker

Tensile properties of collagen fibrils: molecular unfolding and packing defects

Laurent Kreplak * [1], Andrew S. Quigley, Samuel P. Veres, Laurent Kreplak

[1] Dalhousie University – Canada

Collagen fibrils are the load-bearing elements of mammalian tissues, such as skin, tendon and bones. In tendon, collagen fibrils have wide range of diameters from 50 to 500nm and are at least millimetres in length. Here we present a simple experimental approach based on atomic force microscopy that allows stretching of individual fibrils and imaging of their morphology after failure. Our data on collagen fibrils extracted from two different bovine leg tendons point towards two main deformation mechanisms, molecular unfolding and the appearance of defects in the paracrystalline packing of collagen molecules. We will discuss the latter mechanism in light of recent theoretical results on the effect of dislocations and disclinations on the morphology of crystalline bundles of flexible filaments.

*Speaker

Directed Self-assembly of Colloidal Crystal Growth on Engineered Templates with Activation Energy Gradients

Chandan Kumar * [1], Ajay K Sood, Rajesh Ganapathy

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Achieving site-specific colloidal crystal nucleation and subsequent control over the size and symmetry of the growing crystallites is of considerable importance for a wide variety of applications that include structural colors, optoelectronics and composite materials. While for atomic and molecular systems, heteroepitaxy and/or epitaxy over the patterned templates allow for a significant control over the most of the above parameters, for micrometre-sized colloidal particles, owing to their slow dynamics, attempt to achieve control over these parameters continue to remain a challenge. Here, we design templates with activation energy gradients to achieve site-specific crystal nucleation. On these templates, colloidal particles migrate to the specific sites before nucleation and subsequent growth. Remarkably, nucleation kinetics on these templates resembles dislocation mediated growth in atomic heteroepitaxy. Moreover, our approach allows for tremendous control over the size as well as the morphology of the growing crystallites, a prerequisite for any potential technological use of these structures.

*Speaker

Wall slip of polymer gels

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Jammed polymer gels like polyacrylate-based carbopol are complex yield stress fluids widely used in applications like cosmetics or oil extraction: solid-like at rest, they become liquids under a sufficient stress. Besides, their flow properties are very dependent upon wall properties, as they can exhibit significant slip, especially under confinement like in porous rocks or in microfluidic channels. We will present wall slip measurements performed on carbopol in glass microfluidic devices, coupled to fluorescent imaging of the polymer structure. At large polymer concentration, we show that the stress-velocity relation and its dependence upon yield stress and polymer microstructure size are well predicted by the elasto hydrodynamic model developed by Meeker et al. (PRL 2004) for soft spheres, despite the entanglement of polymers in carbopol. At lower concentrations, a different friction regime is evidenced, as in other yield stress fluids (Divoux et al. PRE 2015). Finally, we discuss unsteady effects at the wall and the influence of flow history in this experimental configuration.

*Speaker

A novel route to the spontaneous formation of porous crystals via viscoelastic phase separation

Mathieu Leocmach * [1], Hideyo Tsurusawa, John Russo, Hajime Tanaka

[1] Institut Lumière Matière, CNRS - Université Lyon 1 – France

Viscoelastic phase separation of colloidal suspensions can be interrupted to form gels either by glass transition or by crystallization. With a new confocal microscopy protocol, we unveil a novel crystallization pathway to sponge-like porous structures in a colloid-polymer mixture undergoing viscoelastic gas-liquid phase separation. We show that crystallization leads to a network structure different from the original phase separation pattern. Crystals nucleate inside the liquid network, but grow past it by direct condensation of the gas phase on their surface, i.e. de-sublimation, driving evaporation of nearby liquid. This process represents the colloidal analogue of the Bergeron process, which explains the formation of ice crystals in mixed phase clouds and is at the origin of rain. Our finding gives us full experimental access to the kinetic pathway of this poorly understood phenomenon important for climate science. We argue that similar crystal-gel states can be formed as the result of the gas-liquid phase separation of any crystallizable components, such as monoatomic and molecular systems, if dynamics of the liquid phase is slow enough to induce viscoelastic phase separation, but fast enough to prevent immediate vitrification. This mechanism will provide a novel single-step pathway to form nano-porous crystals of metals and semiconductors without dealloying, which may be important for catalytic, optical, sensing, and filtration applications.

*Speaker

Design and Operation of Eccentric Microswimmers

Yunyun Li * [1], Pulak Ghosh, Fabio Marchesoni, Baowen Li

[1] Tongji University – China

We discuss the two-dimensional diffusive dynamics of an eccentric artificial micro-swimmer in a highly viscous medium. We assume that the swimmer's propulsion results from an effective force applied to a center distinct from its center of mass and allow for angular fluctuations of the velocity. We prove that the ensuing active diffusion of the swimmer is suppressed to an extent that strongly depends on the model parameters. In particular, the active diffusion constant undergoes a transition from a quadratic to a linear dependence on the self-propulsion speed, with practical consequences on the interpretation of the experimental data and the design of new task-oriented micro-swimmers. References 1, P. Ghosh, Y. Li, G. Marchegiani, F. Marchesoni, Memory effects and active Brownian diffusion, J. Chem. Phys. 143, 211101(2015) 2, D. Debnath, P. Ghosh, Y. Li, F. Marchesoni and B. Li, Diffusion of eccentric microswimmers, Soft Matter 12(7), 2017-2024(2016)

*Speaker

Grains unchained: local fluidization of a granular packing by focused ultrasound

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We report experimental results on the dynamics of a granular packing submitted to high-intensity focused ultrasound. Acoustic radiation pressure is shown to remotely induce local rearrangements within a pile as well as global motion around the focal spot in an initially jammed system. We demonstrate that this fluidization process is intermittent for a range of acoustic pressures and hysteretic when the pressure is cycled. Such a first-order-like unjamming transition is reproduced in numerical simulations in which the acoustic pressure field is modeled by a localized external force. Further analysis of the simulated packings suggests that in the intermittent regime unjamming is not associated with any noticeable prior structural signature. A simple two-state model based on effective temperatures is proposed to account for these findings.

*Speaker

Surface nanobubbles and nanodroplets: The big picture

Detlef Lohse * [1]

[1] University of Twente – Netherlands

Surface nanobubbles are nanoscopic gaseous domains on immersed substrates which can survive for days. They were first speculated to exist about 20 years ago, based on stepwise features in force curves between two hydrophobic surfaces, eventually leading to the first atomic force microscopy (AFM) image in 2000. While in the early years it was suspected that they may be an artefact caused by AFM, meanwhile their existence has been confirmed with various other methods, including through direct optical observation. Their existence seems to be paradoxical, as a simple classical estimate suggests that they should dissolve in microseconds, due to the large Laplace pressure inside these nanoscopic spherical-cap-shaped objects. Moreover, their contact angle (on the gas side) is much smaller than one would expect from macroscopic counterparts. This review will not only give an overview on surface nanobubbles, but also on surface nanodroplets, which are nanoscopic droplets (e.g. of oil) on (hydrophobic) substrates immersed in water, as they show very similar properties and can easily be confused with surface nanobubbles and as they are produced in a very similar way, namely by a solvent exchange process, leading to local oversaturation of the water with gas or oil, respectively, and thus to nucleation. We will briefly report how surface nanobubbles and nanodroplets can be made, how they can be observed (both individually and collectively), and what their properties are. We will then explain the long lifetime of the surface nanobubbles. The crucial element is pinning of the three-phase contact line at chemical or geometric surface heterogeneities. The dynamical evolution of the surface nanobubbles then follows from the diffusion equation, Laplace's equation, and Henry's law. In particular, one obtains stable surface nanobubbles when the gas influx from the gas-oversaturated water and the outflux due to Laplace pressure balance. This is only possible for small enough surface bubbles. It is therefore the gas oversaturation ζ which determines the contact angle of the surface nanobubble or nanodroplet and not the Young equation. The talk reports on joint work with Xuehua Zhang

*Speaker

Electrostatic interaction between colloids trapped at an electrolyte interface

Arghya Majee * [1], Markus Bier, S. Dietrich

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Self-assembly of stably trapped colloidal particles at electrolyte interfaces has attracted much interest in recent years. For charge stabilized colloids at the interface, the attractive part of the interaction is dominated by strong van der Waals force which is balanced by a repulsive part coming from the electrostatic repulsion between the colloids. For large separations between the particles, this repulsive part of the interaction can be compared to a dipole-dipole interaction. However for distances close to the particle this simple dipolar picture cannot be applied. In this contribution we will consider the case of colloids situated very close to each other (inter-particle distance small compared to the size of the particles) at an electrolyte interface by using an appropriate model. After a brief discussion of the exact analytic solutions for the electrostatic potential as well as for the surface and line interaction energies under the linearized Poisson-Boltzmann (PB) theory [1], we will introduce non-linearity in the PB theory. Our numerical data shows strong quantitative as well as qualitative changes in the surface and line interaction energies between the two plates at short separation distances [2]. Moreover, a dependence of the line interaction energy on the solvation properties of the two media is observed which is overlooked by the linear theory. Our results contribute to an improved description of the interaction between colloidal particles trapped at fluid interfaces. [1] A. Majee, M. Bier, and S. Dietrich, J. Chem. Phys. **140**, 164906 (2014). [2] A. Majee, M. Bier, and S. Dietrich, in preparation.

*Speaker

Magnetic colloids in rotating fields: from chains through chaos to molecules and clusters

Craig Maloney * [1], Hamed Abdi, Rasam Soheilian, Randall Erb

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We present computer simulations and experiments on dilute suspensions of superparamagnetic particles subject to rotating magnetic fields. We focus on short chains of particles and their decay routes to stable structures. At low rate, the chains track the external field. At intermediate rate, the short chains break up but perform a periodic (albeit complex) motion. At sufficiently high rates, the chains generally undergo chaotic motion at short times and decay to either close-packed clusters or more dispersed colloidal"molecules" at long times. We show that the transition out of the chaotic states follows a first order reaction kinetics.

*Speaker

Ionic transport through hydrophobic nanopores: theory and experiments

Manoel Manghi * [1], B. Loubet, J. Palmeri, F. Picaud, S. Balme

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Fundamental understanding of ionic transport at the nanoscale is essential for developing biosensors based on nanopore technology and new generation high-performance nanofiltration membranes for separation and purification applications. We develop a mesoscopic theoretical approach for the electrolyte conductivity inside nanopores for various reservoir ionic concentrations. The model considers explicitly ion advection by electro-osmotic flow, possible flow slip at the pore surface, dielectric exclusion of the ions, important at low concentrations [1], and hard core repulsion between ions, shown to play a role for concentrations larger than 0.5 mol/L [2]. The theory is compared to experimental measurements of ionic transport through single putatively neutral hydrophobic nanopores with high aspect ratio (of length 6 μm with diameters ranging from 1 to 10 nm) and with a well controlled cylindrical geometry [3]. By fitting the experimental conductance data we show that for nanopore diameters greater than 4 nm a constant weak surface charge density of about 10^{-2} C/m^2 needs to be incorporated in the model to account for conductance plateaus of a few pico-siemens at low salt concentrations. For tighter nanopores, our analysis leads to a higher surface charge density, which can be attributed to a modification of ion solvation structure close to the pore surface. This is confirmed by molecular dynamics simulations. [1] Buyukdagli, Manghi, Palmeri, PRL 105 (2010) 158103; J. Chem. Phys. 134 (2011) 074706. [2] Loubet, Manghi, Palmeri, submitted (2016). [3] Balme et al. Scientific Reports 5 (2015) 10135.

*Speaker

Principles of a biomimetic kidney-on-a-chip for advanced nanofiltration

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The clear need in fresh water is one of the main challenges now faced by humanity. While water desalination and water recycling involve costly separation processes in terms of energy, the domain has been boosted over the last decades by the progresses made in membrane technology for water purification, such as reverse osmosis or nanofiltration, and more recently by the possibilities offered by nanoscale materials. In this paper we investigate the physical mechanisms underlying one of the most efficient filtration devices: the kidney. Building on a minimal model of the Henle Loop - the central part of the kidney filtration -, we investigate theoretically the detailed out-of-equilibrium fluxes in this separation process in order to obtain theoretical bounds for its efficiency in terms of separation ability and energy consumption. A key discovery is that this separation device operates at a remarkably small energy cost as compared to traditional sieving processes, while working at much smaller pressures This unique energetic efficiency originates in the serpentine geometry of the nephron, which operates as an active osmotic exchanger. The principles for such a "kidney on a chip" could be readily mimicked based on existing technologies to build compact and low-energy artificial dialytic devices. They also point to new avenues for advanced water recycling, in particular during sea-water pretreatment for decontamination and hardness reduction.

*Speaker

A statistical physics approach for the creep dynamics in soft matter

Kirsten Martens * [1], Chen Liu, Laura Foini, Jean-Louis Barrat

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One of the highly debated topics in the Soft Matter community is the so-called yielding transition [1], a dynamical phase transition that describes the deviation from a linear response behavior to non-linear flow as a response to external forcing. Many studies and most of the modeling concern the steady state dynamics for forcing at fixed rates or in a oscillatory manner. However, more recently there have been several experimental studies on the critical slowing down of the dynamics prior to yielding, when we apply a constant force. Interestingly these experiments are no longer limited to the measure of the global response, but the combination with light scattering techniques reveals information about the dynamics on the mesoscopic scale. On the theoretical side only few is known about the universality of these dynamics prior to failure or flow and their dependence on initial conditions, age and temperature. In this talk I will discuss possible generalizations of mesoscopic models that have been successfully used to describe the non-linear response at a constant forcing rate and I will introduce a new way of modeling creep dynamics in a mean-field manner in the spirit of the athermal local yield stress (ALYS) models [3], as opposed to formally considered descriptions based on the questionable existence of an effective temperature [4]. Interestingly, even strongly simplified models with only few model parameters are already able to reproduce the complex nonlinear transient behavior prior to flow. Within this framework I will focus on the effect of pre-shearing and aging on the athermal creep dynamics prior to yielding. [1] Driving rate dependence of avalanche statistics and shapes at the yielding transition, C. Liu, E.E. Ferrero, F. Puosi, J.-L. Barrat and K. Martens, Phys. Rev. Lett. 116, 065501 (2016). [2] Probing relevant ingredients in mean-field approaches for the athermal rheology of yield stress materials, F. Puosi, J. Olivier and K. Martens, Soft Matter 11, 7639 (2015). [3] Nontrivial rheological exponents in sheared yield stress fluids, E. Agoritsas and K. Martens, submitted to EPL, arXiv:1602.03484 (2016). [4] Rheology of athermal solids: Revisiting simplified scenarios and the concept of mechanical noise temperature, A. Nicolas, K. Martens and J.-L. Barrat, EPL 107, 44003 (2014).

*Speaker

The evolution of a granular labyrinthine phase across timescales

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Labyrinthine patterns arise in two-dimensional physical systems submitted to competing interactions, ranging from the fields of solid-state physics to hydrodynamics. Here we experimentally investigate a labyrinthine phase in an out-of-equilibrium system constituted of vibrated granular particles. Once sufficiently magnetized, they self-organize into short chains of particles in contact and randomly oriented. We quantitatively characterize the transition from a granular gas state to a labyrinthine phase, and we explain the formation of these chains using a simple model. Focusing on the time evolution of the labyrinthine phase, we describe the aggregation process leading to the formation of the chains at short times, and we identify a slow relaxation at long times. Indeed, the labyrinthine phase does not display any steady state: its morphology evolves with the aging time on very long timescales, due to strong structural rearrangements. We characterize this aging process and evaluate to what extent it is comparable to aging in structural glasses.

*Oral

Crystallization and self-assembly of dipolar particles

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The interaction between magnetic particles has always intrigued the human being. Such objects are ubiquitous in the everyday life at virtually all length scales (biology, nanotechnology, magnets for industry, the earth, etc.). It is well known from solid state studies that strongly confined (i.e., quasi two-dimensional or even one-dimensional) systems exhibit properties and a phase behavior that may drastically differ from those in the bulk. Such features are also vivid in colloidal systems, and those materials represent ideal model systems to analyze (experimentally as well as theoretically) and understand confinement effects on the mesoscopic scale. It will be shown that (macroscopic) dry granular systems can be used to quantitatively mimic the crystallization occurring in wet colloidal suspensions with repulsive dipolar particles in two dimensions. [1] This experimental study is corroborated by computer simulations borrowed from mesoscopic colloidal systems. The self-assembly of attractive dipolar particles will be addressed in a second part of the presentation. I will summarize recent progress achieved in the understanding of self-assembly of spherical magnets in three and two dimensions. The relevance of stacking rings in 3D [2] and onion-like structures in 2D [3] is emphasized. Our theoretical findings are easily reproduced experimentally with millimetric spherical magnets. [1] Messina, Aljawhari, Bécu, Schockmel, Lumay and Vandewalle, Sci. Rep. 5 10348 (2015). [2] Messina, Abou Khalil and Stankovic, Phys. Rev. E 89 011202 (2014). [3] Messina and Stankovic, Europhys. Lett. 110 46003 (2015).

*Speaker

Directed Self-assembly of Colloidal Crystal Growth on Engineered Templates with Activation Energy Gradients

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Achieving site-specific colloidal crystal nucleation and subsequent control over the size and symmetry of the growing crystallites is of considerable importance for a wide variety of applications that include structural colors, optoelectronics and composite materials. While for atomic and molecular systems, heteroepitaxy and/or epitaxy over the patterned templates allow for a significant control over the most of the above parameters, for micrometre-sized colloidal particles, owing to their slow dynamics, attempt to achieve control over these parameters continue to remain a challenge. Here, we design templates with activation energy gradients to achieve site-specific crystal nucleation. On these templates, colloidal particles migrate to the specific sites before nucleation and subsequent growth. Remarkably, nucleation kinetics on these templates resembles dislocation mediated growth in atomic heteroepitaxy. Moreover, our approach allows for tremendous control over the size as well as the morphology of the growing crystallites, a prerequisite for any potential technological use of these structures.

*Speaker

Process-directed self-assembly of copolymer materials

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The free-energy landscape of copolymer materials exhibits a multitude of metastable minima that correspond, e.g., to alternate periodic phases like hexagonally perforated lamellae, grain boundaries between domains of different orientations, or local defects. The barriers between these metastable states exceeds the thermal energy scale by far, resulting in protracted relaxation times. The thermodynamic stable morphology that corresponds to the absolute minimum often cannot be reached in experiments and simulations. Process-directed self-assembly refers to strategies that reproducibly direct the kinetics of self-assembly into a desired (meta)stable morphology by temporal control of thermodynamic variables [1], e.g., temperature or pressure. This strategy allows to access new morphologies, e.g., the bicontinuous I-WP network morphology [1], that do not correspond to stable bulk phases or control the orientation of the microphase-separated domains [3]. In order to exploit this strategy an understanding of the non-equilibrium self-assembly process and its underlying free-energy landscape is required. Using computer simulation of soft, coarse-grained models we illustrate different processing protocols, e.g., pressure jumps [1], solvent-annealing protocols [2], roll-casting [3], or spray coating, and demonstrate how the non-equilibrium, unstable initial condition dictates the spinodal kinetics of structure formation into a desired morphology. Since the initial kinetics occurs on the same time scale as the relaxation of the molecular conformations, chain conformations cannot be assumed to be in equilibrium with the instantaneous densities – an assumption that is invoked in dynamic self-consistent field calculations – but additional, unconventional order-parameters, e.g., the variance of the lowest Rouse-modes [3] or the fraction of bridges in multiblock copolymers, are required to characterize the rapid structure evolution out of a non-equilibrium state into the nearest metastable morphology. In addition to the free-energy landscape as a functional of the densities and the additional order parameters also the single-chain kinetics plays an important role for selecting the nearest metastable morphology [1,3]. [1] Directing the self-assembly of block copolymers into a metastable complex network phase via a deep and rapid quench, M. Müller and D.W. Sun, Phys. Rev. Lett. 111, 267801 (2013) [2] Defect removal in the course of directed self-assembly is facilitated in the vicinity of the order-disorder transition, W.H. Li, P.F. Nealey, J.J. de Pablo, and M. Müller, Phys. Rev. Lett. 113, 168301 (2014) [3] Alignment of copolymer morphology by planar step elongation during spinodal self-assembly, M. Müller and J. Tang, Phys. Rev. Lett. 115, 228301 (2015).

*Speaker

Capillary-like Fluctuations of a Solid-Liquid Interface in a Non-Cohesive Granular System

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One of the most noticeable collective motion of non-cohesive granular matter is clustering under certain conditions. In particular, when a quasi-two-dimensional monolayer of mono-disperse non-cohesive particles is vertically vibrated, a solid-liquid-like transition occurs when the driving amplitude exceeds a critical value. Here, the physical mechanism underlying particle clustering relies on the strong interactions mediated by grain collisions, rather than on grain-grain cohesive forces. In average, the solid cluster resembles a drop, with a striking circular shape. We experimentally investigate the coarse-grained solid-liquid interface fluctuations, which are characterized through the static and dynamic correlation functions in the Fourier space. These fluctuations turn out to be well described by the capillary wave theory, which allows us to measure the solid-liquid interface surface tension and mobility once the granular "thermal" kinetic energy is determined. Despite the system is strongly out of equilibrium and that the granular temperature is not uniform, there is energy equipartition at the solid-liquid interface, for a relatively large range of angular wave-numbers. Furthermore, both surface tension and mobility are consistent with a simple order of magnitude estimation considering the characteristic energy, length and time scales, which is very similar to what can be done for atomic systems.

*Speaker

Long-range nematic order and anomalous fluctuations in 2D suspension of swimming filamentous bacteria

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Collective motion of self-propelled elements, as seen in birds flocks, fish schools and bacterial swarms has driven physicists to search for its universal features and biological significance by constructing mathematical models. Many theoretical and numerical studies following the seminal work by Vicsek et al. have revealed universal properties of simplified flocking models (Vicsek-like models) such as giant number fluctuations in their homogeneous ordered states. Various experimental attempts have been made to illustrate Vicsek-like universality classes by using controllable systems simpler than birds and fish such as protein filaments driven by molecular motors, colloids consuming chemical or electric energy, shaken granular materials and common bacteria. However, no experiments so far have reproduced collective properties predicted by the studies on the Vicsek-like models, especially giant number fluctuations, in the true sense of their claims. Here we report experimental realization of a biological system that belongs to a Vicsek-like universality class. We observed giant number fluctuations in a true long-range nematically ordered state in a quasi-two-dimensional fluid layer with swimming filamentous bacteria obtained by inhibiting cell division using an antibiotic. Their high aspect ratios realized strong nematic interactions, leading to long-range ordered states. Our results provide an experimental foundation to many numerical and theoretical studies on collective motion. We anticipate our experiments to improve our understanding of collective bacterial phenomena such as collective behaviour for survival, including swarming, nutrient mixing and biofilm formation.

*Speaker

Dynamics of drops and bubbles in a confined space

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Recently, the dynamics of fluid drops has acquired considerable attention. We have been working on the dynamics, in particular, in a space confined in between two parallel plates, to find scaling laws, which is the focus of this presentation. In such a Hele-Shaw cell geometry, dimensional crossovers, self-similarity and role of liquid thin films appear as important issues, which are the key concepts of the presentation. We will discuss recent developments from the previous works, such as [1-3], which lead to a recent study on granular materials [4]. Associated with [3], we have recently found non-coalescence of a drop with a bath of the same liquid above a critical electric field, which is significantly lower than the previously reported non-coalescence in a non-confined three dimensional case [5-6]. We propose a simple phenomenological theory for the non-coalescence, which demonstrates a clear collapse of the experimental data. In addition, we found that a self-similar coalescence dynamics established in [3] is preserved even in the non-coalescence case, although the governing partial differential equations are completely different. We discuss the origin of self-similarity in the topological transition (i.e., coalescence), together with another self-similar dynamics we recently found for a singular cusp formation in a liquid bath confined in a Hele-Shaw cell. As for [2], we recently found a crossover of scaling regimes in the thin-film drag dynamics of fluid drops in the Hele-Shaw cell. The present results together with those in [2] imply three different forms of the quasi two-dimensional counterpart for Stokes' viscous drag friction, which will be useful for controlling drops in a confined space, for example, in the context of micro-fluidic applications. As for [1], we have been working on the bursting of a viscous bubble in a Hele-Shaw cell. We show a clear data collapse in the viscous regime of the dynamics by using the original theory and experimental data, together with eliminating scaling arguments associated with the local shape of the bursting front. These studies are results of collaboration with Maria Yokota, Marie Tani, Yuki Yamagishi, Hana Nakazato, Natsuki Kimoto, Misato Yahashi, and Mayuko Murano (all Ochanomizu University). [1] Ayako Eri and Ko Okumura. Bursting of a thin film in a confined geometry: Rimless and constant-velocity dewetting. Phys. Rev. E, 82(3):030601(R), 2010. [2] Ayako Eri and Ko Okumura. Viscous drag friction acting on a fluid drop confined in between two plates confined in between two plates. Soft Matter, 7:5648, 2011. [3] Maria Yokota and Ko Okumura. Dimensional crossover in the coalescence dynamics of viscous drops confined in between two plates. Proc. Nat. Acad. Sci. (U.S.A.), 108:6395, 2011. [4] Yuka Takehara and Ko Okumura. High-velocity drag friction in granular media near the jamming point. Phys. Rev. Lett., 112:148001, 2014. [5] W.D. Ristenpart, J.C. Bird, H.A. Stone et al., Non-coalescence of oppositely charged drops, Nature 461, 377 (2009). [6] J.C. Bird, W.D. Ristenpart, H.A. Stone et al., Critical angle for electrically driven coalescence of two conical droplets, Phys. Rev. Lett. 103, 164502 (2009).

