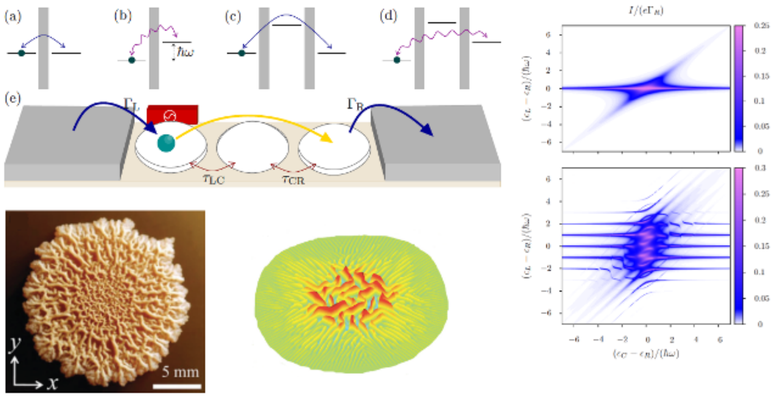

Second Meeting of the Network on Non-Equilibrium Statistical Physics:

Nonequilibrium condensed matter and biological systems

Madrid

March 9–11, 2016

Wednesday, March 9

10:00-10:30 Javier Rodríguez (UC3M)
Modeling epithelial wound/healing using stochastic collective cell motion.

10:30-11:00 David R. Espeso (CNB-CSIC)
Characterizing assembly rules for novel bacterial origami designs.

11:00-11:30 Coffee break

11:30-12:00 Damian Levis (UB)
Synchronization of self-propelled units carrying an internal oscillator.

12:00-12:20 Leticia Valencia (UC3M)
Relation between velocity and density in an advancing cell monolayer.

12:20-12:40 Sara Ruiz López-Loriente (UC3M)
Dynamics of electric potential in a migrating cell colony.

2:45-13:45 Lunch

14:30-15:00 Filippo Terragni (UC3M)
Ensemble-Averaged and Deterministic Descriptions of Tumor-Driven Angiogenesis.

15:00-15:30 Antonio M. Puertas (UAL)
Diffusion of a hard colloidal tracer in a dense ideal gas.

15:30-16:00 Álvaro Domínguez (US)
Interacción efectiva de partículas autocatalíticas por flujos de Marangoni.

16:00-16:30 Coffee break

16:30-17:00 Javier Prior (UPCT)
The Origin of Long-lived Oscillations in electronic 2D-spectroscopy.

17:00-17:30 Rafael Molina (IEM-CSIC)
Superradiance at the localization-delocalization crossover in chlorosomes.

17:30-17:50 Joan Codina (UB)
Emergent interactions in non-equilibrium suspensions.

17:50-18:10 Guillem Rosselló (UIB)
Role of inelasticity in the symmetry of the Onsager matrix.

18:10-18:30 Ana Paula Millán (UGR)
Brain structure under a critical condition mediated by local currents.

Thursday, March 10

09:30-10:00 Björn Sothmann (UNIGEN)
Chiral thermoelectrics.

10:00-10:30 Sun-Yong Hwang (UIB)
Highly efficient thermoelectric devices based on ferromagnet-superconductor quantum dots.

10:30-10:50 Maria Isabel Alomar (UIB)
Theory of thermopower for spin-orbit coupled graphene and 2D spin transistors.

10:50-11:20 Coffee break

11:20-11:40 Javier Osca (UIB)
Local currents in quasi-1D Majorana nanowires.

11:40-12:00 Fernando Gallego-Marcos (ICMM-CSIC)
Interference of real and virtual transitions in quantum dot chains.

12:00-12:20 Miguel Bello (ICMM-CSIC)
Non-local transport of strongly-interacting fermions via topological and Shockley edge states.

12:20-12:40 Laura Ortiz (UCM)
Generic helical edge states due to Rashba spin-orbit coupling in a topological insulator.

12:45-13:45 Lunch

14:30-15:00 Geza Giedke (DIPC)
Dissipative state preparation and phase transitions in quantum dots.

15:00-15:30 Ángel Rivas (UCM)
Quantifying spatial correlations of general quantum dynamics.

15:30-16:00 Coffee break

16:00-16:30 Miguel Ortuño (UM)
Slow relaxation in electron glasses.

16:30-17:00 Juan Jesús Ruiz-Lorenzo (UNEX)
Fluctuation-dissipation relations in finite dimensional spin glasses.

17:00-17:30 Francisco Vega Reyes (UNEX)
Effect of inelastic boundaries on the steady state flows in a dilute granular gas.

17:30-17:50 Vicente Buzón (US)
Análisis del comportamiento de un modelo de gas granular casi-bidimensional vibrado.