*Speaker

Self-assembling topological structures

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Guiding the self-assembly of identical building blocks towards complex three-dimensional structures with a set of desired properties is a major goal in material science and physics. A particularly challenging problem is that of self-assembling structures with a target topology starting by simple geometrical properties of the blocks. Using molecular dynamics simulations we show that one can design the geometry of string-like rigid patchy templates with functionalised sticky ends to promote an efficient and reproducible self-assembly into a wide range of non trivial 3D closed structures including several knots. In particular, by tuning properly the parameters controlling the template geometry, we can direct the assembly process towards the formation of knots that are statistically dominant such as the trefoil, the pentafoil knot and more exotic knots of the torus family. Our results should be relevant to the design of new ways to synthetise molecular knots, which may prove, for instance, to be efficient cargo-carriers due to their mechanical stability.

*Speaker

Collective behavior and pattern formation in chemically active and actuated colloidal suspensions

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Actuated and autocatalytic colloids constitute systems that are intrisically out of equilibrium. As a result of their dynamic interactions, they can show a rich variety of self assembly scenarios. The observed self assembled structures make these systems very sensitive to external forcing, hence making actuated and active matter a fertile ground to explore and develop mechanically tunable materials. In this talk I will analyze the basic physical mechanisms that control the collective behavior of two kinds of colloidal particles that move in a liquid medium. On the one hand, the development of Janus colloids has opened the possibility to create synthetic microrobots that can move due to the chemical reacions they catalyze on their heterogeneous surfaces. The motion of chemically powered colloids is intricate because the chemically active colloids perturb the spatial distribution of the chemical species and also the state of motion of the solvent. As a result, suspensions of chemically active colloids are characterized by long range, non-equilibrium interactions. These dynamic interactions have a strong impact in the collective behavior of these suspensions. Confined magnetic colloids can also rectify their motion when actuated with a rotating magnetic field. I will describe the analogies and specificities in the hydrodynamic coupling that characterize these two types of systems and the different structures they spontaneously form. References: B. Liebchen, D. Marenduzzo, I. Pagonabarraga, M.E. Cates, Phys. Rev. Lett. 115, 258301 (2015) F. Martinez-Pedrer, A. Ortiz-Ambriz, I. Pagonabarraga, P. Tierno, Phys. Rev. Lett. 115, 138301 (2015) A. Scagliarini, I. Pagonabarraga, submitted

*Speaker

Decompaction dynamics of wet granular materials under thermal cycling

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We study the effect of liquid volume fraction on the packing dynamics of wet granular materials under thermal cycling. Dilation of water between the particles due to the thermal nature of the driving force can change the configuration of the pile during the freezing and melting. Our results show that beyond the remarkable attraction capillary force, independently of the initial packing fraction, the granulate tend to converge to the random loose packing configuration which obeys an inverse exponential law related to the liquid volume fraction. The onset and the average rate of decompaction show an exponential dependence on the liquid volume fraction. We have shown that the packing dynamics can be well modeled within a model of an overdamped particle in a tilted potential. It means the granular pile under Laplace pressure is affected by a deep potential which prevents the rearrangement of the grains. In this case the liquid volume fraction controls the required energy to escape the barrier to lead the system to the stable state.

*Speaker

Simple Active Nematic: the role of the repulsion

Aurelio Patelli * [1], Hugues Chaté, Ilyas Djafer-Cherif, Eric Bertin, Igor Aranson

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Our work focuses on the rich dynamics of active rods-like particles repelling each other. An active particle is a particle that, getting energy from the environment, generates a preferred motion, such as a motion at a constant velocity amplitude. A collection of these particles just aligning with the neighbor ones is able to produce a non-equilibrium dynamics, i.e. collective motion phase transition in 2 dimensions, as seen in scales ranging from the bacteria to fish and robots. Specifically, we consider active particles with an nematic alignment interaction and a short range repulsion with the possibility of flipping their velocity direction with a given rate. This scenario comes from an idealization of those particles in experiments and we describe the richness of the phase diagram using different techniques: molecular dynamics simulations, theoretical analysis of the hydrodynamic equations and numerical simulations of the latter. More emphasis will be put on the theoretical results and on their comparison to what is known and seen at the numerical level. In detail we describe the behavior of topological defects appearing in the model and inhomogeneous solution of the continuum equations and our knowledge and question around them.

*Speaker

Effective interactions between chemically active particles and fluid interfaces

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In the last decade significant attention has been paid to micrometer sized particles capable of self-induced motility by promoting at their surfaces catalytically activated chemical reactions in the surrounding solution. They are seen as promising candidates for the development of novel techniques such as chemical sensing or water treatment. There are many application relevant cases in which the suspension containing active colloids is bounded by a fluid-fluid interface, and thus the colloidal particles may reside in the vicinity of the interface or get near the interface during their motion. Here we present theoretical evidence that, in such a case, chemically active (or locally heated) spherical particles experience a very strong, long-ranged effective force field due to the Marangoni stresses self-induced at the interface [1]. This force of hydrodynamic origin gives rise to a drift of the particle towards or away from the fluid interface (depending only on how the tensioactive agent affects the interface) on time scales which can be orders of magnitude shorter than those associated with Brownian diffusion. In particular, this can facilitate significantly the process of particle adsorption towards the interface and therefore has potentially important implications for, e.g., the subsequent self-assembly of particles at fluid–fluid interfaces.
[1] A. Dominguez et al, Phys. Rev. Lett., in press (2016)

*Speaker

Self-assembly of capillary multipoles

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Self-assembly of floating particles driven by capillary forces at some liquid-air interface leads to the formation of two-dimensionnal structures. Using a 3d printer, millimeter scale objets are produced. Their 3d shape is chosen in order to create capillary multipoles. The capillary interactions between these components can be either attractive or repulsive depending on the interface local deformations along the liquid-air interface. In order to understand how the shape of an object deforms the interface, we developed an original profilometry method. The measurements show that specific structures can be programmed by selecting the 3d branched shapes.

*Speaker

Suspensions of non colloidal particles in complex fluids

Olivier Pouliquen * [1], S. Dagois-Bohy, S. Hormozi, F. Madraki, E. Guazzelli

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Despite its long research history and its practical relevance, the mechanics of dense suspensions remains poorly understood. In this study, the rheology of mixture of rigid non colloidal particles in complex fluids is experimentally investigated. We will show that adding particles might be a strategy to control the properties of the complex fluids. Suspension in a yield stress fluid is first studied using an original " pressure imposed " rheometer. Empirical constitutive laws can be proposed, which can be rationalized in the framework of a mean field theory. The case of a suspension in a shear thickening fluid will also be presented.

*Speaker

Breakdown of Nonlinear Elasticity in Amorphous Solids at Finite Temperatures

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It is known by now that amorphous solids at zero temperature do not possess a nonlinear elasticity theory: besides the shear modulus, which exists, all the higher order coefficients do not exist in the thermodynamic limit. Here we show that the same phenomenon persists up to temperatures comparable to the glass transition temperature. The zero temperature mechanism due to the prevalence of dangerous plastic modes of the Hessian matrix is replaced by anomalous stress fluctuations that lead to the divergence of the variances of the higher order elastic coefficients. The conclusion is that in amorphous solids elasticity can never be decoupled from plasticity: the nonlinear response is very substantially plastic.

*Speaker

Simulating emergent phenomena in soft-matter systems

D. C. Rapaport * [1]

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Emergent phenomena are especially fascinating because they are not obvious consequences of the design of the systems in which they appear, a characteristic equally relevant when attempting to simulate them. Examples from the field of soft matter that exhibit surprisingly rich emergent behavior will be described, each studied by MD (molecular dynamics) simulation [J. Phys.: Condens. Matter 26 (2014) 503104]. (a) Modeling self-assembly processes associated with virus capsid growth reveals the ability to achieve complete, error-free shells, where paradoxically, high yields are due to reversible bond formation. (b) Studies of granular mixtures show behavior that, in the case of a rotating drum, reproduces known but counterintuitive axial and radial segregation, and in the case of a vertically vibrated layer, predicts a novel form of horizontal segregation. (c) In fluids simulated at the atomistic level, not only can complex hydrodynamic phenomena in convecting and rotating fluids - the Rayleigh-Benard and Taylor-Couette instabilities - be reproduced within the limited length and time scales accessible to MD, but there is even quantitative agreement. While MD is subject to limitations, both conceptual and computational, the results offer exciting indications of what can be accomplished.

*Speaker

Low-temperature behavior of the dipolar hard sphere fluid

Michela Ronti * [1], Alexey O. Ivanov, Lorenzo Rovigatti, Francesco Sciortino, Sofia S. Kantorovich

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We describe the self-assembly in magnetic nanocolloids by using a dipolar hard sphere (DHS) model. A DHS consists of a point dipole embedded in the center of a hard sphere that generates long-range anisotropic interactions. At low temperature DHS particles self-assemble into complex structures, with primary structures composed by rings and chains; understanding the emerging structures of the system is fundamental for designing new magnetic fluids-based devices for technological and medical applications. We base our theoretical approach on classical Density Functional Theory, an approach that is able to capture the density and temperature dependence of the ring-chain equilibrium.[1] In order to estimate the ability of the theory to predict (i) the cluster size distribution of rings and chains at different values of the temperature and (ii) the individual cluster partition functions, we perform grand-canonical Monte Carlo simulations. We introduce specialized Monte Carlo biased moves, which favor the breaking and reforming of bonds. The knowledge of the cluster partitions functions, together with our analytical approach, allows us to calculate the free energy of systems at low-to-intermediate densities, where the clusters can be considered as weakly interacting.[2] We confirm that for low concentrations and low temperatures, the majority of magnetic nanoparticles is aggregated in rings; for higher concentrations, low temperature clusters merge together into more complex branched structures, characterized by junctions between chains and rings. Our results will allow us to describe the next hierarchical level of self-assembly in magnetic nanocolloids: the aggregation of basic branched clusters into complex networks. [1] S.S. Kantorovich, A.O. Ivanov, L. Rovigatti, J.M. Tavares and F. Sciortino,*Phys. Chem. Chem. Phys.* **17**, 16601 (2015) [2] M. Ronti, A.O. Ivanov, L. Rovigatti, F. Sciortino and S.S. Kantorovich, in preparation

*Speaker

Salt-controlled phase behavior and crystallization pathways in protein solutions

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We present an explicit cation-activated mechanism for patchy attractions between proteins [1], which induces a reentrant phase behavior providing tunable conditions for crystal nucleation. Experimentally, ion bridges of multivalent cations between protein molecules have been observed in protein crystals [2]. Modelling this mechanism via particles with ion-activated attractive patches, a broad variety of experimental results in solutions of globular proteins with multivalent cations is explained and understood very naturally, including charge inversion, reentrant condensation, metastable liquid-liquid phase separation (LLPS), cluster formation and crystallization conditions [1,3]. The protein-cation interaction is characterized as entropically driven, consistent with the observed lower-critical solution temperature of the LLPS [4]. Exploiting the cation-controlled attraction, one-step and two-step pathways of crystal nucleation could be induced and monitored in real time [5]. The overall good agreement between theory and experiments indicates that protein-cation solutions represent a natural model system for patchy particles. The mechanism of ion-activated patches promises rational design of phase behavior and crystallization pathways, and can be embedded seamlessly into theory and simulations of soft matter. // [1] F Roosen-Runge, F Zhang, F Schreiber, R Roth, Scientific Reports 4, 7016 (2014). [2] F Zhang, G Zocher, A Sauter, T Stehle, F Schreiber, J. Appl. Cryst. 44, 755-762 (2011). [3] F Zhang, R Roth, M Wolf, F Roosen-Runge, et al., Soft Matter 8, 1313-1316 (2012). [4] O Matsarskaia, M Braun, F Roosen-Runge, M Wolf, F Zhang, R Roth, F Schreiber, submitted. [5] A Sauter, F Roosen-Runge, F Zhang, G Lotze, RMJ Jacobs, F Schreiber, J. Am. Chem. Soc. 137, 1485-1491 (2015).

*Speaker

Can random pinning change the melting scenario in two dimensions?

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Despite almost 40 years of investigations, controversy about the microscopic nature of melting in two dimensions still exists. In the widely accepted Kosterlitz-Thouless-Halperin-Nelson-Young (KTHNY) theory [1-3] it is supposed, that in contrast to the 3D case, where melting is the first-order transition, the 2D melting can occur through two continuous transitions with the new intermediate phase with quasi-long-range orientational order, which is called the hexatic phase. On the other hand, in two dimensions first-order melting without a hexatic phase is also possible [4-5]. Numerous experimental and simulation studies demonstrate that systems with very short-range or hard-core potentials melt through a weak first order transition, while the melting scenarios for soft repulsive particles favor the KTHNY theory. Recently, a number of papers have appeared in which another melting scenario was proposed [6-7]. It was argued that for the hard-core systems a two-stage melting transition takes place, with a continuous solid-hexatic transition and a first-order hexatic-liquid one. In order to clarify this issue, we present a computer simulation study of the phase diagram of 2D particles interacting through an isotropic core-softened potential [8-9]. Potentials of this type are widely used for the qualitative description of systems with waterlike anomalies. In experiments two-dimensional systems are realized mainly on solid substrates, which introduce quenched disorder due to some inherent defects. The defects of substrates influence the melting scenario of the systems and have to be taken into account in the interpretation of experimental results [10]. We present the results of molecular dynamics simulations of a two-dimensional system with a core-softened potential in which a small fraction of the particles is pinned, inducing quenched disorder. In our previous publications it was shown [11-14] that without random pinning the system demonstrates an anomalous melting scenario: at low densities where the effective potential is soft the system melts through two continuous transitions in accordance with the KTHNY theory with an intermediate hexatic phase, while at high densities the conventional first-order melting transition takes place. We find that the well-known disorder-induced widening of the hexatic phase occurs at low densities [10], while in the high-density part of the phase diagram random pinning transforms the first-order melting into two transitions: a continuous KTHNY-like solid-hexatic transition and a first-order hexatic–isotropic liquid transition [14]. We expect that such a phenomenology can be checked in confined monolayers of charge-stabilized colloids with a softened core and water confined between two hydrophobic plates. The work was supported by the Russian Science Foundation (Grant No 14-12-00820). References [1] D. R. Nelson, B. I. Halperin, Phys. Rev. B 19, 2457 (1979). [2] A. P. Young, Phys. Rev. B 19, 1855 (1979). [3] M. Kosterlitz, D. J. Thouless, J. Phys. C 6, 1181 (1973). [4] S. T. Chui, Phys. Rev. B 28, 178 (1983). [5] V. N. Ryzhov, Zh. Eksp. Teor. Fiz. 100, 1627 (1991) [Sov. Phys. JETP 73, 899 (1991)]. [6] E. P. Bernard and W. Krauth, Phys. Rev. Lett. 107, 155704 (2011). [7] S. C. Kapfer and W. Krauth,Phys. Rev. Lett. 114, 035702 (2015). [8] Yu. D. Fomin, N. V. Gribova, V. N. Ryzhov, S. M. Stishov, Daan Frenkel, J. Chem. Phys. 129, 064512 (2008). [9] Yu. D. Fomin, E. N. Tsiok, V. N. Ryzhov, Phys. Rev. E 87, 042122 (2013). [10] D. R. Nelson, Phys. Rev. B 27, 2902 (1983). [11] D. E. Dudalov, Yu. D. Fomin, E. N. Tsiok, V. N. Ryzhov, Journal of Physics: Conference Series 510, 012016 (2014). [12] D. E. Dudalov, Y. D. Fomin, E. N. Tsiok, V. N. Ryzhov, Soft Matter 10, 4966 (2014). [13] D. E. Dudalov, Y. D. Fomin, E. N. Tsiok, V. N. Ryzhov, J. Chem. Phys. 141, 18C522 (2014). [14] E. N. Tsiok, D. E. Dudalov, Y. D. Fomin, V. N. Ryzhov, Phys. Rev. E 92, 032110 (2015).

*Speaker

Intermittent avalanche dynamics of slow imbibition fronts

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We have developed an experimental study of the dynamics of a viscous wetting fluid interface forced to invade a disordered medium –a model open fracture– at constant flow rate. Distortions of the advancing imbibition front produced by capillary pressure fluctuations (due to the heterogeneities of the medium) are damped by interfacial tension and fluid viscosity. The competition of those stabilizing and destabilizing forces operating at different length scales leads to a kinetic roughness process characterized by critical interfacial fluctuations and a collective avalanches dynamics. Using fast and high-resolution imaging, we could show that the imbibition front motion takes place by localized bursts, whose lateral sizes, areas and durations are power-law distributed up to a cut-off scale, which diverges as the Capillary number of the displacement decreases Ca –¿0, corresponding to a critical depinning transition. Those capillary bursts triggered from the smallest scale of the disorder up to the scale at which viscous dissipation becomes dominant lead to anomalous Gumbel-like fluctuations, and a strongly intermittent –turbulent-like– behavior of the global invasion process.

*Speaker

Minimal entropy production in nematic liquid crystals subject to external dissipative fields such as temperature and velocity gradients

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Due to the lower symmetry, transport phenomena in liquid crystals are much richer than in isotropic liquids. In an axially symmetric nematic liquid crystal, where the molecules are approximately oriented in the same direction in space - the director - the heat conductivity has two independent components - parallel and perpendicular to the director - and the viscosity is a fourth rank tensor with seven independent components. Therefore, the heat flow and the shear stress and thereby the irreversible entropy production vary with the orientation of the director relative to a temperature gradient or a velocity gradient. Simulations of liquid crystal model systems consisting of soft ellipsoids have shown that the director tends to align perpendicularly to a temperature gradient. Since the heat conductivity is lower in the perpendicular direction than in the parallel direction this means that the heat flow is minimized. In shear flows at low shear rates in the linear Newtonian regime it has been observed both by theoreticians and by experimentalists that the director assumes an orientation angle that approximately minimizes the shear stress, even though this does not follow from the linear relation between the pressure and the velocity gradient. However, in planar elongational flow, where the system is elongated in one direction and contracted in the perpendicular direction, it follows directly from this linear relation that the director must orient either parallel or perpendicularly to the elongation direction because of mechanical stability and that the irreversible entropy production is either maximal or minimal in these orientations. Simulations have shown that the elongation direction is stable and that the irreversible entropy production is minimal in this orientation. Thus we have three examples where the director of a nematic liquid crystal subject to an external dissipative field assumes an orientation that minimizes the irreversible entropy production.

*Speaker

Defect-mediated melting of two-dimensional colloidal quasicrystals

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Quasicrystals are structures that possess long range order but no translational symmetry. Due to additional degrees of freedom in quasicrystals there are properties and phenomena that for quasicrystalline structures significantly differ from their counterpart in periodic crystals (cf. [1]).
We study how thermally excited excitations or defects develop in two-dimensional colloidal quasicrystals close to the melting transition. According to an extension of the KTHNY theory [2], the formation and dissociation of pairs of dislocation and disclinations is expected to cause the melting of the quasicrystal. Melting should occur via an intermediate phase termed pentahedratic phase [2].
By using Monte-Carlo and Brownian dynamics simulations and by analyzing the positional and bond-orientational correlation functions during the melting process of a decagonal quasicrystal we reveal an intermediate state with quasi-long ranged orientational order but only short ranged positional order as in the predicted pentahedratic phase. Furthermore, we observe network-like structures composed of defects spanning through defect-free areas as well as a coexistence between the intermediate phase and the fluid. Note that a similar coexistence has been reported for periodic crystals [3].

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*Speaker

Rigid cluster decomposition reveals criticality in frictional jamming

J. M. Schwarz * [1], Silke Henkes, D. A. Quint, Y. Fily

[1] Syracuse University – United States

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

*Speaker

Using a pre-stretching force to reduce the variance of highly driven polymer translocation

David Sean * [1], Gary W. Slater, Hendrick W. de Haan

[1] University of Ottawa – Canada

Driven translocation of DNA through a nanopore, however promising as a technology, has yet to become the method of choice for DNA sequencing and analysis. Even with the use of monodisperse polymers, the distribution of translocation times remains relatively large—a phenomenon largely due to "molecular individualism". The initial polymer conformation at the onset of translocation significantly affects the final translocation time. Using coarse-grained Langevin dynamics simulations, we test how the conformational space can be reduced by applying a pre-stretching force on the two polymer ends before and during the translocation process. Furthermore, the polymer is driven through the pore by simply increasing the magnitude of one of the two forces such that the polymer drifts towards the trans-side. Our simulations allow for an independent control of the two sources of fluctuations: Brownian noise (via k_BT) and conformational noise (via the pre-stretching force). We present the resulting effect on the variance of translocation times across the various regimes, accompanied by theoretical predictions from Tension-Propagation theory.

*Speaker

From Polymers to Proteins: effect of side-chains and broken symmetry in the formation of secondary structure within Wang-Landau approach

Tatjana Skrbic * [1], Artem Badasyan, Trinh Xuan Hoang, Rudolf Podgornik, Achille Giacometti

[1] University of Venice – Italy

We use micro-canonical Wang-Landau techniques to study the equilibrium properties of a flexible homopolymers where consecutive monomers are represented by impenetrable hard spherical beads tangential to each other, and non-consecutive monomers interact via a square-well potential. To mimic the characteristic of a protein-like system, the model is then refined in two different directions. By allowing partial overlapping between consecutive beads, we break the spherical symmetry and thus provide a severe constraint on the possible conformations of the chain. Alternatively, we introduce additional spherical beads at specific positions in the direction normal to the backbone, to represent the steric hindrance of the side chains in real proteins. Finally, we consider also a combination of these two ingredients. In all three systems, we obtain the full phase diagram in the temperature-interaction range plane and find the presence of helicoidal structures at low temperatures in the intermediate range of interaction. The effect of the range of the square-well attraction is highlighted, and shown to play a role similar to that found in simple liquids and polymers. Perspectives in terms of protein folding are finally discussed.
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*Speaker

Self-assembled active colloidal molecules

Rodrigo Soto * [1], Ramin Golestanian

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Catalytically active colloids maintain non-equilibrium conditions in which they produce and deplete chemicals and hence effectively act as sources and sinks of molecules. While individual colloids that are symmetrically coated do not exhibit any form of dynamical activity, the concentration fields resulting from their chemical activity decay as $1/r$ and produce gradients that attract or repel other colloids depending on their surface chemistry and ambient variables. This results in a non-equilibrium analogue of ionic systems, but with the remarkable novel feature of action-reaction symmetry breaking. We study solutions of such chemically active colloids in dilute conditions when they join up to form molecules via generalized ionic bonds. Colloids are found to join up to form self-assembled molecules that could be inert or have spontaneous activity in the form of net translational velocity and spin depending on their symmetry properties and their constituents. The type of activity can be adjusted by changing the surface chemistry and ambient variables that control the surface reactions and the phoretic drift. As the interactions do satisfy detailed-balance, it is possible to achieve structures with time dependent functionality. In particular, we study a molecule that adopts a spontaneous oscillatory pattern of conformations, and another that exhibits a run-and-tumble dynamics similar to bacteria. Our study shows that catalytically active colloids could be used for designing self-assembled structures that posses dynamical functionalities that are determined by their prescribed 3D structures.

*Speaker

Relaxation dynamics of colloidal networks

M. M. Telo Da Gama * [1], C. S. Dias N. A. M. Araujo

[1] University of Lisbon – Portugal

The kinetic pathways for the assembly of equilibrium macroscopic colloidal structures are characterized by multiple metastable configurations where the systems are easily trapped [1]. Here, we investigate the relaxation of non-equilibrium networks of patchy colloids towards equilibrium. We performed extensive Langevin dynamics simulations, where translational and rotational diffusion of single colloids and aggregates are considered. We simulated hours of physical time what allowed us to identify novel mechanisms of relaxation. We first considered patchy-colloid aggregation near an attractive substrate [2]. We identified fast and slow relaxation modes with a nontrivial dependence on the substrate coverage. We also considered three dimensional networks of patchy colloids in the bulk at different temperatures. We found exponential and scale free relaxation regimes depending on the temperature, in the absence or presence of a gel. [1] C. S. Dias, N. A. M. Araújo, and M. M. Telo da Gama, EPL, 107, 56002 (2014). [2] C. S. Dias, C. Braga, N. A. M. Araújo, and M. M. Telo da Gama, Soft Matter, 12, 1550 (2016).

*Speaker

Influence of mechanical vibrations on granular friction

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We investigate experimentally the influence of mechanical vibrations on granular friction. The experimental setup consists of a slider pulled at constant velocity via a cantilever spring over a granular layer. The slider mass, spring stiffness and pulling velocity are chosen such that without mechanical perturbances, the slider exhibits a classical stick-slip motion. Horizontal vibrations are then applied to the whole system. When increasing either the amplitude A or frequency ω of the vibrations, the amplitude of the stick-slip motion decreases, until the system exhibits a transition to a continuous slip motion. Previous numerical studies pointed out the acceleration of imposed vibrations as the governing parameter for the transition, with a value of the order of the gravitational acceleration. In contrast to these results, we show that the quantity that controls the frictional properties is the characteristic velocity $A\omega$, and not the acceleration $A\omega^2$, of the imposed mechanical vibrations. The critical velocity at which the system undergoes the transition to a continuous slip motion is very small, of the order of 100 μm/s. Thus, when the system is statically loaded, the typical acceleration of the vibrations which trigger large slip events is much smaller than the gravitational acceleration. These results may be relevant to understand dynamic earthquake triggering by small ground perturbations.

*Speaker

Chirality-induced helical self-propulsion of cholesteric liquid crystal droplets

Takaki Yamamoto * [1], Masaki Sano

[1] the University of Tokyo – Japan

Artificial swimmers have been intensively studied to understand the mechanism of the locomotion and collective behaviors of cells and microorganisms. Among them, most of the artificial swimmers are designed to move along the straight path. However, in biological systems, chiral dynamics such as circular and helical motion, are quite common because of the chirality of their bodies, which are made of chiral biomolecules. To understand the role of the chirality in the physics of microswimmers, we designed chiral artificial swimmers and the theoretical model for the chiral motion[1]. Recently, Herminghaus et al. reported that nematic liquid crystal droplets dispersed in a surfactant solution swims spontaneously due to the Marangoni effect[2]. Meanwhile, the cholesteric liquid crystal (CLC), which shows a helical director field due to the chirality of molecules, undergoes rotational motion when subjected to external fields such as a temperature gradient[3]. This rotational motion is explained as a result of the coupling between rotational motion and external field only allowed in chiral systems. Hence, a CLC droplet in a surfactant solution can swim in a chiral path owing to the chiral coupling between the Marangoni flow and rotational motion. As a result, we have discovered that CLC droplets, when dispersed in surfactant solutions, swim in the helical path induced by the Marangoni effect. Furthermore, we confirmed that the handedness of the CLC droplet determines that of the helical path. This result strongly suggests that the helical motion is originated from the chirality of the CLC. To study the mechanism of the emergence of the helical motion, we propose a coupled time-evolution equations in terms of a velocity, an angular velocity and a tensor variable[4] representing the symmetry of the helical director field of the droplet. Our model shows that the chiral coupling terms between the velocity and the angular velocity play a crucial role in the emergence of the helical swimming of the CLC droplet. [1] Takaki Yamamoto and Masaki Sano, submitted to Phys. Rev. Lett. [2] S. Herminghaus, et al., Soft Matter, 10, 7008 (2014). [3] T. Yamamoto, et al., Europhys. Lett., 109, 46001 (2015). [4] M. Tarama, et al., Prog. Theor. Exp. Phys., 013A01 (2013).

*Speaker

Moving in a mobile crowded environment: anomalous dynamics beyond the Lorentz gas model

Emanuela Zaccarelli * [1]

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Many natural and industrial processes rely on constrained transport, such as proteins moving through cells, particles confined in nanocomposite materials and gels, individuals in highly dense collectives. These are examples of motion through crowded environments, in which the host matrix may retain some glass-like dynamics. In this talk I will present recent results[1] on constrained transport in a colloidal model system of a slowly rearranging environment, in which dilute small spheres move in a glassy matrix of large spheres. This system is conceptually close to the classical Lorentz gas model.
Using confocal differential dynamic microscopy we are able to resolve the small particles collective dynamics, discovering the appearance of anomalous transport, manifested as a logarithmic decay of the density autocorrelation functions. Molecular dynamics simulations confirm this picture, providing evidence of the existence of a critical size asymmetry for the occurrence of the anomalous behavior. By comparing mobile and immobile matrix environments, simulations also show that the dynamics of the small particles is profoundly altered, in a qualitative way, by the continuous evolution of channels in the mobile matrix, due to the thermal motion of large particles. This turns the power-law behavior expected for the Lorentz model, which is typical for systems close to a percolation transition, to a novel logarithmic decay. While the appearance of logarithmic dynamics has been previously attributed to the presence of competing glass transitions, as suggested by Mode Coupling Theory (MCT), in the present case MCT cannot capture the experimental and numerical behavior. Since a mobile matrix corresponds to an environment in which small intruders move in many real systems and applications, we expect that our findings will inspire the development of a more realistic description of these situations and will stimulate new theoretical studies, combining aspects of both percolation and glassy dynamics.

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*Speaker

Electrolytes at the interface: charge stabilization in colloids, emulsions and polymer blends.

Jos Zwanikken * [1]

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Electrolytes play a vital role in numerous biological processes, and are key to the stability of many systems in Soft Condensed Matter, such as colloids, emulsions, and solutions of charged macromolecules. Since the work of Gouy, Chapman, Debye, Kirkwood et al., it is well known that ions 'screen' the interactions between charged solutes, and that elevated salt concentrations can induce aggregation, an effect also known as 'salting-out'. About three decades ago, however, it became clear that this picture is too simplistic after simulations and experiments had indicated that ions can also induce attractions between like-charged solutes. I will discuss that ion-ion correlations are an important missing factor in the classical picture, and that the ignored 'cohesion' of the ion cloud can induce effects opposite to basic screening. We study ions in a narrow confinement with simulations (Car-Parrinello Molecular Dynamics), and with liquid state theory (Ornstein-Zernike with the anisotropic HNC closure), and find strong density oscillations and a liquid-like structure of ions for parameters that correspond to aqueous solutions of 0.1 M concentrations [1]. Ion-induced interactions between colloidal particles are calculated, and are found to be repulsive, attractive, or both, depending on the specific ion parameters and dielectric properties of the colloids. The ion-induced attractions are verified in experiments using nanoparticles functionalized with non-complementary DNA. In a similar fashion, one can shift the phase diagram of polyelectrolyte blends and block-copolymers in multiple directions by changing the ionic properties, as concluded from a hybrid Liquid-State Self-Consistent Field Theory (LS-SCFT) [2,3]. These correlational effects can be interpreted as the consequence of two 'thermal forces' that originate from direct interaction and the brownian motion of the ions. A generalization of these concepts to driven systems, and solutions with 'memory' could be most relevant for the development of soft ionic materials. Inspiration can be gleaned from recent developments in the field of Active Matter. [1] Ionic structure in liquids confined by planar dielectric interfaces Yufei Jing, Vikram Jadhao, Jos W. Zwanikken and Monica Olvera de la Cruz, JCP (2015) [2] Electrostatic Control of Block Copolymer Morphology Charles E. Sing, Jos W. Zwanikken and Monica Olvera de la Cruz, Nat. Mater. 13, 694–698 (2014) [3] Theoretical Analysis of Multiple Phase Coexistence in Polyelectrolyte Blends Ha-Kyung Kwon, Jos W. Zwanikken, Kenneth R. Shull, and Monica Olvera de la Cruz, Macromolecules (2015)

*Speaker

Topic 7: Nonlinear Physics -Oral

A purely elastic subcritical instability in parallel shear flows at low Re

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It is a common assumption that, in the absence of inertia (and curvature), the flow of a visco-elastic fluid is linearly stable to flow perturbations. Recent evidence, however, suggests that such flow may be unstable to a finite amplitude perturbation. This type of instability is akin to the transition from laminar to turbulent flows in ordinary Newtonian fluids where the control parameter is the Reynolds number (Re). In this talk, we present evidence of a subcritical nonlinear instability for the flow of a dilute polymeric solution in a parallel channel flows using a microfluidic device where the control parameter is the Weissenberg number (Wi). The dimensions of the microchannel are small enough (100 μm wide x 100 μm deep and 2.5 cm long) such that inertial effects are negligible. The flow is investigated using both dye advection and particle tracking velocimetry. Results show large (sustained) velocity fluctuations far downstream (2 cm) away from the initial perturbation for strong enough disturbances; small disturbances decay quickly under the same flow conditions. A hysteresis loop, characteristic of subcritical instabilities, is observed. We also find signatures of "elastic turbulence", characterized by non-periodic velocity fluctuation that are observed both in the wake of cylinders and far downstream in the parallel shear region. The flow in both regions is excited over a broad range of frequencies and wavelengths, consistent with the main features of elastic turbulence observed in Taylor-Couette systems.

*Speaker

The Spectrum of Wind Power Fluctuations

Mahesh M. Bandi * [1]

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Wind is a variable energy source whose fluctuations threaten the stability of the electrical grid, thereby necessitating increased ancillary reserves to maintain grid integrity. Further complications arise when this fluctuating power must be dynamically balanced against a fluctuating consumer demand. The power generated by a wind turbine fluctuates due to the variable wind speed that blows past the turbine. Indeed, the spectrum of wind power fluctuations is widely believed to reflect the Kolmogorov spectrum of atmospheric turbulence; both vary with frequency f as $f^{-5/3}$. This variability decreases when geographically distributed wind farms feed power to the grid and aggregate power fluctuations are averaged via a mechanism known as geographic smoothing. Despite the costs associated with variability, neither the $f^{-5/3}$ wind power fluctuation spectrum nor the mechanism of geographic smoothing are understood. In this work, we explain the wind power fluctuation spectrum from the turbine through grid scales. The $f^{-5/3}$ wind power fluctuation spectrum results from the largest length scales of atmospheric turbulence of order 200 km influencing the small scales where individual turbines operate. This long-range influence spatially couples geographically distributed wind farms and synchronizes farm outputs over a range of frequencies and decreases with increasing inter-farm distance. Consequently, aggregate grid-scale power fluctuations remain correlated, and are smoothed until they reach a limiting $f^{-7/3}$ spectrum beyond which further smoothing becomes impossible. I will close with engineering and policy implications of these results.

*Speaker

Superstatistical approach to Lagrangian quantum turbulence

Christian Beck * [1], Shihan Miah

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Many complex driven nonequilibrium systems are effectively described by a superposition of several statistics on well-separated time scales, in short a 'superstatistics'[1,2]. A simple example is a Brownian particle moving in a spatially inhomogeneous medium with temperature fluctuations on a large scale, but the concept is much more general. Superstatistical systems typically have marginal distributions that exhibit fat tails, for example power law tails or stretched exponentials. In most applications one finds three relevant universality classes: Log-normal superstatistics, chi-square superstatistics and inverse chi-square superstatistics. These can be effectively described by methods borrowed from nonequilibrium statistical mechanics. In this talk I will concentrate on some applications of this concept to better understand the statistics of tracer particles embedded in a) classical fully developed turbulent flows [3] and b) turbulent quantum liquids [4,5]. [1] C. Beck and E.G.D. Cohen, Physica A 322, 267 (2003) [2] C. Beck, E.G.D. Cohen, and H.L. Swinney, Phys. Rev. E 72, 056133 (2005) [3] C. Beck, Phys. Rev. Lett. 98, 064502 (2007) [4] C. Beck and S. Miah, Phys. Rev. E 87, 031002(R) (2013) [5] S. Miah and C. Beck, EPL 108, 40004 (2014)

*Speaker

A dissipative random velocity field for fully developed fluid turbulence

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We investigate the statistical properties, based on numerical simulations and analytical calculations, of a recently proposed stochastic model for the velocity field of an incompressible, homogeneous, isotropic and fully developed turbulent flow. A key step in the construction of this model is the introduction of some aspects of the vorticity stretching mechanism that governs the dynamics of fluid particles along their trajectory. An additional further phenomenological step aimed at including the long range correlated nature of turbulence makes this model depending on a single free parameter that can be estimated from experimental measurements. We confirm the realism of the model regarding the geometry of the velocity gradient tensor, the power-law behaviour of the moments of velocity increments (i.e. the structure functions), including the intermittent corrections, and the existence of energy transfers across scales. We quantify the dependence of these basic properties of turbulent flows on the free parameter and derive analytically the spectrum of exponents of the structure functions in a simplified non dissipative case. A perturbative expansion in power of this free parameter shows that energy transfers, at leading order, indeed take place, justifying the dissipative nature of this random field.

*Speaker

Memory-induced temporal reversibility

Yves Couder * [1], Stephane Perrard, Emmanuel Fort

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The investigation of dynamical systems has revealed a deep-rooted difference between waves and particle-like objects regarding temporal reversibility. Here we focus on a dual entity characterized by an information exchange loop between a particle-like object and an extended wave. It is formed of a droplet bouncing sub-harmonically on a vibrated liquid bath that is self-propelled by its interaction with the waves it generates along its trajectory. The droplet and its associated wave field form a "walker", a structure having, at a classical scale, a dual particle-wave character. In this system the waves generated at each bounce are standing waves damped on a characteristic tunable time τ. The generation of those standing waves by the drop can be considered as an encoding of positional information in a wave medium. These waves being sustained for some time superpose so that the global wave field contains a stored memory of the past trajectory. This path memory(1) can be characterized by a non-dimensional parameter $Me = \tau/TF$ where TF is the bouncing period. At each new bounce the drop "reads" the previously encoded information that determines its next move. It is possible to impose a π phase shift to the droplet's bouncing. The drop thus abruptly becomes out of phase with the previously generated waves. As a result its wave-driven motion is reversed. We investigated this reversal in experiments in which the walker is spatially confined in a potential well(2,3). In these experiments, for large values of Me, the walker can have either steady trajectories(2) or chaotic ones(3). We will show that in all situations, the droplet "reads" the path-memory in reverse, so that it backtracks on its previous trajectory. In the chaotic regimes this means that the natural divergence is transitorily suppressed. It reappears only after a time of the order of Me/2, when the previously recorded memory has been erased. 1. Eddi A., Sultan E., Moukhtar J., Fort E., Rossi M., & Couder Y., J. Fluid. Mech. 674, 433464 (2011). 2. Perrard, S., Labousse, M., Miskin, M., Fort, E. & Couder, Y. Nature Com. 5, 3219 (2014). 3. Perrard, S., Labousse, M., Fort, E. & Couder, Y. Phys. Rev. Lett. 113, 104101 (2014).

*Speaker

Statistical equilibria of large scales in Navier-Stokes turbulence

Vassilios Dallas * [1], Stephan Fauve, Alexandros Alexakis

[1] University of Leeds – United Kingdom

Absolute equilibrium (zero flux) statistical mechanics have been used effectively in the ideal case of zero viscosity to predict the cascade (finite flux) of ideal invariants across scales in Navier-Stokes turbulence. We show numerically that the statistical properties of three-dimensional Navier-Stokes turbulence at scales larger than the forcing scale can be described to a large degree by the truncated Euler equations with the predictions of zero flux in agreement to absolute equilibria, both for helical and non-helical flows. Therefore, the functional shape of the large scale spectra can be predicted with the energy $E(k) \propto k^2$ and the relative helicity $H(k)/(kE(k)) \propto k$ provided that scales sufficiently larger than the forcing length scale but also sufficiently smaller than the box size are examined. This turbulent system is a unique case where equilibrium and out-of-equilibrium statistical mechanics coexist though fluctuations of flux towards large and small scales.

*Speaker

Instantonic solutions and energy transfer in helical shell-models of turbulence

Massimo De Pietro * [1], Alexei A. Mailybaev, Luca Biferale

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In shell models of turbulence the energy transfer is strongly influenced by instantonic solutions representing self-similar structures traveling coherently across the inertial range. It has been argued that anomalous scaling laws might be connected to these structures. We present a study of the instantonic solutions for a class of shell-models of turbulence based on the exact decomposition of the Navier-Stokes equations in helicity eigenstates. In particular we show that the energy transfer due to the instantons are generally consistent with the direction of the energy cascade (forward or backward) in the stationary dynamics. We also studied the dynamics of helicity and how this second invariant influences the energy transfers in these instantonic solutions. We acknowledge funding from the European Research Council under the European Union's Seventh Framework Programme, ERC AdG NewTURB Agreement No 339032.

*Speaker

Thermal motion and interactions of nonlinear localized patterns in a quasi-one dimensional system of interacting particles

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The systems of repulsively interacting particles confined in quasi-one dimensional geometry present a configurational phase transition known as the *zigzag transition*. When the transverse confinement decreases (or when the density increases) it becomes energetically favorable for the particles to adopt a staggered row configuration. The resulting zigzag pattern displays mirror symmetry, and the zigzag transition is basically a pitchfork bifurcation. For short range interactions, and periodic boundary conditions in the longitudinal direction, experimental and numerical studies evidence in actual systems a rich diversity of equilibrium configurations. For instance, we have observed phase coexistence, with particles disposed in staggered row surrounded by phase with particles in line. We have developed a continuous model which couples nonlinearly the longitudinal and transverse displacements of the particles. This model implies a subcritical pitchfork bifurcation, which is consistent with our observation of phases coexistence. Besides, it allows an appropriate description of the localized zigzag pattern as a staggered row phase modulated by a solitary wave envelope that we call a *bubble*. These localized solutions correspond to stable configurations of the system which remain observable even in the presence of thermal noise. In this communication we show that the temperature induces an erratic motion of the bubbles which might be described as the free diffusion of a quasi-particle, with an effective mass that may be calculated from the solitary wave envelope of the localized pattern. We show that the discrete character of the system plays a key role on the bubble behavior at small thermal noise. Then we consider systems with several localized patterns and focus on the interaction between these patterns. We calculate the interaction force between two bubbles by adapting a method developed in the context of instabilities to our specific system, see C. Elphick *et al.* (1990). And we show how the discrete character induces frustration effect, the bubble interaction being attractive for non-frustrated systems and repulsive for frustrated ones.

*Speaker

Statistics of large scales in turbulent flows

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We present an experimental study of the dynamics of large scales in confined turbulent flows driven by a spatially periodic forcing. We show the existence of transitions between different turbulent regimes that are characterized by different probability distribution functions of the velocity field and in some cases by a $1/f$ low frequency spectrum. We study the characteristics of these bifurcations and we understand our observations using simple models.

*Speaker

Time reversal and holography with spacetime transformations

Emmanuel Fort * [1], Vincent Bacot, Matthieu Labousse, Antonin Eddi, Mathias Fink

[1] ESPCI – France

Wave control is usually performed by spatially engineering the properties of a medium. Because time and space play similar roles in wave propagation, manipulating time boundaries provides a complementary approach. Here, we experimentally demonstrate the relevance of this concept by introducing instantaneous time mirrors. We will show with water waves that a sudden change of the effective gravity generates time-reversed waves that refocus at the source. We generalize this concept for all kinds of waves, introducing a universal framework which explains the effect of any time disruption on wave propagation. We show that sudden changes of the medium properties generate instant wave sources that emerge instantaneously from the entire space at the time disruption. The time-reversed waves originate from these 'Cauchy sources', which are the counterpart of Huygens virtual sources on a time boundary. It allows us to revisit the holographic method and introduce a new approach for wave control.

*Speaker

Information scaling in fully developped Turbulence

C. Granero-Belinchón * [1], S.G. Roux, N.B. Garnier

[1] Laboratoire de Physique à l'École Normale Supérieure de Lyon – France

Turbulence can be described in terms of its energy cascade, witnessed in the power law behavior of both power spectral densities and structure functions. In this paper, we propose to analyse Turbulence using Information Theory. We propose a new estimator of the entropy rate at different scales, which heavily relies on Mutual Information. We show that this quantity is an efficient measure of the correlations. We first study the behavior of our new estimator on Fractional Brownian Motion (FBM), a stochastic process which is known to model adequately some characteristics of turbulent signals. For such a signal, the analytical derivation of the scaling of our estimator as function of time increments allows us to measure the Hurst exponent of the FBM signal. We then analyze an experimental velocity field obtained at high Reynolds number in the Modane wind tunnel. We are able to locate characteristic scales defining the dissipative, inertial and integral domains. The Kolmogorov scaling law in the inertial range is recovered for our estimator, which we relate to the behavior of the autocorrelation function. We observe that the information rate is maximal and constant at large scales where energy is injected, whereas it is minimal at small scales where dissipation induces strong correlations. This work is a first step towards a description of Turbulence in terms of an information cascade.

*Speaker

Negative fractal dimensions in random dynamical systems

Robin Guichardaz * [1]

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In chaotic dynamical systems, strange attractors have fractal structures, characterized by a (positive) dimension. The correlation dimension, D_2, describes the density of points $\rho(\Delta x)$ in phase space around a given trajectory: $\rho(\Delta x) \sim |\Delta x|^{D_2}$. We extend this notion to the case of stable stochastic dynamical systems for which all the Lyapunov exponents are negative, meaning that all trajectories converge to a point-like attractor with probability unity. Nevertheless, in the presence of an additive noise, we find a power-law distribution for the separation of trajectories: $\rho(\Delta x) \sim |\Delta x|^{D_2}$, but with $\alpha < 0$. The value of α does not depend on the amplitude of the additive noise; it is a property of the unperturbed dynamical system, in the absence of any noise. The straightforward analogy between the definition of α and that of D_2 leads us to interpret α as a *negative* fractal dimension. Specifically, we illustrate these notions with a simple one-dimensional model of colloidal particles in a randomly generated flow. We reformulate the dynamics of close trajectories in terms of a *sedimentation process*. Both numerical determinations and analytic tools to compute α are presented. A large deviation approach is proposed, without reference to any specific model.

*Speaker

Fluctuation statistics in the condensate state of 2D turbulence

Corentin Herbert * [1], Gregory Falkovich, Anna Frishman

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Understanding the interaction of a mean flow with turbulent fluctuations is a central problem in turbulence theory. Here, we shall tackle this issue in the framework of incompressible 2D turbulence in a finite box. In the presence of small-scale energy injection and small large-scale friction, the inverse cascade of energy leads to a stationary state made of a pair of coherent vortices, upon which incoherent turbulent fluctuations are superimposed. Due to the time scale separation between the mean-flow and turbulence, an asymptotic expansion of the hierarchy of moments can be carried out to obtain closed equations describing both the mean flow and the fluctuations profiles. Using extensive numerical simulations, we will test the validity of these analytical predictions. In particular, we will discuss how the components of the Reynolds stress tensor scale with both distance from vortex core and large scale friction, which is the small parameter in the theory.

*Speaker

Resonance energy transfer in weakly-dissipative oscillator chains

Agnessa Kovaleva * [1]

[1] Space Research Institute, Russian Academy of Sciences – Russia

This study analytically and numerically examines the non-linear dynamics of a chain consisting of identical linearly coupled Duffing oscillators subjected to periodic forcing applied to one of them. The emergence and stability of resonance oscillations in a weakly coupled weakly dissipative chain is investigated. An asymptotic analysis shows that resonance in the entire chain may arise if the excitation and coupling parameters exceed certain critical values but dissipation in the oscillators is small enough. In addition, an effect of the growing energy dissipation is revealed. It is demonstrated that the actual rate of energy dissipation depends on the index of the oscillator and grows with an increase of this index as well as with an increase of the total number of the oscillators in the chain, even though the coefficients of viscous damping are equal for all oscillators. This implies that resonance may occur either in short-length chains or in a chain with very small viscous damping (including non-dissipative chains). Explicit asymptotic approximations of the solutions are obtained. Close proximity of the derived approximations to exact (numerical) results is demonstrated.

*Speaker

Aging in Excitable and Oscillatory Systems

Hildegard Meyer-Ortmanns * [1], Florin Ionita

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We consider classical nonlinear oscillators like rotators and Kuramoto oscillators on hexagonal lattices of small or intermediate size. When the coupling between these elements is repulsive and the bonds are frustrated, we observe coexisting states, each one with its own basin of attraction. For special lattices sizes the multiplicity of stationary states gets extremely rich. When disorder is introduced into the system by additive or multiplicative Gaussian noise, we observe a noise-driven migration of oscillator phases in a rather rough potential landscape. Upon this migration, a multitude of different escape times from one metastable state to the next is generated [1]. Based on these observations, it does not come as a surprise that the set of oscillators shows physical aging. Physical aging is characterized by non-exponential relaxation after a perturbation, breaking of time-translation invariance, and dynamical scaling. When our system of oscillators is quenched from the regime of a unique fixed point towards the regime of multistable limit-cycle solutions, the autocorrelation functions depend on the waiting time after the quench, so that time translation invariance is broken, and dynamical scaling is observed for a certain range of time scales [2]. We point to open questions concerning a possible relation between physical and biological aging. References: [1] F.Ionita, D.Labavic, M.Zaks, and H.Meyer-Ortmanns, Eur. Phys.J.B 86(12), 511 (2013). [2] F.Ionita, H.Meyer-Ortmanns, Phys.Rev.Lett.112, 094101 (2014).

*Speaker

Spot growth in plane Couette flow

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Plane Couette flow is a typical example of subcritical transition to turbulence. In the subcritical range, laminar and turbulent domains coexist and the dynamics of laminar-turbulent fronts is complex and far from being understood. It may for example lead to the formation of organized inclined patterns that still remain unexplained. We experimentally and numerically investigate turbulent spot growth in plane Couette flow in order to elucidate the mechanisms at work along the growth process: we show that large scale flows present whenever laminar and turbulent areas coexist play a crucial role. We indeed reveal a so far unexpected growth mechanism based on the spot advection by large scale flows and a wavelength instability occurring within the turbulent spot. Large scale flows imply long range spatial correlations that have to be taken into account in any attempt of modeling subcritical transitions to turbulence.

*Speaker

Gravity driven instability in solid elastic

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Many materials such as biological tissues can withstand huge elastic deformations of more than several hundred percent. The amplitude of the stress is then of the order of the elastic modulus, a situation commonly encountered with soft materials. Specific and fascinating patterns, reminiscent of those that can be seen in hydrodynamics, can then occur spontaneously. Here we demonstrate the instability of the free surface of a soft elastic solid facing downwards. Experiments are carried out using a gel of constant density ρ, shear modulus μ, put in a rigid cylindrical dish of depth h. When turned upside down, the free surface of the gel undergoes a normal outgoing acceleration g. It remains perfectly flat for $\rho gh/\mu < \alpha^*$ with $\alpha^* \simeq 6$, whereas a steady pattern spontaneously appears in the opposite case. This phenomenon results from the interplay between the gravitational energy and the elastic energy of deformation, which reduces the Rayleigh waves celerity and vanishes it at the threshold [1]. In addition, a non-linear analysis of the instability well captures the features of the patterns observed beyond the instability threshold. [1] S. Mora, T. Phou, J.M. Fromental, Y. Pomeau. Phys. Rev. Lett. 113, 178301 (2014).

*Speaker

Energy transmission in the gap of nonlinear media triggered by deterministic and stochastic driving

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These past years, a growing interest has been devoted to the analysis of the response of nonlinear media to various excitations wether random or deterministic in order to better characterize their transmission properties [1, 2, 3]. Especially, since the introduction of the concept of soliton, the development of nonlinear electrical transmission lines has provided an efficient tool to experimentally investigate the behaviour of these nonlinear waves [4]. Recently, some efforts have focused on the energy transmission in the gap of media obeying to equations deriving from the nonlinear Schrödinger model [5, 6]. Indeed, Geniet and Leon have shown that such nonlinear systems, which present a natural forbidden band gap , can transmit energy of a signal even if the frequency is chosen in the gap [7]. Indeed, instead of the classical evanescent wave, which is observed for weak amplitudes of the driving signal, nonlinear modes are triggered when the driving amplitude exceeds a particular threshold. This effect, called supratransmission, has been reported in various media ranging from optics to electronics [8, 9, 10, 11, 12]. In this communication, we propose an overview of nonlinear supratransmission from both numerical and experimental points of view. We carried out our study in a Klein-Gordon electrical lattice which exhibits Supratransmission [13]. Next, a numerical study is performed to reveal this effect in the sine-Gordon model where it is shown that noise can also trigger this effect [14]. We finally conclude by considering the influence of nonlinear coupling on the condition of supratransmission triggering. Acknowledgements The authors thank the Regional Council of Burgundy for financial support (IRAP - Convention 2014-9201AAO49S01401 (SSTIC 6)). References [1] L., Gammaitoni, P. Hänggi, P. Jung and F. Marcesoni, “Stochastic Resonance” Rev. Mod. Phys., 70, (1998). [2] B. Lindner, J. García-Ojalvo, A. Neiman, L. Schimansky-Geier, “Effects of noise in excitable systems” Physics Reports 392, 321–424 (2004). [3] S. Flach, A. Gorbach, “Discrete breathers - Advances in theory and applications”, Physics Reports 467 1-116 (2008). [4] M. Remoissenet, “Waves called solitons : concepts and experiments” (3rd revised and enlarged edition), Springer-Verlag, Berlin 1999. [5] F. Geniet and J. Leon, “Energy Transmission in the forbidden band gap of a nonlinear Chain” Phys. Rev. Lett. 89, 134102, (2002). [6] J. E. Macias-Dias, “Bistability of a two-dimensional Klein-Gordon system as a reliable means to transmit monochromatic waves: A numerical approach” Phys. Rev. E, 78, (2008). [7] F. Geniet and J. Leon, “Nonlinear supratransmission” J. Phys. Cond. Matt. 15, 2933-2949, (2003). [8] K. Tse Ve Koon, J. Léon, P. Marquié, P. Tchofo-Dinda, “Cut-off solitons and bistability of the discrete LC electrical line: Theory and experiments”, Phys. Rev. E, 75, pp. 066604-1/8, (2007). [9] S. B. Yamgoué, S. Morfu and P. Marquié, “Noise effects on gap wave propagation in a nonlinear discrete LC transmission line”, Phys. Rev. E, 75 , 036211, (2007). [10] P. Anghel-Vasilescu, J. Dorignac, F. Geniet, J. Leon, and A. Taki, “Generation and dynamics of quadratic birefringent spatial gap solitons”, Phys. Rev. A 83, 043836, (2011). [11] A. B. Togueu Motcheyo, C. Tchawoua, and J. D. Tchinang Tchameu, “Supratransmission induced by waves collisions in a discrete electrical lattice”, Phys. Rev. E 88, 040901(R) (2013). [12] K. Tse Ve Koon, P Marqui, P. Tchofo-Dinda, “Experimental observation of the generation of cutoff solitons in a discrete LC nonlinear electrical line”, Phys. Rev. E, 90, 052901, (2014). [13] B. Bodo, S. Morfu, P. Marquié and M. Rossé, “A Klein-Gordon electronic network exhibiting the supratransmission effect”, Electron. Lett., 46 (2), pp. 123, (2010). [14] B. Bodo, S. Morfu, P. Marquié, B.Z. Essimbi “Noise induced breather generation in a sine-Gordon chain”, J. Stat. Mech. P01026, (2009).

*Speaker

Robust Chaotic Synchronization of Large Laser Arrays

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One of the key aspirations in the modern theory of dynamical systems is to understand, predict, and build a network that guarantees robust and high-level phase synchrony between the network elements. While a sound level of progress in understanding network phase synchrony for some specific designs (such as for nearest neighbor and globally coupled arrays) has been achieved, substantial challenges to design and build an experimentally feasible networks that can show robust phase synchrony still exist. We consider existence and stability of spatial modes of the external cavity of the semiconductor laser diode array. By using a decayed nonlocal coupling scheme (the coupling strength of the lasers decreases as the distance between the elements increases), it is possible to induce a very robust and close to perfect stable CW and unstable chaotic phase synchronous state of the array. For such a coupling scheme the leading spatial mode forges almost perfect and stable phase synchronization that is robust to noise and disorder. Moreover, the critical coupling strength for which the synchronous state destabilizes increases approximately linearly with array size. To understand how phase organization and phase synchrony occur in large laser diode systems, we derive an extension to the Master Stability Function (MSF) theory. We show how synchronous states of fixed-point, periodic, and chaotic dynamics can be achieved and how these states scale with array size. For the coupling scheme we consider, the leading spatial mode is stable, very close to synchronous, robust to noise and disorder. The critical coupling strength for which this mode destabilizes increases approximately linearly with array size. While we consider equations of motion for an array of semiconductor laser diodes, our findings could be relevant for other nonlinear arrays that could, in principle, be coupled in a similar manner as the semiconductor laser diodes we consider. Finally, we discuss our group's experiments involving large arrays of broad area, high power semiconductor diode arrays in the V-shaped external cavity where almost perfect phase locking with close to perfect diffraction limited beam emitted from the array has been demonstrated. While it is not obvious whether our experiments can be described using delayed Lang-Kobayashi model, the mode structure of such phase-locked arrays may be similar to the synchronized mode structure of single mode diode arrays described by Lang-Kobayashi equations. Moreover, the coupling structure of the experimentally phase-locked diode arrays in the V-shaped cavity may be comparable to the decayed nonlocal coupling scheme that we introduced in describing phase synchronization of single mode semiconductor diode arrays. References: [1] N. Nair, E. Bochove, Y. Braiman, Conditions for robust synchronization of weakly coupled diode lasers (submitted to Phys. Rev. Lett.). [2] B. Liu, Y. Braiman, Coherent beam combining of high power broad-area laser diode array with near diffraction limited beam quality and high power conversion efficiency. Opt. Express 21, 31218 (2013). [3] B. Liu, Y. Liu, Y. Braiman, Coherent beam combining of high power broad-area laser diode array with a closed-V-shape external Talbot cavity. Opt. Express 18, 7361 (2010).

*Speaker

Wave turbulence approach to thermalization of the α and βFPU system

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We study theoretically the α and the β Fermi-Pasta-Ulam (FPU) system with $N = 32$ masses connected by a nonlinear spring. Our approach is based on the wave turbulence approach, i.e. we assume that the irreversible transfer of energy leading to thermalization takes place only when waves interact through exact resonances. We show theoretically and numerically that the time needed to reach equilibrium is proportional to $1/\epsilon^8$ with ϵ the non linear parameter of the system. This results holds for both the α (quadratic nonlinearity) and β (cubic nonlinearity). We measure numerically the dispersion relation and observe that, even in the absence of frequency overlap, thermalization is reached. Part of the results presented are contained in [1] [1] Onorato, M., Vozella, L., Proment, D., and Lvov, Y. V. (2015). Route to thermalization in the α-Fermi–Pasta–Ulam system. Proceedings of the National Academy of Sciences, 112(14), 4208-4213.

*Speaker

Diverging fluctuations of the finite-time Lyapunov exponent in Hamiltonian lattices

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The fluctuations of the finite-time Lyapunov exponent (FTLE) contain important information encoded in certain "higher-order invariants". We have recently predicted that, in dissipative spatially extended systems, the diffusive process linked to the fluctuations of the largest FTLE has a diffusion coefficient D that decays with the system size as $D \sim L^{-\gamma}$. The universal value of the exponent $\gamma > 0$ can be derived by mapping the Lyapunov vector to a rough surface. In this communication we report on radically different results obtained for two prototypical Hamiltonian lattices: the Φ^4 and FPU models. We show that the diffusion coefficient characterizing the fluctuations of the FTLE diverges with the system size, as $D \sim L^{-\gamma}$, with $\gamma < 0$. This divergence implies a violation of the central limit theorem in the thermodynamic limit. The occurrence of a negative γ exponent appears to be related to the long-range and long-term correlations of system variables enabled by the Hamiltonian dynamics.

*Speaker

Particle motion and irreversibility of turbulent flows

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Three-dimensional turbulent flows are characterized by a flux of energy from large to small scales, which breaks the time reversal symmetry. I will present evidence to show that the motion of tracer particles, which tend to lose energy faster than they gain it, is in fact irreversible. I will also discuss how this irreversibility in the motion of single tracers is related to vortex stretching and thus with the generation of the smallest scales.

*Speaker

Wave turbulence theory for gravitational waves in general relativity: The Space-Time Kolmogorov spectrum.

Sergio Rica * [1]

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Recent evidence of the existence of gravitational waves [Phys. Rev. Lett. **116**, 061102 (2016)] predicted by Einstein's theory of gravitation, motivates the question of the longtime evolution of the space-time fluctuations. Space-time fluctuations propagate and interact themselves through the intrinsic nonlinearities of Einstein's equations of general relativity as the universe evolves. In this way the spatio-temporal ripples travel and interact themselves allowing the transfer of the energy produced by the space and time itself from mode to mode. Einstein's equations for the weak deformation of the Minkowski metric, $\epsilon h_{\mu\nu}$, reads, up to first non linear order,

$$\partial_\lambda \partial^\lambda h_{\mu\nu} \sim \epsilon \partial_\lambda h_{\mu\rho} \partial^\lambda h^\rho{}_\nu,$$

here $\partial_\lambda \partial^\lambda$ stands for the D'Alembertian wave operator, ϵ is the measure of the weakness of the wave amplitude and the above equation summarizes only the right scaling in $h_{\mu\nu}$ and its derivatives, naturally other terms with the same scaling arises. It was established that the long time statistical properties of a random fluctuating wavy system possess a natural asymptotic closure because of the weakly nonlinear wave interaction. Indeed this so-called "wave turbulence theory" has shown to be a powerful method to study the evolution of nonlinear wave systems. It results that the longtime dynamics is driven by a kinetic equation for the distribution of spectral densities. This method, was applied for surface gravity waves in fluids, surface capillary waves in fluids, plasma waves, sound waves, nonlinear optics, nonlinear elastic plates, *etc.* An application of the wave turbulence theory for nonlinear interaction gravitational waves leads to the existence of three almost co-linear resonant wave interaction, which are ruled in the longtime regime by a three wave kinetic equation including gain and decaying process, $1+1 \leftrightarrow 1$. The resulting kinetic equation for the spectrum wave n_k, reads

$$\begin{aligned}\frac{d}{dt} n_{\boldsymbol{k}} &= \frac{\epsilon^2}{2(2\pi)^2} \int d^3\boldsymbol{k}_1 d^3\boldsymbol{k}_2 \times \Big[|V(\boldsymbol{k},\boldsymbol{k}_1,\boldsymbol{k}_2)|^2 \left(n_{\boldsymbol{k}_1} n_{\boldsymbol{k}_2} - n_{\boldsymbol{k}_1} n_{\boldsymbol{k}} - n_{\boldsymbol{k}_2} n_{\boldsymbol{k}}\right) \delta^{(3)}(\boldsymbol{k}-\boldsymbol{k}_1-\boldsymbol{k}_2)\delta(|\boldsymbol{k}|-|\boldsymbol{k}_1|-|\boldsymbol{k}_2|) + \\ &+ 2|V(\boldsymbol{k}_2,\boldsymbol{k},\boldsymbol{k}_1)|^2 \left(n_{\boldsymbol{k}_1} n_{\boldsymbol{k}_2} + n_{\boldsymbol{k}} n_{\boldsymbol{k}_2} - n_{\boldsymbol{k}} n_{\boldsymbol{k}_1}\right) \delta^{(3)}(\boldsymbol{k}+\boldsymbol{k}_1-\boldsymbol{k}_2)\delta(|\boldsymbol{k}|+|\boldsymbol{k}_1|-|\boldsymbol{k}_2|) \Big].\end{aligned}$$

here the nonlinear interaction $V(k+k_1,k,k_1)$ scales as $\sqrt{ck}$. The resulting kinetic equation suggests the existence of a Kolmogorov-Zakharov spectrum for spatio-temporal fluctuations resulting on an energy flux from the long-wave scales up to short wave regime of the form $n_k \sim P^{1/2} k^{-7/2}$. Therefore an energy cascade

$$E_k = 4\pi c k^3 n_k \sim c P^{1/2} k^{-1/2}$$

arises as a consequence of weakly interacting classical gravitational waves. Evidence of this cascade may be already extracted in the fluctuating signal of the recent observations.

*Speaker

Exceptional point in coupled oscillators and its role in collective dynamics.

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We study the transient behaviors of coupled dissipative dynamical systems based on the linear analysis around the steady state. We find that the systems show the largest damping rate at an exceptional point, at which not only eigenvalues but also the associated eigenvectors coalesce. For the case of coupled limit-cycle oscillators, the transient behavior into the amplitude death state is studied. We demonstrate that the exceptional point is associated with a critical point of frequency locking, as well as the transition of the envelope oscillation.

*Speaker

Hyperbolic Kolmogorov-Anosov C-systems and Random Number Generators

George Savvidy * [1]

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The hyperbolic dynamical systems have homogeneous exponential instability of all trajectories and as such they have mixing of all orders, countable Lebesgue spectrum and positive Kolmogorov entropy. These extraordinary ergodic properties follow from the C-condition introduced by Anosov. The C-condition defines a rich class of dynamical systems which span an open set in the space of all dynamical systems. The important property of C-systems is that they have a countable set of everywhere dense periodic trajectories and that their density exponentially increases with entropy. Of special interest are C-systems that are defined on a high dimensional torus. The C-systems on a torus are perfect candidates to be used for Monte-Carlo simulations. Recently an efficient algorithm was found, which allows very fast generation of long trajectories of the C-systems. These trajectories have high quality statistical properties and we are suggesting to use them for multipurpose Monte-Carlo simulations.The MIXMAX family of random number generators based on Anosov C-systems provide high quality statistical properties, thanks to their large entropy, have the best combination of speed, reasonable size of the state, tuneable parameters and availability for implementing the parallelisation. This MIXMAX random number generator is currently made available in a portable implementation in the C language at hepforge.org and is implemented into the ROOT and GEANT projects at CERN

*Speaker

Statistical physics approaches of rare transitions between turbulent jets through an adaptive multilevel splitting algorithm

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Many natural and experimental turbulent flows display a bistable behavior: rare and abrupt dynamical transitions between two very different subregions of the phase space. The most prominent natural examples are probably the Earth magnetic field reversals (over geological timescales), the Kuroshio bistability, or the Dansgaard-Oeschger events that have affected the Earth climate during the last glacial period, and are probably due to several attractors of the turbulent ocean dynamics. Those phenomena have never been studied in turbulent flows from first principles, or from direct numerical simulations, because of the huge time scale needed to observe the rare transitions, incompatible with current or foreseeable computational capabilities. In order to overcome this problem we will study these phenomena using statistical physics approaches. We will present recent results in the context of stochastic quasi-geostrophic models (beta-plane turbulence) that show that bistability occurs for the turbulent dynamics of atmosphere jets. Zonal atmospheric jets are known to naturally emerge from beta-plane turbulence due to the arrest of inverse energy cascade by Rossby waves. Transitions between jets of different wavenumbers are indeed observed in a weakly dissipative barotropic quasigeostrophic model forced by a weak noise. Those abrupt transitions, analogous to the one observed on Jupiter troposphere, are extremely rare events that change drastically the nature of the flow and are thus of paramount importance. Our main tool will be a rare event algorithm developed for statistical physics applications: an adaptive version of the multilevel splitting algorithm. With this algorithm we are able to compute large statistical ensembles of trajectories connecting jets of different wavenumbers. We show that in regime of very long transition rates, these so-called reactive trajectories concentrate on a narrow region of phase space suggesting the existence of instantons.Moreover, these transitions are strongly asymmetric in time as expected in non-gradient systems. The algorithm is able to describe the effective dynamics as well as some large-deviation behavior.

*Speaker

An optimal closure for decaying turbulence

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Equilibrium Statistical mechanics ideas have been widely used in the past to account for the large scale 2d organization of atmospheric flows, as caused by the small-scale turbulent motions. Spectacular applications are many, from Kuroshio currents in the Pacific ocean to the Great Red Spot on Jupiter. In a non-equilibrium perspective, statistical mechanics can also be used to describe the smallest scales of a non-viscous classical turbulent fluid. From this point of view, decaying turbulent dynamics can be thought of as a thermalization process, caused by the strongly nonlinear interaction between the far-from-equilibrium inertial scales on one hand and a small-scale "heat bath" on the other hand. In order to derive an effective coarse-grained dynamics, traditional turbulent approaches would typically invoke a mean-field behavior to close the hierarchy of cumulants and resort to phenomenological transport coefficients, such as eddy viscosities. The purpose of the talk is to expose an alternative "optimal closure framework", which provides a systematic way to derive closed reduced equations from the underlying ideal dynamics and its statistical properties. In conceptual outline, our method is to impose a parametric statistical model on the full turbulent dynamics, and to "best-fit" that model to the underlying dynamics equations by minimizing a certain cost functional over paths of model states. The cost functional is designed to quantify a net information loss rate incurred by reduction from the deterministic dynamics to the statistical model. One benefit of a best-fit closure is that the reduced equations have a generic thermodynamical structure, in which the reversible and irreversible parts of the governing equations are separately identified and the optimal cost of reduction is related to entropy production. In the context of turbulence modeling these desirable properties guarantee that no realizability issues arise in a best-fit closure. We illustrate the skills of the theory using a variety of prototype turbulent problems, for which quantitative predictions were obtained.

*Speaker

Equilibrium statistical mechanics and energy partition for the shallow water model

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Geophysical flows are highly turbulent, and yet embody large-scale coherent structures such as jets and long lived vortices. Understanding how these structures appear and predicting their shape are major theoretical challenges. Equilibrium statistical mechanics is a powerful approach that describes with only a few thermodynamical parameters the long time behavior of the largest scales of those geophysical flows within the inertial limit. This approach has also been proven useful to describe self-organization in weakly forced-dissipated configurations. Previous applications of the theory led to successful description of the Great Red Spot of Jupiter, or of ocean rings and jets [1]. Because of essential theoretical difficulties, all those previous applications were up to now limited to quasi-geostrophic models. Here we generalize the equilibrium statistical mechanics theory to the more comprehensive shallow water system, including inertia-gravity waves and the possibility of energy transfers towards small scales, with the concommittant emergence of a large scale vortical flow [2]. This is a key step towards an understanding of the energy balance of geophysical flows. Using large deviation theory, we compute the entropy of macrostates for the microcanonical measure of the shallow water system. The main prediction of this full statistical mechanics computation is the energy partition between the large scale vortical flow and small scale fluctuations related to inertia-gravity waves. We introduce for that purpose a semi-Lagrangian discrete model of the continuous shallow water system, and compute the corresponding statistical equilibria. We argue that microcanonical equilibrium states of the discrete model in the continuous limit are equilibrium states of the actual shallow water system. We show that the presence of small scale fluctuations selects a subclass of equilibria among the states that were previously computed by phenomenological approaches that were neglecting such fluctuations. We provide explicite computations of the equilibria within the quasi-geostrophic limit (strong rotation limit), taking into account the presence of small scale fluctuations. This allows us to discuss the important role of bottom topography and rotation to sustain a large-scale flow structure. We finally address the possible role of small scale dissipation and shocks within this framework, and geophysical applications of those results. [1] F. Bouchet, A. Venaille Physics Reports 515: 227–295, 2012. [2] A. Renaud, A. Venaille, F. Bouchet. Journal of Statistical Physics, 10.1007/s10955-016-1496-x, 2016

*Speaker

Decoding Physics of Convective Turbulence using Extreme Computing

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In this abstract we present the turbulence phenomenology of turbulent thermal convection (Rayleigh-Bénard convection, RBC). We performed numerical simulation of RBC for Rayleigh number $\mathrm{Ra} = 1.1 \times 10^{11}$ and Prandtl number $\mathrm{Pr} = 1$ on a 4096^3 grid. We observed that in the inertial range, the energy spectrum $E(k) \sim k^{-5/3}$ and energy flux $\Pi(k)$ is a constant [1], consistent with the Kolmogorov's theory of fluid turbulence. We rule out the Bolgiano-Obukhov's spectrum $E(k) \sim k^{-11/5}$ for convective turbulence due to the positive energy feed by buoyancy; this is in contrast to the negative energy feed by buoyancy in the stably stratified flows for which the Bolgiano-Obukhov theory is valid [1]. We also compute the rms values of various terms of the momentum equation of turbulent convection. We show that the acceleration of a fluid parcel is provided mainly by the pressure gradient, and the buoyancy and dissipation term are quite close to each other [2]. The above force balance is also observed in the inertial range [1]. Thus, the effect of buoyancy is annulled in convective turbulence, leading to Kolmogorov's theory of turbulence. In addition, we also show that the flow in convective turbulence is quite close to isotropy, consistent with the Kolmogorov's spectrum for the flow. In summary, we show that the physics of convective turbulence is quite close to that of fluid turbulence. These important results are important for modelling the convective flows in the interiors and atmospheres of planets and stars. [1] A. Kumar, A. G. Chatterjee, and M. K. Verma, Energy spectrum of buoyancy-driven turbulence, Phys. Rev. E, 90, 023016 (2014); [2] A. Pandey, A. Kumar, A. G. Chatterjee, and M. K. Verma, Dynamics and scaling in Rayleigh-Bénard convection, Preprint.

*Speaker

New experiments on the subcritical transition to turbulence in Couette-Poiseuille flow

Wesfreid, José Eduardo * [1], Lukasz Klotz, Idalia Frontczak, Grégoire Lemoult,

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We present a new experimental set-up which enables us to create two dimensional shear flow with zero mean advection velocity. Our concept is a generalization of classical plane Couette experimental set-up, where the base flow is generated by imposing the velocity of opposite sign at each wall of the test section. We investigate a plane Couette-Poiseuille configuration, completing the first experimental results for this flow which had only been studied theoretically to-date. This configuration consists of a single loop of plastic belt, which imposes the speed at one wall (the second one remains stationary) and generates the pressure gradient in the streamwise direction. The resulting plane Couette-Poiseuille flow can be considered as two subregions. The first one is parabolic (Poiseuille like) and occupies approximately two-thirds of the gap. The second region (Couette like) is characterized by a much higher with respect to the Poiseuille region. Using flow visualizations we characterize subcritical transition to turbulence. For low Reynolds numbers the flow is globally laminar in the test section. When we increase the Reynolds numbers we observe a nearly stationary v-shaped turbulent spot which is very slowly advected through the test section. The coexistence of laminar and turbulent phases is observed, even in the form of bands. Finally for high enough Reynolds numbers the turbulent region occupies most of the test section. To our knowledge this is the first time when turbulent spots in plane Couette-Poiseuille flow are observed and when the advection velocity of turbulent structures in a flow with non-zero pressure gradient is so drastically reduced. We follow the intermittent dynamics of the turbulent spots by time-resolved Particle Image Velocimetry (PIV) in the gap of the channel and compare these expérimental observations with the results of nonlinear reduced models of shear flows transitions.

*Speaker

Topic 8: Interdisciplinary and Complex Systems -Oral

Silent avalanches, Omori's law and predictability

Mikko Alava * [1], S. Janicevic, L. Laurson, M. Ovaska, S. Santucci, L. Viitanen

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Systems exhibiting so-called crackling noise - intermittent response to slow driving – are characterized both by the avalanches' properties [1] and often surprise by the fact that the crackling noise events are separated by waiting times which follow fairly clean power-law distributions. As the normal expectation would be instead Poissonian statistics this indicates correlations and we present some results that explain this by our inability to follow properly avalanches: the waiting time behaviour is due to detecting sub-avalanches that all belong to the same correlated event. Experimental data from a slow (in-plane) crack propagation experiment and studies of a coarse-grained depinning model are presented to this effect [2]. Other avalanching systems like compressional deformation [3,4] show more complex correlations. We illustrate how these can be used for obtaining (much) "better than random" predictions of next avalanches utilizing on-line the known signal correlation properties [5].
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*Speaker

Emergence of Cooperative Long-term Market Loyalty in Double Auction Markets

Aleksandra Aloric * [1], Peter Sollich

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Loyal buyer-seller relationships can arise by design, e.g. when a seller tailors a product to a specific market niche to accomplish the best possible returns, and buyers respond to the dedicated efforts the seller makes to meet their needs. In our work we ask whether it is possible, instead, for loyalty to arise spontaneously, and in particular as a consequence of repeated interaction and co-adaptation among the agents in a market. We devise a stylized model of discrete time double auction markets with a global trading price and adaptive agents, who strategize with the choice of market, but their trading strategy is Zero Intelligence. These agents can choose where to trade (which market) and how to trade (to buy or to sell) based on their previous experience. We find that when the typical scale of market returns (or, at fixed scale of returns, the intensity of choice) become higher than some threshold, the preferred state of the system is segregated: both buyers and sellers are segmented into subgroups that are persistently loyal to one market over another. We characterize the segregated state analytically in the limit of large markets: it is stabilized by some agents acting cooperatively to enable trade, and provides higher rewards than its unsegregated counterpart both for individual traders and the population as a whole. We conclude that the key driver of segregation is agent's adaptation which is described by a generic rule wiledly used in literature and observed in experiments. Above the segregation threshold we also note that the agent's memory size plays a role - when it's longer than a threshold there are multiple segregated states with different demand to supply ratios, ie differently sized loyalty groups. In this talk we will present these states and characterise their stability, lifetimes and the way they influence returns across the population. We will conclude with the discussion on the robustness of our results by relaxing simplifying assumptions on agents' trading strategies and market mechanism, showing that even then the system is stabilized by emergence of segregation.

*Speaker

Statistical Physics contributions to Data Science

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The recent availability of large socio-economical databases expanded the realm of scientific problems for which quantitative investigations are possible. In this talk I advocate that ideas and methods that originated in Statistical Physics can make important contributions to this emerging field. After a general introduction, I will illustrate my general point through specific examples of my recent research: the use of entropies in textual analysis, how to sample network ensembles, and applications of stochastic processes to social media.

*Speaker

The evolution of dispersal of reproducing competitive individuals

Flora Souza Bacelar * [1], Danis Kiziridis, Chistóbal López, Emïlio Hernàndez-Garcia

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Dispersal is a life-history trait that influences the dynamics and persistence of populations, the distribution and abundance of species, and community structure. "To understand dispersal, we need to measure its spatial patterns, to explore the mechanisms that generate them, and to examine their consequences" [1]. In this work we address attention to the interplay between dispersal and interactions among particle and try to answer the main question, what kind of movement strategy is optimal for mobile organisms, for that we adopt a model of competing particles in which considers reproducing particles with birth and death rates depending on the number of other individuals in the neighbourhood [2]. We have used a simple model without incorporating environmental heterogeneity, and analyzed spatial and temporal variability in terms of aggregated individuals (clustering) and changes in competing parameters to see how this affects movement that evolves. In the simulation without evolution we observe that population dynamics of faster individuals diminishes clustering and so spatial variability, agreeing to previous studies. Performing evolution when we have higher competition intensity the population evolves to a majority of faster individuals and this is accentuated when the competition impacts more on the deaths rates. However, for higher competition but influencing only birth rates the evolutionary dispersal could reach different outcomes depending on the starting population. If it starts at majority of slow individuals the population fluctuates around slow disperses, otherwise the population evolves to faster dispersers. This happens because population with slow dispersers increase in density due patter formation, i.e., inside crowded environments exists a kind of mutual protection, and the individuals in the interclusters space suffers more against competition. In the case of beginning with faster individuals there is less spatial variability and more temporal variability and so less protector spaces leading to a more homogeneous spatial configuration. †

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*Speaker

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Robust accessible states allow efficient training of neural networks with very low precision synapses

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Training of neural networks in which the synaptic connections strengths are discretized and their precision is limited to only a few bits has long been considered a challenging task even for the simplest neural architectures: local search algorithms tend to be easily trapped in local minima, and equilibrium statistical analysis shows that global optima are typically isolated ("golf-course scenario"). However, biological experiments show that the precision of brain's synapses does not exceed very few bits (and may even be as low as 1 bit). Furthermore, machine learning applications would greatly benefit from reduced requirements. We performed a large deviations analysis which shows that there exist peculiar dense regions in the space of synaptic states which account for the possibility of learning under these constraints. These regions are characterized by a large local entropy, such that: 1) they are accessible to very simple and efficient heuristic algorithms which exploit their characteristics; 2) the optima are very wide and thus robust; 3) they have good generalization properties. The analytical results give us an "effective capacity" measure which saturates fast with the number of synaptic values and thus indicates that very few bits are indeed sufficient for effective learning. Our numerical observations match the theoretical results where available, and indicate that the scenario extends to complex multi-layer neural architectures trained on real-world data (potentially providing a framework to explain the success of deep learning techniques). The analysis may also be extended to other models. Bibliography: [1] C Baldassi, A Ingrosso, C Lucibello, L Saglietti and R Zecchina. Subdominant Dense Clusters Allow for Simple Learning and High Computational Performance in Neural Networks with Discrete Synapses. PRL 2015. [2] C Baldassi, F Gerace, C Lucibello, L Saglietti and R Zecchina. Learning may need only few bits of synaptic precision. http://arxiv.org/abs/1602.04129

*Speaker

Lost in diversification

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There is a growing consensus around the idea that increasingly complex financial products play an important role in the emergence of new instabilities and systemic risk (see A. Haldane and R. May, Nature 469, 351 (2011)). In particular, complex financial products can become easily information-insensitive, which has profound consequences on the efficiency of the markets (see for instance J. E. Stiglitz, The American Economic Review 92(3), 460 (2002)). This phenomenon is considered to be one of the key factors that led to the massive devaluation of structured financial products in 2007, the main trigger of the global financial crisis. In this contribution we introduce stylised models in which the aforementioned insensitivity to information can be quantified using information theoretic concepts. Such effect is particularly severe in structured financial products which, when assets are not independent, exhibit non-trivial properties that can be traced back to the inverse Ising problem. Finally, we investigate whether and how information losses should affect the pricing of financial products and risk management strategies.

*Speaker

Statistical properties of non-linear random walks on networks

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Random walks on networks define general models for transportation systems that have an applications in many fields from biochemical networks to human mobility. These models allow to introduce a dynamical system on the geometrical structure of a network that takes into account of the complexity of the transportation system. One associates a dynamical state to each node, whose evolution depends on the interaction with the connected nodes in a stochastic way by means of weighted links. Assuming a fast decay of time correlation of the random effects, the random walks realize the dynamics of a Markov field on the phase space of the network states. Then, under suitable assumptions, the probability distribution satisfies a Master equation that balance the incoming and outgoing probability flows on each state and allows computing the stationary distribution. Despite of their reductionist nature, the random walks on network display many open problem to understand the relation among the statistical properties of stationary distributions and transient states, and the network structure and the dynamical rules. In this work we consider the statistical properties of the stationary states for conservative random walks (i.e. the number of particles is preserved) whose transition probabilities depend in a non-linear way from the network state. The stationary state plays a relevant role for the development of a Statistical Physics approach to describe the macroscopic emergent properties of Complex Systems. In particular we show that the effect of introducing a finite transport capacity and a finite volume in each node may be interpreted in term of entropic forces that attract the system towards the state at the boundary conditions (i.e. states containing empty nodes or congested nodes). Moreover if one considers a synchronous and an asynchronous upgrade of the network state (one step processes), we point out the existence of a positive correlation between the connected nodes with a state near the boundary values, that mimics the effect of an attractive forces among these nodes and change the stationary distribution. Under this point of view, the number of synchronous movements per unit time may play the role of control parameter for random walks that perform a phase transition when the number of connected couples of nodes whose states have a boundary value overcome a critical threshold. We discuss the relevance of this phenomenon for congestion formation in transportation systems

*Speaker

Network geometry

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Networks are mathematical structures that are universally used to describe a large variety of complex systems such as the brain or the Internet. Characterizing the geometrical properties of these networks has become increasingly relevant for brain research, routing problems, inference and data mining. In real growing networks, topological, structural and geometrical properties emerge spontaneously from their dynamical rules. Here we show that growing simplicial complexes constructed not only by nodes and links but also by triangles and higher dimensional simplices can generate complex network geometries with non-trivial distribution of curvatures, combining complexity with finite spectral dimensionality. When manifolds of arbitrary dimension are constructed, and energies are assigned to their nodes these networks can be mapped to quantum network states and they follow quantum statistics despite they do not obey equilibrium statistical mechanics.

*Speaker

Critical price impact and the intrinsic fragility of financial markets

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How does the very fact of buying (or selling) an asset modify its price? This is a fundamental question, not only to understand how financial markets operate and whether they are stable, but also to shed light on the still active debate on market "efficiency". One can measure, as for a physical system, the "response" of the price to a small perturbation, for example a buy of total volume Q. The surprise is that the average impact of such a transaction is not linear in Q (as one would naively guess) but behave as the square-root of Q. This implies a formal divergence of the linear response, as for a critical system. Interestingly, the square-root behaviour is universal, i.e. independent of the market and the epoch. We will present a consistent theory for such an effect, confirmed by numerical simulations and further experimental observations. Our scenario suggests that markets are intrinsically fragile and turbulent.

*Speaker

Memory effects and heterogeneous activation patterns in time varying networks

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In many social and information systems, the network of the interactions generated by the agents activity is a rapidly evolving time-varying structure, where two mechanism seem to play a central role: memory effects with strong ties creations, and the burstiness of interactions amongst social actors.
Indeed, links activation for each agent is not random and people tend to distribute their social events and attention toward already contacted nodes (strong ties), reserving a smaller amount of their social activity towards less frequently activated edges (weak ties). Moreover, social ties in real world networks are activated in a non-poissonian way, so that social interactions typically display an heterogeneous, heavy-tailed distribution of the waiting times. Using extensive datasets, we extract a simple form for the reinforcement mechanism leading to strong ties formations and we measure the bursty inter-event time distribution. We then propose an analytical approach to non-Markovian dynamics underlying the evolution of the network in the framework of activity driven models. Solving the master equation of the process, we obtain an asymptotic analytic form for the evolving degree distribution and for the average degree of the network, as a function of the activity probability distribution and memory parameters.
We find a non trivial phase diagram for the interplay of strong ties creations and burstiness and determine when they engages a competition to be the leading term of the dynamics. Interestingly, if ties reinforcement is sufficiently strong, burstiness can be suppressed and it can play a sub-leading role also in the presence of large fluctuations of the inter-event time distribution. We test our results against numerical simulations, and we compare the analytical predictions with large empirical datasets, finding a very good agreement between the two.

*Speaker

The Origin of Sparsity in the Interaction Networks of Living Systems

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Living systems are composed by interacting entities such as genes, individuals and species, with the ability to rearrange and tune their own interactions in order to achieve a desired output. A common property of the interaction networks of these living systems is their sparsity, i.e. the link density in the network scales inversely to the size of the system itself. In inanimate matter, particles or spins always have their mutual interactions turned on, with an intensity decaying with their relative distance, and the network describing their interaction is dense, with most of the interactions present. In contrast, for instance in an ecosystem, species interact selectively even if they coexist at short distances. Here we propose a theoretical framework which explains the emergent property of sparsity as a result of a search of an optimal network allowing a living system the maximal flexibility to explore the stationary states where it can stably persist adapting to the constraints imposed by the environment. We find that the tree-like structures are the optimal solutions which guarantee both the maximal explorability in the space of stationary solutions and the optimal asymptotic stability. Such a concomitance will be named convergent optimality. Higher connectivity, obtained as we increase the number of interactions in the system, lead to incremental difficulty to find a stationary solutions of the living system which are both stable and adapted to external conditions. The optimal solution is also self-similar when we deal with aggregation of communities, a situation that resembles the real-world complexity in living systems.

*Speaker

Scaling properties of dynamical fluctuations in temporal networks

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The factorial moments analyses are performed to study the scaling properties of dynamical fluctuations in temporal networks based on empirical data sets. The intermittent behavior is not evident between normalized factorial moment F_q and bin number M over the whole time range. But the strict power-law dependence of F_q on F_2, $F_q \sim F_2^{\beta_q}$, indicates that the interaction has self-similarity structure in time interval and the fluctuations are not purely random but dynamical and correlated. We further find that β_q has a well-fitted power-law relationship with $q-1$. The exponents are very close to that for systems undergoing second-order phase transition in Ginzburg-Landau theory and describe the strength of intermittent behavior in the dynamical fluctuations.

*Speaker

Percolation transitions following the cascades of activations and deactivations on multiplex lattices

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Many complex systems are best modeled by multiplex networks of layers of various types of connections. Functional cooperativity between network layers such as interdependency has shown to affect the percolation properties of multiplex networks by inducing discontinuity and hysteresis. Here we study the percolation transitions of the so-called multiplex viability models [B. Min and K.-I. Goh, Phys. Rev. E 89, 040802(R) (2014)] on two-layer square lattices. Depending on the way establishing the viability, either by the cascade of activations (CA) or by the cascade of deactivations (CD), the model was shown to exhibit different critical points and thereby hysteresis. In this study we found by extensive Monte Carlo simulations on two-layer square lattice that the two processes not only have different percolation transition points but also exhibit different critical behaviors with distinct sets of critical exponents. For CA, the order parameter exponent β and the correlation length exponent ν are obtained to be consistent with those of ordinary percolation (OP) in 2D. For CD, however, the transition belongs to different universality class from OP but shows the same critical behaviors as the 2D mutual percolation model. The viable cluster size distributions of the two processes show distinct behaviors from OP including the unusual exponent $\tau < 2$. The obtained results are tested for consistency through the scaling relations.

*Speaker

Zipf's law and Heaps' law do not hold for English books

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In Zipf-like systems, individual entities, here called tokens, can be classified into types. Zipf's law is verified when the number of tokens corresponding to any type is a power-law function of the type rank, with exponent close to one. A second formulation consists in performing the statistics of the number of types with the same number of counts, for which Zipf's law states a power-law distribution of type counts, with exponent around two. These two options are equivalent for qualitative purposes, but not in a quantitative sense, due to the discrete nature of the number of counts. In order to find which of the two formulations (if any) is the correct one, we need to properly fit each of them to empirical data. The difficulties of using maximum likelihood estimation for the rank representation are mentioned. Solving these inconveniences, we find that the rank version of Zipf's law is practically irrelevant for texts, whereas the type-count version fits a much larger set of books from Project Gutenberg. This has important consequences for the dynamics of the type-token growth (governed by the lowest counts, for which the two versions of Zipf's law are most diverging). We derive the form of the type-token growth curve for a random system fulfilling Zipf's law for the distribution of counts and show that this is not a power law, in contrast with the so-called Herdan's law or Heaps' law. Quite unexpectedly, real books are well fitted by our curve, signaling that, despite the fact words do not happen at random in texts, their first appearance seems indeed to be random. We acknowledge financial support from FIS2012-31324 and 2014SGR-1307 (Spanish MINECO and AGAUR). Bibliography F. Font-Clos and A. Corral, Physical Review Letters 114, 238701 (2015). I. Moreno-Sánchez, F. Font-Clos, and A. Corral, PLoS ONE 11(1), e0147073 (2016).

*Speaker

The path of growth of countries

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Keywords: Economic Complexity, Dynamical systems, Bipartite networks, Growth, Technology ecosystems
Which will be the growth of the Gross Domestic Product and the competitiveness of China, United States, and Vietnam in next 3, 5 or even 10 years? Despite this kind of question has a large societal impact and an extreme value for economic policy making and economic practice, how to provide a scientific basis for economic predictability is still a very challenging problem. Recent results of a new branch - Economic Complexity, EC hereinafter - set basis for a framework to approach such a challenge and provide new perspectives to cast economic forecast into the framework of forecasting the evolution of a dynamical system as in the case of weather dynamics. Economic Complexity refers to a new line of research, which portrays economic determinant of growth as a process of evolution of ecosystems of technologies and industrial capabilities [1-3]. Complex systems analysis, simulation, systems science methods, and big data capabilities offer new opportunities to empirically map technology and capability ecosystems of countries and industrial sectors, analyze their structure, understand their dynamics and measure economic complexity. This approach provides a new vision of a data driven fundamental economics in a strongly connected, globalized world. EC overturns the standard bottom-up approaches to assess economic systems' competitiveness: it does not go anymore from hardly commensurable and com-measurable endowments and capabilities to competitiveness but it instead uses the final output of an economy to assess in a synthetic estimate the endowments and the interaction networks of this endowments/determinants. Such a vision has lead to a data-driven approach close in spirit to the aim of the Google's algorithm (the PageRank) for the world wide web. Similarly to PageRank which measure the importance of a page from the network defined by the links among the website, we define an algorithm which measures the competitiveness (hereinafter fitness) of countries and the complexity of products from the final output of a country (as a proxy of the final output we use the bipartite network defined by countries and exported products - bilateral trade network). However, differently from PageRank, economic systems' features call for different and non-linear mathematical specifications to properly address the competitiveness of countries [1-4]. The mathematical specifications of the algorithm defining the two above-mentioned metrics are the results of the empirical features of this bipartite network. As a consequence of its nested structure, we expect a fit country to be able to produce a diversified set of products, and we expect a product to be produced just by those countries that have at least a minimum level of fitness. Thus a fit country produces many complex products, and a complex product is one that is produced only by a fit country. The two definitions are self-consistent and give rises to the coupled non-linear iterative equations defining the metrics which are the fixed points of these equations [1-2]. A major success of EC has been the understanding of the growth paths of countries [4]. This result relies on coupling the information deriving from this metrics with its natural economic counterpart the per capita Gross Domestic Product (GDPpc), the former is an assessment of the fundamentals of a country while the latter is somehow the current measure of this performance. By underpinning the discrepancy between these two economic dimensions, it is possible to develop a framework to uncover long-term hidden potential of growth or potential sources of risk for country economies. In practice, these two dimensions define a plane where it is possible to study the evolution of countries in a completely novel fashion with respect to standard approaches: we can address growth including heterogeneity, dynamics and non-linear feedbacks between determinants of growth (synthetically measured by the fitness) and the growth itself. In this plane we observe that country dynamics present strongly heterogeneous patterns of evolution. The flow in some zones is found to be laminar while in others a chaotic behavior is instead observed (see [4]). These two regimes correspond to very different predictability features of the country evolution: in the former regime we find strong predictable pattern while the latter scenario is characterized by a very low predictability. In such a framework, standard regressive approaches are no more the appropriate one to deal with such a heterogeneous scenario and new concepts, borrowed from dynamical systems theory, are needed. We will discuss how dynamical systems allow to frame economic forecasts in a novel perspective [4]. We will discuss how this scheme acts as a feature selector: it permits to select those events in the past which are candidates to be analogues to be used to assess the future evolution of the systems and, at the same time, it allows to assess the goodness of this selection and therefore it provides not only an estimate of the forecast but also the reliability (i.e. predictability) of the economic evolution prediction. In this perspective, we will be able for instance to provide an answer to which past has the higher chance to be informative to forecast the Vietnam's or Brazil's future on the mid-long term.We will see that developing a scheme

*Speaker

which allows to underpin the most fit analogues to provide an assessment of the evolution of the economic systems holds at a more detailed level as well. Similarly to the regularity of the paths of development in specific areas of the previously mentioned plane, we observe that there exist preferred paths of developed even at product/sector level. The industrialization and development process of an economic systems in order to achieve sustained growth tend to follow specific patterns which we will discuss. In addition the dynamics in the fitness-GDPpc plane is a natural playground to empirically provide a data-driven modeling of the economic feedbacks. In order to achieve such goal we discuss how to model and estimate the laws of motion of the dynamics defined by GDPpc and fitness borrowing techniques and methods from dynamical systems [7-9]. This kind of approaches has been proven to be effective in a wide range of fields from biology where they permitted a purely data-driven modeling of the laws of evolution of ecosystems [7] to social sciences where they reversed the longstanding casual relation between democratic degree and growth [8-9] and finally to economics where they have shown that forecasting country growth faces issue close to the prediction of the evolution of the weather [4]. We will also discuss how this framework permits to deal with the so-called economic traps and to define clear Stylized Facts for the different regime of growth of countries (exit from the poverty trap, catching up, maturity) and permits to discuss in a generalized way the reversion to mean of growth rates [6]. EC has received a massive attention on the press (e.g. [10]) and has been discussed in an editorial by Nature [11]. EC has been proven to be of great interests not only for academicians but also for practitioners as witnessed by collaborations with the IPPR [12], the Italian Ministry for Foreign Affairs, Alibaba, Shell, Boston Consulting Group [13] and Azimut group. References [1] Tacchella, A.; Cristelli, M.; Caldarelli, G.; Gabrielli, A. ; Pietronero, L. Scientific Reports [Online] 2012, 2, 723 [2] M. Cristelli, A. Gabrielli, A. Tacchella, G. Caldarelli and L. Pietronero, Measuring the Intangibles: A Metrics for the Economic Complexity of Countries and Products, PLOS One Vol. 8, e70726 (2013) [3] A. Tacchella, M. Cristelli, G. Caldarelli, A. Gabrielli, L. Pietronero, Economic complexity: conceptual grounding of a new metrics for global competitiveness, Journal of Economic Dynamics and Control, 37(8), 1683-91 (2013) [4] Cristelli, M.; Tacchella, A.; Pietronero, L. PLoS ONE [Online] 2015 10(2): e0117174. doi: 10.1371/journal.pone.0117174 [5] M. Cristelli, A. Tacchella, A. Zaccaria, L. Pietronero, Development and growth paths of subsaharan countries in the framework of economic complexity (submitted, 2015) [6] Lant Pritchett, L.; Summers, L.H. NBER Working Paper 2014 No. 20573 [7] Ye, H.; Beamish RJ.; Glaser SM.; Grant SCH.; Hsieh CH.; Richards LJ.; Schnute JT.; Sugihara G. 2015 PNAS 112 E1569-E1576 [8] Ranganathan, S.; Spaiser, V.; Mann, R.P.; Sumpter, D. J.T. PLoS ONE [Online] 2014 9(1). e86468. [9] Spaiser, V.; Ranganathan S.; Mann, R. P.; Sumpter D.J.T., PLoS ONE [Online] 2014 9(6). e97856. [10] Buchanan M., Bloomberg Views [Online] 2015 http://www.bloombergview.com/articles/2015-03-01/china-might-still-be-booming [11] Van Noorden, R., Nature News [Online] 2015 http://www.nature.com/news/physicists-make-weather-forecasts-for-economies-1.16963?WT.mc_id=TWT_NatureNews [12] Institute for Public Policy Research: Gathering Strength, Backing clusters to boost Britain's exports. [Online] Dec. 2014 [13] Alsén, A. et al. National Strategy for Sweden: From Wealth to Well-being BCG press 2013

Competition of simple and complex adoption on multi-layer networks

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We consider two different mechanisms for adoption processes, named as simple and complex adoption and we couple them in a two layered system. Dynamics in one of the layers is governed by a threshold model (complex adoption), where individuals change internal states based on the global state of their neighbourhood (social reinforcement). The second layer follows SIS rules of dynamics (simple adoption), where individuals states are a result of successive and independent contacts with others. threshold dynamics leads to a discontinuous transition between adoption (endemic) and non-adoption (healthy) phases. In contrast, SIS contagion leads to a continuous transition from healthy to endemic phase. We address the question of the competition between these two adoption or spreading processes when they are coupled, and we discuss what type of transition will happen in this coupled mixed dynamics. We look for the critical values of the two parameters controlling the spreading processes, i.e., individuals thresholds θ_c for adoption and adoption probability λ_c in SIS. We discuss their dependence on the interlayer connectivity m and on the average intralayers connectivities. We find that θ_c increases with m, whereas in the case of an isolated single network it would decrease with average connectivity. In addition the transition in the threshold layer becomes continuous when the interlayer connectivity is increased. In the SIS layer we find that there are two transitions when interlayer coupling is present. A first discontinuous transition from non-adoption to adoption phase occurs for an infection probability that equals zero when coupling is present (any $m > 0$). A second transition occurs for $\lambda \approx \theta_c$, leading to an abrupt decrease of the number of adopters.

*Speaker

Stochastic model for phonemes uncovers an author-dependency of their usage

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We study rank-frequency relations for phonemes, the minimal units that still relate to linguistic meaning. We show that these relations can be described by the Dirichlet distribution, a direct analogue of the ideal-gas model in statistical mechanics. This description allows us to demonstrate that the rank-frequency relations for phonemes of a text do depend on its author. The author-dependency effect is not caused by the author's vocabulary (common words used in different texts), and is confirmed by several alternative means. This suggests that it can be directly related to phonemes. These features contrast to rank-frequency relations for words, which are both author and text independent and are governed by the Zipf's law.

*Speaker

Efficient dynamic algorithm to study the resilience of multiplex networks

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Mutually connected components (MCCs) in multiplex networks play an important role as a measure of resilience in multi-layered systems. Despite their importance, an efficient algorithm to obtain the statistics of all MCCs during the removals of links had thus far been absent. Here, we introduce an efficient algorithm to accomplish this task using a well-known fully dynamic algorithm for graph connectivtivy. We show that the time complexity of this algorithm is approximately $O(N^1.2)$ for random graphs, which is more efficient than $O(N^2)$ of the brute-force algorithm. We confirm the correctness of our algorithm by comparing the behavior of the order parameter as links are removed with existing results for three types of double-layer multiplex networks: (i) ER random graphs, and (ii) scale-free random graphs, in which degree of a node in one layer is stochastically the same as the one of the corresponding node in the other layer, and (iii) two-dimensional regular lattices. We also applied our algorithm to investigate the percolation transition of MCCs in multiplex networks. The percolation transition is hybrid phase transition in which both characteristics of discontinuous and continuous phase transitions exist together. The critical exponents and scaling relations are obtained successfully from the numerical simulations with our algorithm.

*Speaker

Which publication is your representative work?

Ying Fan * [1], Qikai Niu, Jianlin Zhou, An Zeng, Zengru Di

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As much effort has been made to accelerate the publication of research results, nowadays the number of papers per scientist is much larger than before. In this context, how to identify the representative work for individual researcher is an important yet uneasy problem. Addressing it will help policy makers better evaluate the achievement and potential of researchers. So far, the representative work of a researcher is usually selected as his/her most highly cited paper or the paper published in top journals. Here, we consider the representative work of a scientist as an important paper in his/her area of expertise. Accordingly, we propose a self-avoiding preferential diffusion process to generate personalized ranking of papers for each scientist and identify their representative works. The citation data from American Physical Society (APS) is used to validate our method. We find that the self-avoiding preferential diffusion method can rank the Nobel prize winning paper in each Nobel laureate's personal ranking list higher than the citation count and PageRank methods, indicating the effectiveness of our method. Moreover, the robustness analysis shows that our method can highly rank the representative papers of scientists even partial citation data are available or spurious behaviors exist. The method is finally applied to revealing the research patterns (i.e. consistency-oriented or diversity-oriented) of different scientists, institutes and countries.

*Speaker

A Weird Fate for Words: A Stochastic Usage-Based Model of Meaning Change

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The meaning of words is sometimes slippery as an eel, and can be affected drastically throughout the history of language. "Weird", for instance, has known a vast variety of fortunes. Its Indo-European root meant "turning", and from this it came to be used for "become" (see "werden" in German), which brought forth the idea of fate – that is, what is to become. Then, as fate, in the Old English world view, was woven by the three Norns, the so-called "weird sisters", which were reputedly strange in appearance, "weird" has been reinterpreted as referring to their physical oddities instead of their specific function. Yet, such changes in meaning does not come up for obvious reasons. As language is entrenched by large communities of speakers, and correspond to an established convention, why would it ever come to change? Several explanations have been proposed: language can become a marker of social groups which would then want to have their own way of speaking [1], it can be affected by historical and cultural vicissitudes [2], or it can also be mislearned by new generations of speakers [3]. However, one observes strong regularities in patterns of language changes across languages [4], and none of the above scenarios account for them. Another puzzling fact arises in the so-called grammaticalization processes, by which a word happens to acquire a new functional use. For instance, the word "about", initially meaning "in the neighborhood of", can now be discursively used in sentences such as "What about this one?", or even in prospective uses such as "The end is about to begin". In such a process, the meaning of a word becomes so wide that it is said to be blurred, or "bleached" [5]. At the same time, it can also be seen as a semantic enrichment [6]. How to reconcile these two views, both true in their own way? To explore these questions, we first quantitatively tracked language changes from corpora, which can be done since when a word gains a new meaning or function, its frequency tends to increase accordingly. We made use of the Frantext database, composed of texts of significant proportions reflecting the trends of written French from different periods of time. Over several hundreds cases of language changes, we observe a prototypical pattern: a long latency phase - the frequency of the word as it shows up in new contexts remains low, but above zero -, followed by a rapid change with a sigmoidal shape of the evolution of this frequency. Whereas the sigmoidal pattern has already been the subject of studies in the literature, the highlighting and characterization of the latency phase is new. To our knowledge, this is the first large scale quantitative study of language change. Next, we propose a stochastic usage-based model of language accounting for both the latency phase and the rapid transition which follows. The model is designed to mimic the cognitive processes at work when people are producing and interpreting language [7]. To each meaning, we attach a population of occurrences, that is, words that have been repetitively used to express this meaning. Change is initiated by a basic mechanism: meaning is not an isolated monad, but rather evokes other meanings through asymmetric associations, so that there may be leaks from one meaning to another. Consequently, as language is used, diffusion in semantic space occurs: the population of a given meaning invades the population of related meanings, by which process a word gains new semantic territory. The strength of the conceptual association between meanings provides a control parameter which governs a transition between staticity and change. Close to the transition, we observe a long latency phase: The frequency of the invading word in the newly achieved meaning remains low during a long period of time, positing the near-critical linking between meanings as a suitable explanation of the empirically observed lurking behavior. In addition, the model predicts the "bleaching" mechanism evoked above. [1] Baxter, G. J., Blythe, R. A., Croft, W. & McKane A. J., "Utterance selection model of language change", Physical Review E, vol. 73, n° 4, pp. 46-118, 2006. [2] Meillet, A., Linguistique historique et linguistique générale, Champion, 1948. [3] Kirby, S., " Spontaneous evolution of linguistic structure-an iterated learning model of the emergence of regularity and irregularity ", IEEE Transactions on Evolutionary Computation, vol. 5, n° 2, pp. 102-110, 2001. [4] Heine, B., Cognitive foundations of grammar, Oxford University Press, 1997. [5] Givón, T., On understanding grammar, Academic Press, 1979 [6] Carlier, A., & Lamiroy, B., "The grammaticalization of the prepositional partitive in Romance", Partitive Cases and Related Categories, De Gruyter, pp. 477-419, 2014. [7] Feltgen, Q., Fagard, B. & Nadal, J.P., "Représentation du langage et modèles d'évolution linguistique : la grammaticalisation comme perspective", TAL, vol. 55, n° 3, pp. 43-71, 2014.

*Speaker

Collective versus hub activation of epidemic phases on networks

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The study of epidemic processes on complex networks represents one of the cornerstones in modern network science. Capital in this field was the discovery of the effects of a complex, scale-free (SF) topology, given in terms of a degree distribution with a power-law form, $P(k) \sim k^{-\gamma}$, in the position of the critical point of a epidemic transition in networks. Based on initial studies made in terms of heterogeneous mean-field theories, it was observed that epidemic thresholds in most disease spreading models were inversely proportional to the second moment of the degree distribution, $\lambda_c \sim 1/\bar{k^2}$. These results led to the conclusion that the epidemic threshold vanishes in SF networks with $\gamma \leq 3$, while it is finite for $\gamma > 3$. Additional research, based on more sophisticated theoretical approaches and extensive numerical simulations, indicated that some epidemic models, such as the susceptible-infected-susceptible (SIS) model, have instead a vanishing threshold for any value of γ. In this contribution, we present a general analysis of epidemic models on networks, based in the comparison of hub lifespan and mutual infection time. According to the balance of these two quantities, we propose that epidemic models can be divided in two radically different classes: In the case that the hub lifespan is larger than the hub infection time, epidemic transitions are ruled by a local hub activation dynamics: hubs (nodes with the largest degrees) remain active for very long times, and are able to infect each other, establishing a long-lived macroscopic infected state. In this case, a diverging hub lifetime will originate a vanishing threshold in the thermodynamic limit. On the other hand, when the hub lifespan is smaller than the hub infection time, possible epidemic transitions cannot be due to hub activation, and must be accounted for by a the collective activation of the whole network, in what amounts to a standard phase transition. By means of analytic calculations and numerical simulations for different epidemic models on synthetic and real networks, we show the robustness of our results. In particular, a waning immunity, irrespective of its strength, leads to collective activation with finite threshold in scale-free networks with large exponent, at odds with canonical theoretical approaches.

*Speaker

Cycle-based Cluster Variational Method for Direct and Inverse Inference

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Inference problem in machine learning like for example traffic inference on large scale road networks can be addressed with help of Markov random fields and belief propagation algorithms. There are two related problems here, the first one is to find off line the parameters of the MRF from empirical data (inverse problem); the second one (direct problem) is to make the inference algorithm as precise and fast as possible to be able to deal with real time and large scale applications. In this work we address both the direct and inverse problem. We elaborate on the idea that loop corrections to belief propagation could be dealt with in a systematic way on pairwise Markov random fields, by using the elements of a cycle basis to define region in a generalized belief propagation setting. The region graph is specified in such a way as to avoid dual loops as much as possible, by discarding redundant Lagrange multipliers, in order to facilitate the convergence, while avoiding instabilities associated to minimal factor graph construction. We end up with a two-level algorithm, where a belief propagation algorithm is run alternatively at the level of each cycle and at the inter-region level. The inverse problem of finding the couplings of a Markov random field from empirical covariances can be addressed region wise. It turns out that this can be done efficiently in particular in the Ising context, where fixed point equations can be derived along with a one-parameter log likelihood function to minimize. Numerical experiments confirm the effectiveness of these considerations both for the direct and inverse MRF inference, in particular where large scale heterogeneous graphs can be dealt with. [1] C. Furtlehner, A. Decelle, arXiv:1602.03102 (2016)

*Speaker

Estimating topological properties of weighted networks from limited information: applications to socio-economic field

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A problem typically encountered when studying complex systems is the limitedness of the information available on their topology, which hinders our understanding of their structure and of the dynamical processes taking place on them. A paramount example is provided by financial networks, whose data are privacy protected: Banks publicly disclose only their aggregate exposure towards other banks, keeping individual exposures towards each single bank secret. Yet, the estimation of systemic risk strongly depends on the detailed structure of the interbank network. The resulting challenge is that of using aggregate information to statistically reconstruct a network and correctly predict its higher-order properties. Standard approaches either generate unrealistically dense networks, or fail to reproduce the observed topology by assigning homogeneous link weights. Here [1,2], we develop a reconstruction method, based on statistical mechanics concepts, that makes use of the empirical link density in a highly nontrivial way. Technically, our approach consists in the preliminary estimation of node degrees from empirical node strengths and link density, followed by a maximum-entropy inference based on a combination of empirical strengths and estimated degrees. Our method is successfully tested on the international trade network and the interbank money market, and represents a valuable tool for gaining insights on privacy-protected or partially accessible systems. [1] G. Cimini, T. Squartini, A. Gabrielli, and D. Garlaschelli, Phys. Rev. E vol. 92, 040802(R) (2015). [2] G. Cimini, T. Squartini, D. Garlaschelli, A. Gabrielli, Scientific Reports vol. 5, 15758 (2015).

*Speaker

Statistical physics and melting Arctic sea ice

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Polar sea ice is a key player in the climate system and a critical indicator of climate change. For example, it reflects sunlight and helps mitigate solar heating of the Arctic Ocean. During late spring and summer, sea ice reflectance or albedo, a principal parameter in climate modeling, is largely determined by the evolution of surface melt ponds. As the ponds grow and coalesce, their fractal dimension undergoes a transition from 1 to about 2, around a critical length scale of 100 square meters in area. The ponds take on complex, self-similar shapes with boundaries resembling space-filling curves. I will discuss how methods from statistical physics, such as percolation, network and Ising models, are being used to quantitatively describe melt pond evolution and to address other multiscale problems in sea ice physics. Our work is helping to advance how sea ice is represented in climate models and to improve climate projections.

*Speaker

Simplicial characterisation of time series networks: Theory and an application

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We set up characterisers of time series network graphs obtained from time series using the visibility algorithm. Our characterisers are set up using methods of algebraic topology and are both global and local in nature. Quantities like structure vectors and local entropies are set up using these methods. These methods have proved to be useful in picking up the edge of the jamming transition in traffic on networks and in identifying chaotic regimes of evolving dynamical systems. Here we apply these techniques to neural time series obtained from ten subjects carrying out reading tasks. Our techniques are successful in identifying differences between adult and child readers, and also between subjects reading their mother tongue and other languages.

*Speaker

Layer-switching cost and optimality in information spreading on multiplex networks

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We study a model of information spreading on multiplex networks, in which agents interact through multiple interaction channels (layers), say online vs.offline communication layers, subject to layer-switching cost for transmissions across different interaction layers. The model is characterized by the layer-wise path-dependent transmissibility over a contact, that is dynamically determined dependently on both incoming and outgoing transmission layers. We formulate an analytical framework to deal with such path-dependent transmissibility and demonstrate the nontrivial interplay between the multiplexity and spreading dynamics, including optimality. It is shown that the epidemic threshold and prevalence respond to the layer-switching cost non-monotonically and that the optimal conditions can change in abrupt non-analytic ways, depending also on the densities of network layers and the type of seed infections. Our results elucidate the essential role of multiplexity that its explicit consideration should be crucial for realistic modeling and prediction of spreading phenomena on multiplex social networks in an era of ever-diversifying social interaction layers. This presentation is based on the work published in [B. Min, S.-H. Gwak, *et al.* Sci. Rep. **6**, 21392 (2016)].

*Speaker

Cooperative Effects on Epidemic Dynamics

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We discuss the nature of phase transitions in the generalized epidemic process (GEP) [1,2] and its variant with two different diseases [3] as the network topology varies. In order to study the crucial role of cooperative contagion in epidemic dynamics, we study that positive feedback by multiple infected neighbors can accelerates outbreaks on modular and random networks [3]. The basic dynamics of the GEP is based on the well-known "Susceptible-Infected-Recovered" (SIR) model, which exhibits a continuous phase transition at the outbreak threshold and belongs to the ordinary bond-percolation universality class in the mean-field regime. However, the cooperative effect on the GEP yields both continuous and discontinuous phase transitions as well as the tricriticality in between. Both modularity and homogeneity of networks change not only the location of outbreak thresholds, but also yield the nature of phase transitions. In particular, we focus on the exact phase diagram and the universality class of the GEP for threshold scaling behaviors, where we employ the generating function method as the analytic technique and the extended finite-size scaling theory as the numerical analysis for Monte-Carlo simulation data. Finally, we consider the GEP with heterogeneity of networks [4] and argue the scenario of discontinuous phase transitions: whether phase coexistence exists or not. Our analytic results and intuitive arguments are numerically checked, which are also compared with those for continuous phase transitions. This work has been supported by the National Research Foundation of Korea (NRF) funded by Korea government [Grant No. 2014R1A1A4A01003864].

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*Speaker

Modelling the "peak-end rule" of behavioural economics: random walkers with extreme value memory

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Motivated by the psychological literature on the "peak-end rule" for remembered utility, I will describe a recent analysis within a random walk framework of a discrete choice model where agents' future choices depend on the peak memory of their past experiences. In particular, this approach can be used to investigate whether increased noise/disruption always leads to more switching between decisions. Here extreme value theory illuminates different classes of dynamics indicating that the long-time behaviour is dependent on the scale used for reflection; I will briefly discuss implications and possible future extensions of these results. [Based on: R. J. Harris, New J. Phys. 17 053049 (2015).]

*Speaker

Multilayer network approach to mutualistic ecosystems

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Ecosystems research, and particularly the study of mutualistic communities (like plant-pollinators or plant-seed dispersers), witnessed a major leap in the last decade under the auspices of two great advances: the exploitation of nonlinear dynamics, aimed at explaining the evolution of those communities beyond the linear random matrix interaction model of May [1], and the ontroduction of a networked perspective that uncovered the consequences of certain structural arrangements of the system [2, 3].
Bipartite matrices describing mutualistic ecosystems, display a particular structure called nestedness [4–7] which reveals that the interactions are not uniformly distributed. Instead, these systems consist of specialist and generalist species (having a small and a large number of counterparts, respectively) of both guilds, with a marked tendency of specialists species of eachguild to interact with a generalist counterpart, while the interaction between specialist species is rare.
Indeed, it was by surpassing the mean-field approach (where any species of each guild may interact with any species of the other), through the introduction of actual inter-guild mutually beneficial interactions, that the concept of nestedness was introduced in mutualistic settings. Since then, its role in the coevolutive behavior of ecosystems is discussed, in particular, the hypothesis that nestedness screens competition, thus facilitating the coexistence of interacting species [3]. Additionally, nestedness has emerged as a rather common mesoscale pattern in complex bipartite networks, suggesting that other systems, beyond ecological communities [8–11], may follow a similar competition-minimization logic [3].
However, the bipartite representation fails to incorporate intra-guild (competitive) links –so far accounted for within a mean-field approach–, precluding current research to develop an even more realistic framework. A representation upgrade is then necessary, which may include any (positive, negative) interaction in a parsimonious way.
An interesting way to do so, is to represent the ecosystem in terms of a multilayer network, as this allows us to to encode different types of nodes and links in a network, in a unified manner. Some attempts already exist in the ecosystems arena [12–14], and yet they have not been formulated explicitly in the language of multilayer systems.
In this work, we propose a novel way to encode both competitive (intra-guild) and mutualistic (inter-guild) interactions, under the shape of a multilayered bipartite network. Then, we explore how this updated representation affects the outcome of mutualistic dynamics. Our work, as per numerical simulations and analytic approximation, points at unexpected results which call for a reconsideration of previous findings in theoretical ecology, as they may affect our understanding of structural and dynamical stability.
In particular our results reveal the important role played by the network structure of the inter-species competition term, on the structural stability of the system. When this interaction is treated in the mean-field approximation, thus considering a single layer bipartite network, the persistence of biodiversity is independent of the intensity of mutualism. On the contrary, in the multi-layer approach that includes both the structure of the mutualistic and in the interspecies competition interactions, the region of the parameter space, where the biodiversity persists, depends non trivially on the intensity of both, mutualism and competition. In other words, increasing the intensity of mutualism (for a given network) does not necessarily increase biodiversity.

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Sequential Visibility Graph Motifs

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Visibility algorithms transform time series into graphs and encode dynamical information in their topology, paving the way for graph-theoretical time series analysis as well as building a bridge between non-linear dynamics and network science. In this work we present the sequential visibility graph motifs, smaller substructures of n consecutive nodes that appear with characteristic frequencies inside visibility graphs. We show that the motif frequency profile is a highly informative feature which can be treated analytically for several classes of deterministic and stochastic processes and in general computationally efficient to extract. In particular we have found that this graph feature is surprisingly robust, in the sense that it is still able to distinguish amongst different dynamics even when the signals are polluted with large amounts of observational noise, what enables its use in practical problems such as classification of empirical time series. As an application, we have tackled the problem of disentangling meditative from general relaxation states from the horizontal visibility graph motif profiles of heartbeat time series of different subjects performing different activities. We have been able to provide a positive, unsupervised solution to this question by applying standard clustering algorithms on this simple feature. Our results suggest that visibility graph motifs provide a mathematically sound, computationally efficient and highly informative simple feature which can be extracted from any kind of time series and used to describe complex signals and dynamics from a new viewpoint. In direct analogy with the role played by standard motifs in biological networks, further work should evaluate whether visibility graph motifs can be seen as the building blocks of time series. References: [1] Lacasa L. et al. "From time series to complex networks: The visibility graph." Proceedings of the National Academy of Sciences 105.13 (2008): 4972-4975. [2] Iacovacci J. and Lacasa L. "Sequential visibility graph motifs" (2015) (Accepted for publication in Physical Review E)

*Speaker

Statistical Physics of Evolutionary Games: from the emergence of cooperation to optimization problems

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We introduce an analytical model for studying the evolution towards equilibrium in spatial games. In particular, we focus our attention on the spatial Prisoner's Dilemma and on the spatial Public Goods Game, as they constitute emblematic examples of games whose Nash equilibrium is defection. Previous investigations showed that, under opportune conditions, it is possible to reach, in both games, an equilibrium of cooperation. Notably, it seems that mechanisms like motion and rewards may lead a population to become cooperative. In the proposed models, we map agents to particles of a gas so that, on varying the system temperature, they randomly move. In doing so, we are able to identify a relation between the temperature and the final equilibrium of the population, explaining how it is possible to break the classical Nash equilibrium in the spatial Prisoner's Dilemma. Furthermore, we show the critical role of the temperature in the Public Goods Game. Eventually, we introduce a formalism to study order-disorder phase transitions in these dynamics. As result, we highlight that the proposed model allows to explain analytically how a population, whose interactions are based on defection-based games, may reach an equilibrium far from the expected one; opening also the way to define a direct link between evolutionary game theory and statistical physics. To conclude, a final application showing how the proposed models can be used for solving the Travel Salesman Problem is presented.

*Speaker

Critical behaviors of hybrid phase transitions for percolation-type models

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Hybrid phase transition (HPT) has been often observed in diverse complex systems and thus draws considerable attention from statistical physics community. The HPT means that the order parameter exhibits properties of continuous and discontinuous transitions at the transition point. While recent studies of the HPT focused on whether the order parameter is continuous or discontinuous, one of the fundamental questions how the critical behavior of the HPT is exerted by the discontinuity of the order parameter has not been thoroughly investigated yet. Here, we study the critical behaviors including diverging behaviors of the susceptibility and the correlation length (or size), and the scaling and the hyperscaling relations between the critical exponents of the HPT for several percolation-type models in either cluster merging or deleting processes. Based on numerical and analytical results, we reach the conclusion that the conventional theory for the critical behavior of the second-order transition need to be reestablished for the HPT, particularly for the hyperscaling relations.
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*Speaker

Kinetics of social contagion

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There are remarkable analogies between the social contagion of information, behavioural patterns or innovation and some physical or epidemic spreading processes, where global phenomena emerge through the diffusion of microscopic states. All evolve in networks with nodes characterised by relevant state variables, and links that represent direct interactions between nodes. In biological systems epidemics are driven by binary interactions that lead to the emergence of "simple contagion" phenomena. Social diffusion processes are usually characterised by " complex contagion" mechanisms, where node states are determined by comparing individual thresholds with all neighbour states. This property, capturing the effect of peer pressure and commonly assumed in social spreading phenomena, has consequences on the dynamics and the final outcome of the contagion process. Moreover, the theoretical approach to these systems has much in common, which greatly helps us to understand their behaviour. Models employing threshold mechanisms mostly focus on cascading phenomena where, under some circumstances, a macroscopic fraction of nodes in the network is converted rapidly due to microscopic perturbations. This approach, motivated by earlier social theories, has been implemented by Watts in an elegant model of cascading behaviour [1]. Watts showed that a global cascade (occupying a macroscopic fraction of the network and induced by local perturbations) can occur due to the interplay between network structure and individual thresholds. He further identified the phase with a non-zero probability of global cascades in the space of the average threshold of nodes and the average degree of the network. While the relevance of this model is indisputable, its limitations become clear from real social spreading data. The Watts model focuses on the (instantaneous) emergence of global cascades triggered by single local perturbations, while in reality there are empirical examples where threshold mechanisms do play a role yet global adoption phenomena emerge slowly and often not induced by microscopic perturbations but by a larger fraction of people. Moreover, decisions of individuals depend on external impulses arriving from mass media or advertising, resulting in a perpetual stochastic perturbation. In addition, there are individuals entirely reluctant to adopt. Furthermore, since the Watts criterion for macroscopic adoption is purely deterministic, coded in the network structure, threshold distribution and perturbation site – it does not concern time, which is clearly a feature of empirical stochastic processes of adoption spreading. In this work we present a general threshold-driven model [2] of social contagion phenomena that captures various spreading scenarios, ranging from rapid cascading behaviour to dynamically evolving non-explosive patterns, and sheds light to the different kinetics behind them. Motivated by empirical observations, we extend Watts' threshold model by considering blocked nodes, which are immune to social influence and discuss their effect on cascade formation. In addition, we introduce spontaneous adopters with a constant rate, and present analytical and numerical results based on an Approximate Mean Field solution. In particular we find that, as a function of the blocked node density, there is a transition from fast to slow spreading governed by entirely different mechanisms. This transition happens below the percolation threshold of network fragmentation, and has its origin in the competition between cascading behaviour induced by adopters, and annealing due to blocked nodes. This change is accompanied by a percolation transition of the induced clusters. [1] D. J. Watts, Proc. Natl. Acad. Sci. USA 99, 5766 (2002). [2] Z. Ruan, G. Iñiguez, M. Karsai, and J. Kertész, Phys. Rev. Lett. 115, 218702 (2015).

*Speaker

Cascading collapse of an online social network: Data analysis and theory

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The largest Hungarian online social network (OSN) service, iWiW, was launched 2002 and stopped functioning 12 years later. 2010, at its peak, it had 4.2 million accounts (the number of Hungarian speaking people is 13 million around the globe). With this unique data set about the full life cycle of an OSN we show how a complex contagion process [1] leads to the rapid collapse of the site. There are two main governing factors: The exogenous flow of information about Facebook, the international, successful competitor and the peer pressure. At the early stage the former one dominates the decline. We identify the time dependence of the interest in the competitor by Google trend and conclude that the rate of churners increases linear in time. At later stage the cooperative effect of peer pressure sets in resulting in cascades of churners, which accelerate the process and causes the final, rapid collapse. We measure the threshold for the peer pressure (the rate of churning neighbors at leaving the OSN) and conclude that the early churners have most of their friends active while the later ones leave when about half of their friends already left. A generalized contagion model based on simple assumptions about the underlying network, the information flow and the threshold distribution reproduces the observations very well. [1] Z. Ruan, G. Iniguez, M. Karsai, J. Kertesz: Kinetics of Complex Contagion, PRL, 115, 218702 (2015)

*Speaker

Backup pathways in metabolic networks

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Living organisms perform diverse functions while confront continually internal and external perturbations. Such stability must be supported by the structural and functional organization of cellular networks, which remain to be understood. In particular, multiple pathways can be beneficial to help the related elements to remain connected when a pathway is broken as long as they are organized efficiently. Here we investigate the genome-scale metabolic networks of hundreds of species. We first compute the biconnected components, in which every pair of nodes are connected by at least two paths, and find their difference from those in randomized networks. This result allows us to define the cross-species biconnectivity of individual metabolites, which turns out to be an indicator of the metabolites' vulnerability, quantified by the average prevalence of their associated diseases. Next, we compute the contribution of each reaction to generating biomass components by flux-balance analysis to classify the functional importance of each reaction into four ranks and identify the pairs of reactions which back up each other. We find that the fraction of backup pairs is widely varying from species to species while that of essential reactions is not significantly varying. Inferring the rank of each reaction in all nodes in the phylogenetic tree by the maximum parsimony, we find that essential reactions, which absence may stop the biomass generation, tend to change to active ones, implying backup pathways may have been introduced to reduce their lethality. Cross-species analysis allows us to define the essentiality and backups of individual reactions, which are correlated with each other and with the evolutionary age as well, helping us to understand how cellular networks organize multiple pathways by evolution.

*Speaker

Surrogate-assisted network analysis of nonlinear time series

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A recent milestone in the field of statistical physics has been complex network theory [1]. The constituents of complex systems are translated into the nodes of a network and their interactions are represented as edges. While this procedure is straightforward for systems like social or neural networks, there is no "natural" way of how to create a network from a time series. In this contribution, we compare recurrence networks [2] and symbolic networks [3] to the nonlinear prediction error concerning their performance in detecting nonlinearities in time series [4]. The tests are based on surrogate data sets, uncovering the disparity of the different surrogate generating algorithms. For synthetic data of the Lorenz system, the network measures show a comparable performance. In the case of relatively short and noisy real-world data from active galactic nuclei, the nonlinear prediction error yields more robust results than the network measures. In addition, we examine the correlations in the Fourier phases of data sets from some surrogate generating algorithms. The phase correlations tend to (anti)correlate with the measures of nonlinearity and can thus be held responsible for the weak performance of the algorithms in question. These findings may further increase the knowledge of the role the Fourier phases in the field of time series analysis [5]. [1] R. Albert and A.-L. Barabási, Rev. Mod. Phys. 74, 47 (2002) [2] R. V. Donner, Y. Zou, J. F. Donges, N. Marwan, and J. Kurths, New J. Phys. 12, 033025 (2010) [3] X. Sun, M. Small, Y. Zhao, and X. Xue, Chaos 24, 024402 (2014) [4] I. Laut and C. Räth, submitted to Phys. Rev. E. (2016) [5] C. Räth and I. Laut, Phys. Rev. E 92, 040902(R) (2015)

*Speaker

Quantitative analysis on contrast effect in the evolution of paintings

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Painting is an integral component of art and culture as a major outlet of creative expression. Like literature and music, the style and content of paintings have undergone continuous change throughout history. The use of color for contrast effect is one of key elements that characterize a painting. In this study, we propose a statistical mechanics-inspired methodology for quantifying the color contrast in a painting that takes into account two essential ingredients of color contrast in a unified form, the color difference between nearby pixels and patches of pixels similar colors. Based on this method we analyze a large set of 179,836 paintings collected from high-quality online painting archives. Our analysis suggests three distinct periods of color contrast, which can be attributed to emergence of fundamental technical developments. We study the correlation of three factors, namely technique, genre, and school, with stylistic changes in painting. We also investigate individual artistic styles for modern painters. Our work contributes towards the development of scientific methods for stylometric analysis of cultural artifacts.

*Speaker

Land use and density in the European city: monocentric analysis and scaling laws

Rémi Lemoy * [1], Geoffrey Caruso

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In this work we study the profile of land use and population density in European cities with respect to the distance to the city centre. More specifically, we address the scaling of land use and density curves with respect to city population and rely on fine grained land use data. Considering that the city has one center around which activities are organized is the so-called "monocentric" approach, which is widely used in the city modelling literature. Our main objective is to retrieve generic laws that can support the calibration or comparison to reality of monocentric urban models for European cities. We use the GMES Urban Atlas database, providing a precise description of land use at 5m resolution in the 305 major European urban areas (more than 100 000 inhabitants). We combine this dataset with population density from the Geostat population grid, which covers the whole of European Union (EU) with a $1km^2$ resolution. Population is allocated proportionally to surface and weighted by soil sealing and density classes of the GMES data. We analyse the evolution with distance to the city centre, which we define for convenience as the location of the city hall, of population density and of the share of land used for different purposes: housing, roads, railways, urban green, water, agriculture, forest. To this end, we define concentric rings of fixed width around the city centre, in which we average each land use and population. In order to compare different cities and to identify a global picture, i.e. a standard representative European city, we study scaling relationships for the obtained monocentric land use shares and density curves. We analyse the scaling of these curves with respect to city population, following similar approaches conducted in the literature for different variables (such as income or road space). The total population for each city is computed from the population grid. We find that land use curves, in particular housing and roads shares, tend to scale like the square root of city population. Population curves have roughly exponential shapes, as it has been widely modelled in the literature, although usually not based on land use and soil sealing data but census data with raw densities. These curves tend to scale like the city population to a power close to 1/3. Considering that the city population is a measure of the "volume" of a city, this work shows that housing and road surfaces are roughly proportional to this volume and have a similar internal structure in different cities, and that population densities, whose sum on the whole city corresponds to this volume, have a similar structure across different cities. These results allow us to propose a simple monocentric description of land use shares and population curves in a generic European city, whose size can be chosen based on the scaling relationships we obtain. This result is especially interesting, and of practical use, for the purpose of calibration and validation of monocentric urban models.

*Speaker

Spatial scaling in cities: a unified model for population, road network, and socioeconomic interactions

Ruiqi Li * [1], Lei Dong, Jiang Zhang, Xinran Wang, Wenxu Wang

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The interaction and cooperation of people in cities have created more than half of the wealth and 90% of the innovation in the world. However, the quantitative prediction of the spatial distributions of three main elements, population, roads, and socioeconomic interactions, remains challenging. Here, we propose a "spatial attraction" mechanism to reproduce the observed spatial scaling of these three elements. The key to our success lies in the use of the active population, a mixture of the residential and working populations, to quantify spatial attraction. All numerical and theoretical results are consistent with empirical data on 10 representative cities. Our model provides a general explanation for the origins of the universal super- and sub-linear aggregate scaling laws and offers a precise prediction of kilometre-level socioeconomic activity. Our work opens a new avenue to uncovering the evolution of cities in terms of the interplay among elements and has broad applications.

*Speaker

Topological mechanics and phononics

Tom Lubensky * [1]

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Frames consisting of nodes connected pairwise by rigid rods or central-force springs, possibly with preferred relative angles controlled by bending forces, are useful models for systems as diverse as architectural structures, crystalline and amorphous solids, sphere packings and granular matter, networks of semi-flexible polymers, proteins, origami, and an increasing number of lab-constructed micron-scale metamaterials. The rigidity of these networks depends on the average coordination number z of the nodes: If z is small enough, the frames have internal zero-frequency modes, and they are "floppy"; if z is large enough, they have no internal zero modes and they are rigid. The critical point separating these two regimes occurs at a rigidity threshold that for central forces in d-dimensions occurs at or near coordination number $z_c = 2d$. At and near the rigidity threshold, elastic frames exhibit unique and interesting properties, including extreme sensitivity to boundary conditions, power-law scaling of elastic moduli with $(z - zc)$, and diverging length and time scales.
This talk will explore elastic and mechanical properties and mode structures of model periodic lattices, such as the square, kagome, pyrochlore, and jammed packings with central-force springs, that are just on verge of mechanical instability. It will discuss the origin and nature of zero modes and elasticity of these structures under both periodic (PBC) and free boundary conditions (FBC), and it will investigate lattices [1-4] (a) whose zero modes under the two boundary conditions are essentially identical, (b) whose phonon modes in the bulk are "gapped" with no zero modes in the periodic spectrum (except at zero wavenumber) but include zero-frequency surface Rayleigh waves in the free spectrum, and (c) whose bulk phonon modes include isolated points or lines where their frequency is zero. In case (a), lattices are generally in a type of critical state that admits states of self-stress in which there can be tension in bars with zero force on any node. Distortions away from that state gap the spectrum and give rise to surface modes under free boundary conditions whose degree of penetration into the bulk diverges at the critical state. The gapped states have a topological characterization, similar to those of polyacetylene and topological insulators, that define the nature of zero-modes at the boundary between systems with different topology. Case (c) is closely analogous to Weyl semi-metals with isolated points in the Brillouin zone where valence and conduction bands meet. These critical lattices generally have macroscopic elastic distortions, called Guest Modes, that cost no energy.
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*Speaker

The role of persistence in visual search strategies

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As any cognitive task, visual search involves a number of underlying processes that cannot be directly observed and measured. In this way, the movement of the eyes certainly represents the most explicit and closest connection we can get to the inner mechanisms governing this cognitive activity. A lot of effort has been made in order to understand and model the ocular movement while performing free viewings of a wide variety of scenes. However, not so much has been done to model the eye paths emerging from the searching of a hidden target in the absence of saliencies. Starting from the results of our experimental studies on visual search with human subjects, we present a simple two-parameter visual search model based on the persistent random walk. The model captures the basic visual search strategies observed that range from systematic or reading-like to completely random. Using the parameter space of the model, we are able to quantify the strategies used by different individuals in three searching tasks and show that the average searching strategy changes along these three groups. Thus, suggesting that the average strategy depends on the scene content and structure. Furthermore, we discuss the efficiency of the search strategies employed and whether the standard definitions based on first-passage times or space-filling capabilities are really adequate in this context.

*Speaker

Statistical mechanics of General Equilibrium Theories of economies

Matteo Marsili * [1], Marco Bardoscia Giacomo Livan

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In the pursuit of ever increasing efficiency and growth, our economies have evolved to remarkable degrees of complexity, with nested production processes feeding each other in order to create products of greater sophistication from less sophisticated ones, down to raw materials. This evolution has occurred alongside with the expansion of competitive markets. General Equilibrium Theory (GET) provides a framework for describing the state of economies that result from market interactions under specific conditions. Within a maximum entropy approach, we derive statistical mechanics description of GET for economies with give structural properties (e.g. number of available technologies, number of goods of different type) and discuss their properties. We find that *i)* a regime where new technologies are adopted with high probability is separated from one where the technological repertoire is not saturated; *ii)* a non-trivial phase transition occurs: when the fraction of non-primary goods, i.e. goods that result as an output of a production process, exceeds a critical threshold, or when the repertoire of technologies is not rich enough, the economy freezes in a state where all production processes collapse. Within the stylised picture of an economy offered by this approach, the Industrial Revolution arises as a sharp transition between different phases. At the same time, well developed economies can collapse if too many intermediate goods are introduced.

*Speaker

Emergence of Anomalous Diffusion and Long-Range Navigation on Complex Networks

Jose L. Mateos * [1], Alejandro P. Riascos

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We analyze the mobility, searching and navigation of random walkers on networks using a long-range dynamics. We discuss the efficiency of searching using Levy flights, in comparison with normal random walks, and the possibility that scale-free mobility emerges from the interaction with a complex environment. The dynamical effect of using the Levy flight searching strategies is to transform a large-world network into a small world. We motivate the problem with examples from foraging of primates in behavioral ecology and human mobility. Our exact results provide a general framework that connects two important fields: Lévy navigation strategies and dynamics on complex networks. See Phys. Rev. E 86 (2012) 056110 and Phys. Rev. E 90 (2014) 032809

*Speaker

Learning internal representations in feedforward neural networks

Marc Mézard * [1]

[1] Ecole normale supérieure – France

The recent success of deep networks in several applications calls for a better theoretical understanding of the mechanisms at work. This presentation will discuss the connection of this problem to recent developments in information theory and learning, notably around dictionary learning

*Speaker

Nonlinear q-voter model with zealotry: switching dynamics and non-equilibrium steady state

Mauro Mobilia * [1], Andrew Mellor, Royce Zia

[1] University of Leeds – United Kingdom

The importance of relating "micro-level" interactions with "macro-level" phenomena in modeling social dynamics is well established. The study of parsimonious models like the variants of the voter model, commonly used in statistical mechanics, has therefore received a growing interest in the last decades. In this talk, I will discuss the properties of two variants of the nonlinear q-voter model with inflexible zealots in a finite well-mixed population. I will consider a two-opinion model in which each individual supports one of two parties and is either a zealot or a susceptible voter of type q1 or q2. While zealots never change their opinion, a qi-susceptible voter (i=1,2) consults a group of qi neighbors at each time step, and adopts their opinion if all group members agree. When q1=q2 m¿1, the detailed balance is satisfied and the model is characterized by a bimodal distribution below below a critical zealotry density [1]. The long-time dynamics is thus driven by fluctuations and after a characteristic time, most susceptibles become supporters of the party having more zealots with an asymmetric opinion distribution. When the number of zealots of both parties is the same, susceptibles endlessly swing from the state where they all support one party to the opposite state. When q2 and q1 are not equal, this model violates the detailed balance and its non-equilibrium stationary state is characterized by its probability distribution and currents in the distinct regimes of low and high zealotry density. In particular, the opinion distribution and the circulation of probability currents, as well as the unequal-time two-point correlations are computed [2]. This is a joint work with Andrew Mellor (Leeds) and Royce Zia (Virginia Tech). Refs.: [1] M. Mobilia, Physical Review E 92, 012803 (2015); e-print: http://arxiv.org/abs/1506.04911; [2] A. Mellor, M. Mobilia, R.K.P. Zia, EPL 113, 48001 (2016); e-print: http://arxiv.org/abs/1601.03766

*Speaker

Universality in human activity patterns

Anders Mollgaard * [1], Joachim Mathiesen

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We investigate the dynamics and interplay between human communication, mobility, and social proximity by analysing data collected from smartphones. The question we consider is: to what extent do humans follow universal activity patterns? We find that an analysis of general activity patterns across a large population allows us to predict most individual behavior. In particular, we predict individual activity and inactivity from general patterns with a precision ranging from 74% to 96%. The general activity patterns are similar to those constructed from a linear model, thereby indicating that models of general human activity may be restricted to linear relations.

*Speaker

Phase transition approach to bursting in neuronal cultures : Quorum Percolation models

Pascal Monceau * [1], S. Metens, S. Bottani, R. Renault

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In vitro cultures of living neuronal networks have turned out to be a powerful tool in investigating fundamental questions about biological computation, mechanisms of information spread, plasticity, and drug action. The growth of neuronal networks in vitro and the associated change in scale required by the associated studies are irreplaceable because they enable to record by means of fluorescent calcium imaging, or multi-electrode array devices, data unreachable in vivo. The Quorum Percolation model has been specifically designed to describe activity bursts observed in such cultures. Under its original form, it is a bootstrap percolation discrete time dynamics model of information propagation on a directed graph, built up according to a simplification of the most relevant biological features : The neurons, located at the nodes, are two state systems whose activation is governed by a threshold (Quorum) rule. A burst is seen as a discontinuity in the activity of the network, interpreted as the occurrence of a giant cluster. We go beyond such a model by introducing several biological relevant developments.

- 1) A decay of the nodes state value accounts for ionic leakage through the membrane of neurons since they do not behave as perfect capacitors; we model the decay by a discrete time disintegration process. Although it is no longer possible to write down a self consistency equation in the framework of a mean-field approach, we were able to establish a recursive relation enabling us to fully describe the stochastic dynamics in the presence of decay. As a mean result, we show that the decay changes the behavior of the percolation transition where discontinuities are replaced by steep but finite slopes.
- 2) Neuronal cultures contain also inhibitory neurons. We model them by allowing the output discrete signal of an active neuron to be negative. Hence the state of a neuron is no longer a monotonous function of time during the activation process. Nevertheless, we were able to write down a self consistency equation in the framework of a mean field approach neglecting temporal correlations; we show that, in average, a network with inhibitory neurons behaves as a network without inhibitory neurons but with a different probability distribution of incoming links than the initial mixed excitatory and inhibitory network.
- 3) While quenched disorder arises from the graph connectivity randomness, we study the modifications induced in the behavior of a Quorum Percolation model by taking into account an uncorrelated Gaussian variability of the neuronal thresholds (excitability).

We were able to achieve a mean field approach describing the evolution of the phase diagram as a function of such an additional disorder. Moreover, finite size analysis of Monte Carlo simulations enabled us to confirm the relevance of the mean field approach and to show that the order parameter is weakly self averaging.

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*Speaker

Phase transition of non-linear Pólya urn and empirical tests in human collectives

Shintaro Mori * [1], Masato Hisakado Taiki Takahashi

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Let $f : [0, 1] \to [0, 1]$ be any function, non-linear Pólya urn is a stochastic process where $z(1), z(2), \cdots$ are the successive proportions of red balls in an urn to which at the $(t + 1)^{th}$ stage a red ball is added with probability $f(z(t))$ and a blue ball is added probability $1 - f(z(t))$. The fixed points for f are stable and $z(t)$ converges to one of them if $f(z)$ crosses the diagonal downwardly. We will report two findings about the process. 1: If we adopt $f(z)$ where the number of stable states changes between one and two by the change of the parameters of $f(z)$, the system shows a non-equilibrium phase transition [Phys.Rev.E92,2015]. If $f(z)$ has Z_2 symmetry, i.e. $f(z) = 1 - f(1 - z)$, the order parameter $C(t)$ satisfies the scaling relation $C(t) \sim \ln t^{-1/2} g((1 - f'(1/2)) \ln t)$ and the transition is continuous. The critical exponent for the order parameter is $\beta = 1/2$. Otherwise the transition is discontinuous. 2: We realize the stochastic process as two kinds of information cascade experiments [Phys.Rev.E86,2012,J.Phys.Soc.Jpn.85,2016]. There are two options, TRUE and FALSE, and subjects choose options one by one with referring to the previous subjects' choices. Information cascade is defined as the tendency to choose the majority choice even if one think the minority choice is correct or optimal. Previous subjects' choices affect one's choice and we estimate f(z). It has one (two) stable fixed point(s) if the question is easy (difficult), which suggests the phase transition. We study the order parameter $C(t)$ and show that the phase transition occurs.

*Speaker

Infrared Divergence Separated for Stochastic Force - Langevin Evolution in the Inflationary Era -

Masahiro Morikawa * [1]

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Inflation in the early Universe is a grand phase transition which have produced the seeds of all the structures we now observe such as galaxies, clusters... We focus on the non-equilibrium aspect of this phase transition especially the inevitable infrared (IR) divergence associated to the quantum and classical fields during the inflation. There is a long history of research for removing/canceling this IR divergence for consistent quantum field theory and its perturbation calculations though no conclusive answer has yet been obtained. On the other hand in the macroscopic level, the same IR divergence is quite relevant and is the essential mechanism that have developed the seed density fluctuations in the early Universe. We do not attempt to remove nor cancel this IR divergence but to separate it from the quantum field theory. We develop a unified theory of the effective action method in Keldysh form. According to this approach, the IR divergence is clearly separated from the microscopic quantum field theory but only appear in the statistical classical structure at macroscopic level. We derive the classical Langevin equation for the order parameter within the quantum field theory through the instability of the de Sitter vacuum during the inflation. The IR divergence turned out to be associated to the statistical part of the effective action and the deterministic quantum mechanical part is free form IR divergence. This association is shown to be true for general scalar fields in the inflation. Our formalism is relevant to derive the basic properties of statistical mechanics within the quantum field theory. This will be the backbone of the statistical mechanics. - Ref. M. Morikawa (2016), arxiv.org 'Infrared Divergence Separated for Stochastic Force'

*Speaker

Why a regular pattern of traffic jams? The origin of intermediate states in the Biham-Middleton-Levine traffic model

Jose Daniel Muñoz * [1], Luis Eduardo Olmos

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The Biham-Middleton-Levine (BML) model, a cellular automaton with eastbound and northbound cars moving by turns on a square lattice, it the simplest model to investigate the car flux in neighborhoods of squared blocks (like Manhattan), and has been an underpinning model in car traffic. Contrary to initial beliefs, is was shown more than a decade ago [1,2] that the model does not exhibit a sharp phase transition from freely flowing to fully jammed; instead, a region of intermediate stable phases appear, with jams drawing a regular pattern, but their origin was unclear. By analyzing the model as an anisotropic system with a preferred fluid direction (northeast), we found [3] that it actually exhibits two differentiated phase transitions, either if the system is longer in the flow direction (longitudinal) or perpendicular to it (transversal). The critical densities where these transitions occur enclose the region of intermediate states and can be approximated by mean-field analysis from the anisotropic exponent relating the longitudinal and transversal correlation lengths. Thus, the puzzling intermediate states are just a superposition of these two different behaviors of the phase transition, solving most mysteries behind the BML model, which reveals itself as a novel paradigmatic example of such anisotropic critical systems. Furthermore, the existence of intermediate states is also a consequence of the connecting network: BML models with a preferred direction, but built on hexagonal meshes, show a single sharp transition with perfectly identified critical exponents, and are more robust against changes than those on square networks. [1] W.K. Yung, Master's Thesis, University of Hong Kong (1998). [2] R.M. D'Souza, Phys. Rev. E 71, 066112 (2005). [3] L.E. Olmos and J.D. Muñoz, Phys. Rev. E 91, 050801(R) (2015).

*Speaker

Modeling the contagion dynamics of the 2005 French riots

Nadal Jean-Pierre * [1], Laurent Bonnasse-Gahot, Henri Berestycki, Marie-Aude Depuiset, Mirta B Gordon, Sebastian Roche, Nancy Rodriguez

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About 10 years ago, riots spread in poor neighborhoods in French cities after two youths died while trying to escape from a police control. Thanks to an access to a detailed account of these events, we analyzed the dynamics of these riots. I will show that a parsimonious (less than 10 free parameters) data driven epidemic model, taking into account both local and non-local contagion, allows to reproduce the full time course of the riots hitting more than 800 municipalities and lasting about 3 weeks. I will make explicit the specificity of the model as compared to the modeling of the spread of infectious diseases. Finally, I will discuss the methodology in the broader context of modeling social phenomena, showing in particular how modeling provides a kind of regularization of the data. In the case of the riots in the suburbs of Paris, it allows to visualize the wave propagating from the triggering event in Clichy-sous-Bois.

*Speaker

Anomalous critical and supercritical connectivity transitions

Jan Nagler * [1]

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The emergence of large-scale connectivity on an underlying network or lattice, the so-called percolation phase transition, has a profound impact on the system's macroscopic behaviours. There is thus great interest in controlling the location of the percolation transition to either enhance or delay its onset and, more generally, in understanding the consequences of such control interventions. In my talk I will report on anomalous critical and jumpy supercritical connectivity transitions that result from repeated, small interventions designed to delay the percolation transition. Models of aggregation processes ranging from random network percolation, fragmentation, the dynamics of salad dressing to DNA replication are discussed. We observe a rich phenomenology that includes non-self-averaging and stochastic Devil's staircases (D'Souza & Nagler, Nature Physics 11:531, 2015; Nagler et al., unpublished).

*Speaker

Mean field approach to segregation of traders accross double auction markets

Robin Nicole * [1], Peter Sollich

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With the development of electronic commerce, transactions between large populations of buyers and sellers are becoming increasingly common. A standard mechanism for agreeing transactions in this scenario is a double auction. When traders can choose between markets, then for markets to attract as much trade as possible they need to use an appropriate market mechanism for implementing double auctions. Accordingly research into double auction mechanisms is a growing field that uses tools coming from game theory. The motivation for the current study is the phenomenon of segregation in situations with market choice, as observed in e.g. online (CAT game) tournaments where different market mechanism designs were competing against each other in trying to attract traders from a population provided by the tournament. Even if initially traders had the same settings, they could later split into subpopulations trading predominantly at one of the markets. We want to understand the origins of such segregation phenomena. We study a minimal model of double auctions created by Aloric et al. in [1]. It is a game in which there are players (traders) of two types, one with a preference for buying and the other for selling. In each trading round, every player chooses one of two markets at which to trade one unit of good. Then he sends a buy or sell order to this market, at a price randomly drawn from two fixed distributions for bids (buying) and asks (selling). In the double auction mechanism we are using, markets set the trading price as a weighted mean of the average bids and asks received. Orders with prices are on the wrong side of the trading price are rejected. Finally, to equalize the number of buy and sell orders, orders from the majority group are chosen randomly for rejection. We want to study the Nash equilibria of this game, and understand the conditions under which segregated Nash equilibria might become possible. In the limit of a large number of players we are able to use a mean field approach. This allows us to classify the Nash equilibria into 4 categories; in spite of the simplicity of the model some of these classes do show segregation of the agent types into subgroups. We obtain "phase diagrams" showing in which regime of the system parameters the various equilibria exist, providing insights into the driving forces behind segregation. To understand which of the Nash equilibria are most relevant, we extend the model to an iterated game where players update their attractions toward the two markets using reinforcement learning. These attractions are then converted to probabilities for choosing each market, using a soft-max rule. Our conjecture, which we verified numerically, is that the steady state of the dynamics will be consistent with a specific, dynamically selected, Nash equilibrium, provided players update their preference towards the market they did not choose in each trade with appropriate fictitious scores, and use the soft-max rule in the limit where this reverts to deterministic choice of the market with the higher attraction. A numerical challenge was to avoid trapping in metastable states of the iterated game, to ensure genuine steady state, this has been addressed by large deviation methods (Freidlin-Wentzell theory) which provided an efficient numerical algorithm to obtain the steady states of the dynamics defined above. [1] Aloric, Aleksandra, et al. "Emergence of Cooperative Long-term Market Loyalty in Double Auction Markets." arXiv preprint arXiv:1510.07927 (2015).

*Speaker

Maximum-entropy priors for graph ensembles

Robert K. Niven * [1], Markus Abel, Germany Michael Schlegel

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Over the past decade, the statistical mechanics of networks has experienced a tremendous growth, triggered by applications to the internet, financial and human social networks. Such studies almost universally invoke the Shannon entropy $H = -\sum_{\Omega_G} P(G) \ln P(G)$, where $P(G)$ is the probability of the graph G in the ensemble Ω_G. We argue that these analyses can more appropriately and conveniently be cast in terms of the relative entropy (negative Kullback-Leibler) function $H = -\sum_{\Omega_G} P(G) \ln P(G)/Q(G)$, where G now represents the graph macrostate, and $Q(G)$ is the prior probability of the macrostate in the ensemble. By this method, the user can exploit the fundamental property of statistical physics: the aggregation of individual microstates into observable macrostates. Depending on the partition considered, a wide variety of graph priors can be rigorously derived from combinatorial principles. Many such priors have finite asymptotic limits for the number of nodes $N \to \infty$. We present a suite of such priors, for both microcanonical and various canonical graph ensembles, partitioned by node or edge counts, adjacency matrix elements, graph degree structure and/or connectivity.

*Speaker

Complex Contagions with Lazy Adoption

Se-Wook Oh * [1], Mason Alexander Porter

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A great deal of efforts has gone into trying to model spreading phenomena. Some existing binary-state models, such as the Watts threshold model, can exhibit cascades, in which local adoption becomes widespread throughout a network. Those models tend to assume that individuals instantaneously react to their neighbours' changes without any time delay – which is often not true in social contexts, where different agents have different response times or different degrees of laziness. In our work, we present a timer model, where each node's adoption gets delayed for the size of its timer. Formulating our model in this way enables us to apply the timer model to any existing social-influence models where nodes change their states by influence from other nodes. Here we illustrate the incorporation of a timer using the Watts threshold model. We seek to understand the relationship between the delay of the adoption process and the initial distribution of timers. Our study shows that compared to homogeneous timers, heterogeneous timers can either delay or advance the time to steady state, depending on the way timers are distributed. Furthermore, the degree of the heterogeneity of the initial distribution of the timers decides the degree of the delay. We also derive a pair approximation that incorporates a timer by modifying a pair approximation of the Watts threshold model, and it exhibits good agreement with the numerical results of the Watts thresholds model with a timer on random graphs. We also examine this model on real networks.

*Speaker

Early indicators of desertification transitions

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Regime shifts in ecosystems can imply relevant economic and social effects. This is especially true when they involve abrupt transitions occurring on a relatively short timescale [1,2]. A special case of regime shift is given by desertification transitions of semi-arid ecosystems which can be strongly affected by climatic or anthropogenic factors [1,2,3]. A crucial issue in this field concerns the identification of early and reliable transition indicators, providing not only an estimate of the desertification risk, but also a tool to monitor the effectiveness of actions devoted to contrast it [1]. To this purpose, several new transition indicators have been proposed [1,2,3]. In particular, at increasing values of the mortality rate (control parameter of the transition) very early indicators have been recently identified in the case of continuous or nearly continuous transitions (where the order parameter of the transition is the fraction of vegetation covered surface). These new early indicators are associated with a change in the skewness sign of the fluctuation distribution of the size of both the biggest clusters: the vegetation covered and the non-vegetated one [3]. On the other hand, numerical simulations based on a stochastic cellular automaton model [2,3] showed that several physical and ecological parameters, like in particular the colonization rate and the aridity parameter, can affect the character of the transition: from continuous to abrupt or vice versa [3,4]. Here we discuss the possibility of extending the new indicators to the case of abrupt transitions.

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*Speaker

Langevin dynamics and Entropy analysis for studying human movement and human actions

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We present different situations where Langevin dynamics, Mutual Information and Symbolic Transfer of Entropy can provide interesting insights on human actions. The perspective is organically provided by statistical physics approach and the way of understanding natural phenomena in Physics. We will first explain the possibilities of reading human mobility with a Langeving dynamics where there is a collection of gravitational attractive potential wells. We describe an example of a scalable experiment exploiting these circumstances at a public, outdoor fair in Barcelona (Spain). Participants were tracked while wandering through an open space with activity stands attracting their attention. We develop a general modeling framework based on Langevin Dynamics, which allows us to test the influence of two distinct types of ingredients on mobility: *reactive* or context-dependent factors, modelled by means of a force field generated by attraction points in a given spatial configuration, and *active* or inherent factors, modelled from intrinsic movement patterns of the subjects. The additive and constructive framework model accounts for some observed features. Starting with the simplest model (purely random walkers) as a reference, we progressively introduce different ingredients such as persistence, memory, and perceptual landscape, aiming to untangle *active* and *reactive* contributions and quantify their respective relevance. The proposed approach may help in anticipating the spatial distribution of citizens in alternative scenarios and in improving the design of public events based on a facts-based approach. We will secondly explore the capacities of mutual information and symbolic transfer of entropy approaches to respectively deal with non-trivial cross-correlations and even detect non-evident cause-effect relations when data is highly non-linear. Decisions taken in our everyday lives are based on a wide variety of information so it is generally very difficult to assess what are the strategies that guide us. Stock market therefore provides a rich environment to study how people take decision since responding to market uncertainty needs a constant update of these strategies. For this purpose, we run a lab-in-the-field experiment where volunteers are given a controlled set of financial information -based on real data from worldwide financial indices- and they are required to guess whether the market price would go up or down in each situation. From the data collected we explore basic statistical traits, behavioural biases and emerging strategies. In particular, we detect unintended patterns of behavior through consistent actions which can be interpreted as *Market Imitation* and *Win-Stay Lose-Shift* emerging strategies, being *Market Imitation* the most dominant one. We also observe that these strategies are affected by external factors: the expert advice, the lack of information or an information overload reinforce the use of these intuitive strategies. We will finally address to non-expert traders in real markets to also study there how external factors trigger buy and sell orders and how we can detect non-trival cause-effect phenomena with innovative observables which are not generally considered by financial analysts but that can anyway be seen as very natural tools in statistical physics world. Our results are of interest for better handling clients expectations of trading companies, avoiding behavioural anomalies in financial analysts decisions and improving not only the design of markets but also the trading digital interfaces where information is set down. Strategies and behavioural biases observed can also be translated into new agent based modelling or stochastic price dynamics to better understand financial bubbles or the effects of asymmetric risk perception to price drops.

*Speaker

Evacuation dynamics of social groups

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The effects of social groups on pedestrian dynamics, especially in evacuation scenarios, have attracted some interest recently. However, due to the lack of reliable empirical data, most of the studies focussed on modelling aspects, see e.g. [1] and references therein. Here, we propose and analyse extended floor field cellular automaton models for evacuation dynamics of inhomogeneous crowds of pedestrians with social groups. Different group sizes are studied as well as different types of intra-group interactions (e.g. homogeneous and follower-leader interactions). It is shown that social groups can have a considerable effect, e.g. on evacuation times. In order to test the model predictions we have performed laboratory exeriments of evacuations with different types and sizes of the social groups. Parameters that have been considered are (1) group size, (2) strength of intra-group interactions and (3) composition of the groups (young adults, children and mixtures). For all experiments high-quality trajectories for all participants have been obtained using the PeTrack software [2]. This allows for a detailed analysis of the evacuation time and the group dynamics. One main result is a decrease of evacuation time with increasing group size [3]. We propose quantities that allow to describe the dynamics of the groups during the evacuation in a quantitative way. References:

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*Speaker

Impact of lexical and sentiment factors on the popularity of scientific papers

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We investigate how textual properties of scientific papers relate to the number of citations they receive. Our main finding is that correlations are non-linear and affect differently most-cited and typical papers. For instance, we find that in most journals short titles correlate positively with citations only for the most cited papers, while for typical papers the correlation is in most cases negative. Our analysis of 6 different factors, calculated both at the title and abstract level of 4.3 million papers in over 1500 journals gathered form the Web of Science database, reveals the number of authors, and the length and complexity of the abstract as having the strongest influence on the number of citations.

*Speaker

Discovering the laws of urbanisation

Filippo Simini * [1], Charlotte James

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In 2012 the world's population exceeded 7 billion, and since 2008 the number of individuals living in urban areas has surpassed that of rural areas. This is the result of an overall increase of life expectancy in many countries that has caused an unprecedented growth of the world's total population during recent decades, combined with a net migration flow from rural villages to urban agglomerations. While it is clear that the rate of natural increase and migration flows are the driving forces shaping the spatial distribution of population, a general consensus on the mechanisms that characterise the urbanisation process is still lacking. Indeed, births, deaths, and migrations are all we need to consider if we want to describe the population change in a given region. However, it is not as simple as it may sound when it comes to combining these fundamental processes into a mathematical model that can accurately describe one of the most striking consequences of population dynamics – urbanisation, i.e. the formation and growth of cities. Not only does such a model not exist, but the answers to the following fundamental questions on urbanisation have been ignored: How do cities form? What determines the number of cities in a country, and what is their spatial distribution? Here we shed light on these issues by analysing a comprehensive dataset on the population and location of cities globally. Data reveals two fundamental laws of urbanisation: 1) the number of cities in a country is proportional to the country's total population, irrespective of the country's area, and 2) the average distance between cities scales as the inverse of the square root of the country's population density. To explain these empirical laws of urbanisation, we investigate the effect of national migrations on the cities' demographic dynamics by studying how microscopic dynamical processes (individual migrations) characterise the statistical properties of the emerging large scale structures (cities). Traditionally, two main families of models have been used to estimate migrations and other aggregated spatial flows: Gravity models and Intervening Opportunities (IO) models. In both approaches flows are estimated as the product of two types of variable; one type that depends on an attribute of each individual location (the number of opportunities, usually identified with population), and the other type that depends on a quantity relating a pair of locations (i.e. a distance). The difference between the two models pertains to the distance variable considered: the geographical distance in Gravity models, and the number of intervening opportunities in IO models (the number of intervening opportunities between locations i and j is defined as the sum of the opportunities of all locations that are closer to i than j is). Both models can fit migration flows with comparable accuracy, and currently there is no objective quantitative criterion for selecting one modelling approach over the other. Analysing both the deterministic and stochastic versions of the spatio-temporal population dynamics obtained using a Gravity or an Intervening Opportunities model, we show in all generality that the two families of spatial flow models produce different spatial patterns of cities. This enables the possibility to assess their compatibility with the empirical laws of urbanisation, hence providing a criterion to determine which between geographic distance or number of intervening opportunities is the correct variable to describe migration flows. Preprint available at http://arxiv.org/pdf/1512.03747v1.pdf

*Speaker

The Build up of Diversity in Complex Ecosystems

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Diversity is a fundamental feature of ecosystems, even when the concept of ecosystem is extended to sociology or economics. Diversity can be intended as the count of different items, animals, or, more generally, interactions. There are two classes of stylized facts that emerge when diversity is taken into account. Diversity explosions are the first stylized fact: evolutionary radiations in biology, or the process of escaping "Poverty Traps" in economics are two well known examples. The second stylized fact is nestedness: entities with a very diverse set of interactions are the only ones that interact with more specialized ones. In a single sentence: specialists interact with generalists. Nestedness is observed in a variety of bipartite networks of interactions: Biogeographic (Islands-Animals), macroeconomic (countries-products) and mutualistic (e.g. Pollinators-Plants) to name a few. This indicates that entities diversify following a pattern. For the fact that they appear in such very different systems, these two stylized facts seem to point out that the build up of diversity might be driven by a fundamental mechanism of probabilistic nature, and we try to sketch its minimal features. Namely we show how the contraction of a random tripartite network, which is maximally entropic in all its degree distributions but one, can reproduce stylized facts of real data with great accuracy which is qualitatively lost when that degree distribution is changed. We base our reasoning on the combinatoric picture that the nodes on one layer of these bipartite networks (e.g. animals, or products) can be described as combinations of a number of fundamental building blocks. We propose the idea that the stylized facts of diversity that we observe in real systems can be explained with an extreme heterogeneity (a scale-free distribution) in the number of meaningful combinations (usefulness) in which each building block is involved. We show that if the usefulness of the building blocks has a scale-free distribution, then maximally entropic baskets of building blocks will give rise to very rich behaviors in accordance with what is observed in real systems.

*Speaker

Phase transitions of statistical estimation

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In statistical estimation, a true probability density of signal sources gradually becomes identified as the sample size increases. Practically, there is a situation that has some signal sources but the number of them is unknown. Hare is a fundamental question that has not been elucidated: at least how many samples are needed to identify the true number of signal sources? In this study, we show that a minimum required sample size is related to the phase transition points. This is based on the fact that Bayesian statistics is nearly equivalent to statistical mechanics, and the sample size asymptotically corresponds to the inverse temperature. We introduce a state function which we call Bayesian specific heat. This function shows that it has maxima on transition points, which is a sign of continuous changes in the posterior density.

*Speaker

The noisy voter model on complex networks

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We propose a new analytical method to study stochastic, binary-state models on complex networks. Moving beyond the usual mean-field theories, this alternative approach is based on the introduction of an annealed approximation for uncorrelated networks, allowing to deal with the network structure as parametric heterogeneity. As an illustration, we study the noisy voter model, a modification of the original voter model including random changes of state. The proposed method is able to unfold the dependence of the model not only on the mean degree (the mean-field prediction) but also on more complex averages over the degree distribution. In particular, we find that the degree heterogeneity —variance of the underlying degree distribution— has a strong influence on the location of the critical point of a noise-induced, finite-size transition occurring in the model, on the local ordering of the system, and on the functional form of its temporal correlations. Finally, we show how this latter point opens the possibility of inferring the degree heterogeneity of the underlying network by observing only the aggregate behavior of the system as a whole, an issue of interest for systems where only macroscopic, population level variables can be measured.

*Speaker

The dynamics of innovation through the expansion in the adjacent possible

Francesca Tria * [1], Vittorio Loreto, Vito D.P. Servedio, Steven H. Strogatz

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Novelties are part of our daily lives. We constantly adopt new technologies, conceive new ideas, meet new people, experiment with new situations. At different scales, innovation is also a crucial feature of many biological, technological and social systems. Recently, large databases witnessing human activities allowed the observation that novelties - such as the individual process of listening to a song for the first time - and innovation processes - such as the fixation of new genes in a population of bacteria - share striking statistical regularities. I will here briefly review scientific attempts to effectively model the emergence of the new and its regularities. I will then present a new framework based on Polya's urn. What seems to be key in the successful modelling schemes proposed so far is the idea of looking at evolution as a path in a complex space, physical, conceptual, biological, technological, whose structure and topology get continuously reshaped and expanded by the occurrence of the new. This will be identified as a process of expansion into the adjacent possible, a concept originally introduced by Stuart Kauffmann in the framework of biological evolution. We will identify statistical signatures of the presence of the expansion into the adjacent possible in the analyzed datasets, and we will show that our modeling scheme is able to predict remarkably well these observations.

*Speaker

Spectral renormalization group theory on nonspatial networks

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We recently proposed a "spectral renormalization group" scheme, for non-spatial networks with no metric defined on them. We implemented the spectral renormalization group on two deter- ministic non-spatial networks without translational invariance, namely the Cayley tree and diamond lattice . The thermodynamic critical exponents for the Gaussian model are only functions of the spectral dimension, d. The Gaussian fixed point is stable with respect to a ψ^4 perturbation up to second order on these lattices with $d = 2$, the lower critical dimension for the Ising universality class. This is expected for the Cayley tree, but for the diamond lattice it is an indication that the pertur- bation expansion up to second order breaks down at $d = 2$, as it does for the Wilson scheme on the square lattice. On generalized diamond lattices, with $2 < d < 4$, we find non-Gaussian fixed points with non-trivial exponents. For $d > 4$, the critical behavior is once again mean field.

*Speaker

Rescue of endemic states in interconnected networks with adaptive coupling

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We study the dynamics of the susceptible-infected-susceptible model for epidemic spreading on interconnected networks with adaptive coupling, where healthy individuals in one layer avoid contact with infected nodes in the other layer by rewiring at random their internetwork connections. Our goal is to assess the effects of such rewiring on the prevalence of the epidemics. To understand the non-trivial behaviors of the interconnected system, we put forward a model and provide an analytical formalism based on the mean field and pair approximation assumptions and we also perform extensive numerical simulations. We find that the rewiring reduces the effective connectivity for disease transmission between layers. This brings important consequences, like a reduction of the disease prevalence in each layer as compared to the values for static interconnections, which approach their single network values as the rewiring increases. In the thermodynamic limit, the rewiring can even induce a transition to the healthy phase if it overcomes a finite and small critical value in a region of infectivities where the interconnected networks support weak endemic states. We find this threshold analytically as a function of the infectivity for some specific values of average intra- and inter-connections in identical layers. For finite systems, we find that a disease outbreak in one network does not always imply an outbreak in the other network, a genuine effect which is not observed in the case of static interconnections. The effective decrease in connectivity caused by the rewiring is able to keep the disease confined in only one of the networks until finite size effects cut out the disease. Therefore, in finite systems there is a finite probability that an endemic state never spreads to the whole system.

*Speaker

Phase Diagram of Collective Motion of Bacterial Cells

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The collective motion of bacterial cells in a shallow circular pool is systematically studied using the bacterial species Bacillus subtilis. The ratio of cell length to pool diameter (i.e., the reduced cell length) ranges from 0.06 to 0.43 in our experiments. Bacterial cells in a circular pool show various types of collective motion depending on the cell density in the pool and the reduced cell length. The motion is classified into six types, which we call random motion, turbulent motion, one-way rotational motion, two-way rotational motion, random oscillatory motion, and ordered oscillatory motion. Two critical values of reduced cell lengths are evaluated, at which drastic changes in collective motion are induced. A phase diagram is proposed in which the six phases are arranged.

*Speaker

Quantitative Analysis on the Editing History of Massive Online Open-editing Encyclopedia, Wikipedia

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Wikipedia is a free Internet encyclopedia with enormous amount of contents. This encyclopedia is written by volunteers with various backgrounds in a collective fashion; anyone can access and edit most of the articles. This open editing nature may give us prejudice that Wikipedia is unstable and unreliable sources; yet many studies suggest that Wikipedia is even more accurate and self-consistent than traditional encyclopedias. Scholars have attempted to understand such extraordinary credibility, but usually used the edit number without consideration of real-time. In this work, we probe the formation of such collective intelligence through the systematic analysis using the entire history of 34,534,110 English Wikipedia articles, between 2001 and 2014. From this massive data set, we observe the universality of both timewise and lengthwise editing scales, which suggests that it is essential to consider the real-time dynamics. By considering real-time, we find the existence of various growth patterns that are unobserved in terms of the number of edits as the time step. To account these results, we present a mechanistic model that adopts both the article editing dynamics based on editor-editor and editor-article interactions. The model successfully generates some key properties of the real Wikipedia articles such as distinct types of articles for the editing patterns characterized by the interrelationship between the numbers of edits and editors, and the article size. In addition, the model indicates that infrequently referred articles tend to grow faster than frequently referred one, and articles attracting high motivation of edit counterintuitively reduce the number of participants. We suggest that this decay of participants eventually brings inequality among the editors, which will be more severe with time.

*Speaker

How the Network of Products Drives the Economic Development of Countries

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Motivation Is there a common path on countries' development, or each country must follow his own way? In order to produce cars, one has to learn how to produce wheels before? To answer to these questions, we have imagined countries as walkers in a network made of goods, defined such that if a country steps on one product, it will export it. Obviously, paths can be very different: while Germany has already explored much of the available space, underdeveloped countries have a long road ahead. Which are the best paths in the product network?
Let us start from the data needed to build the network. The flow of global trade over time [1] offers a fundamental insight into countries' development, while it can help define an empirical framework to assess the validity of the theoretical paradigms within the field of economics. If we suppose that products are defined by means of the set of capabilities which are needed for a country to be able to produce it, the presence (or the absence) of a product in a country's export basket will represent a hint on the capability basket of the country itself, i.e. all the ingredients that are needed to build the products it exports (i.e. specific technological skills, materials, industrial infrastructures). In particular, we want to build a **network of products** in which two nodes are connected if they share some capabilities, but capabilities are very hard to measure and so, in practice, what is usually done is to link two products if many countries produce both of them. This network, called the product space, has been introduced and studied in [2]. However, our research activity aims at building a different network of products, in which two products are connected not only if they are similar, but also if the first is **necessary** to produce the second, like transistors for smartphones, cows for leather, and wheels for cars. In this kind of network links have to be **directed**: a country usually goes from one product to another, but not vice versa.

Algorithm To extract this information we start from the empirical export matrix $\mathbf{M}$ whose binary element M_{cp} indicates if country c exports product p. In order to obtain a monopartite network of products we project on the dimension of products. In formula, the element $B_{pp'}$ of the adjacency matrix $\mathbf{B}$ defines the strength of the link between the products p and p' via

$$B_{pp'} = \frac{1}{\max(u_p, u_{p'})} \sum_c \frac{M_{cp} M_{cp'}}{d_c} \tag{1}$$

where d_c is the number of products exported by the country c and u_p is the number of countries that export the product p. Finally, we filter the (almost) fully connected network of products defined by $\mathbf{B}$ taking the maximum values for each row and, in case of degeneracies, taking the highest contribution with respect to the column. The normalization takes into account the nested structure of the export matrix $\mathbf{M}$, giving more strength to the links that have complex products as targets. As a consequence, the algorithm naturally introduces a preferred direction of development when one filters the (almost) fully connected network $B_{pp'}$ to obtain the final network. A detailed description of the algorithm and a number of tests on toy models and synthetic examples can be found in [3].

Results We called this structure the *taxonomy network*: nodes (such as products) are connected by a directed link, which represents the causality relationship between them. We have studied the influence of the structure of our network on countries' development and, in particular, we have focused on the industrialization of South Korea, noticing for many components a diffusion from the center (root product) towards the borders of the components, where more complex products are located. Driven by this example, we analyzed all countries in our database, finding that when countries get industrialized they walk in the taxonomy network following the directed links from one product to another, retracing the structure of our network. In other words, we are able to spot which products are connected by a causal relationship, that is, which products are helpful to start to export new

*Speaker

products. Moreover, we have found that once countries are industrialized, they start to specialize again, but now in complex products. These results suggest paths in the network of products which are easier to achieve, and so can drive countries' policies in the industrialization process.

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