17:50-18:10 Carlos A. Plata (US)
Exact solution of the HCS in a 1d lattice model of granular media.

Friday, March 11

09:30-10:00 Holger T. Grahn (PDI, Berlin)
Chaotic current self-oscillations in weakly coupled semiconductor superlattices for true random number generation.

10:00-10:20 Miguel Ruiz-García (UC3M)
Spontaneous chaotic oscillations and noise in a semiconductor superlattice model.

10:20-10:40 Rubén Seoane Souto (UAM)
Non-stationary and noise properties of molecular junctions in the polaronic regime.

10:40-11:00 Eloy Navarro (UB)
Self-assembly in rotating magnetic colloids.

11:00-11:30 Coffee break

11:30-12:00 Verónica Ahufinger (UAB)
Geometrically induced complex tunnelings for ultracold atoms carrying orbital angular momentum.

Characterizing assembly rules for novel bacterial origami designs

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The use of genetically engineered bacteria as effective and cheap catalytic agents for biotechnological applications is currently limited by the existence of several difficulties that make them not viable for industrial purpose. One of the most serious drawbacks to face is the increasing metabolic burdening derived from performing the required chemical transformations inside the cells, which drastically reduce their viability and suppose a serious chemical and operative bottleneck diminishing the chemical efficiency. New approaches are required to overcome these limitations. Here we introduce and detail the concept of "bacterial origami" as a specific-purpose strategy to assemble bacterial aggregates composed by synthetic strains whose attachment and chemical properties can be manipulated to optimize the target chemical process.

By performing a combination of experiments and theoretical modeling we detail some characteristics of these systems by analyzing a simple case study: the aggregation of two synthetic strains in a planktonic culture. Our results showed an aggregation process leading to a lognormal distribution of the cluster population, with relative compact structures showing a fractal-like configuration for larger sizes. The impact of other connectivity-related variables such as the steric allocation of binding sites, the attachment probability, the number of synthetic strains and their connectivity pattern are also evaluated theoretically.

Synchronization of self-propelled units carrying an internal oscillator

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We adress the question of how self-propulsion, and the dynamical patterns emerging from it, affects the synchronization of motile physical entities, like moving cells synchronizing their intracellular genetic oscillators. In order to do that, we introduce a simple model of self-propelled hard disks moving in 2D carrying an internal variable which follows a Kuramoto dynamics. We find that, in the absence of particle-particle interactions, self-propulsion promotes the synchronization of the particles up to a saturation threshold that we identify with the parameters of the model. However, the presence of steric interactions give rise to an optimal self-propulsion for synchronization as a consequence of the clustering of the particles. We single out several dynamic regimes where the topology of the underliying time-evolving network is strongly correlated with the oscillators? motion. We study the relaxation of the system and show that synchronization proceeds throught a mechanism that verifies dynamical scaling.

Relation between velocity and density in an advancing cell monolayer

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Cell migration plays an important role in governing various biological processes such as shape and vascularize tissues, in wound healing, tumour spreading and as a part of immune response. Although epithelia are generally assumed to be spatially constrained, it has been observed that in morphogenesis cells rearrange slightly but in a highly coordinated way in order to maintain tissue integrity. Collective cell migration is a dynamic process that requires physical (mechanical) and also chemical (signalling) interactions with the environment which are essential for cell movement.

We are focused in understanding the mechanisms of tissue repair in epidermal cell monolayers which is a model problem less complex than wound healing. The purpose of this study is to introduce a quantitative approach of the biological problem through in vitro assays and subsequent image analysis which allows to compute cellular velocities and densities for two different set of problems, normal conditions and starvation, inhibiting cell proliferation.

We found clear differences in the mean border displacement between experiments at normal conditions and those carried out in starvation that at some point they stop, although for some time both show similar velocity. We also explore the spatio-temporal evolution of velocity and density inside the monolayer obtaining that the distribution of the density within the monolayer at the end of the experiment is quite similar among all cases, whether the gap is closed or not.

In contrast, the velocity distribution at different depths shows that initially, the shallower cell layers develop the same speed in both cases but in normal conditions close to the edge the fastest cells are found. In other words, the velocity decays slowly with depth. However, in starvation the velocity is zero everywhere, consistently with the null advance velocity of the front. This is a clear evidence that the density is not driving the population of cells.

Finally, since the distribution of the density within the monolayer at the end of the experiment is quite similar between among all cases, whether the gap is closed or not. This is a clear evidence that the density is not driving the population of cells. Density might be considered given by an universal distribution or “advance formation” with respect to the density profile which is kept even when the population stops.

Dynamics of electric potentials in a migrating cell colony

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[1] *Universidad Carlos III de Madrid, Avda. Universidad 30, 2811 Leganés, SPAIN*

Cell migration is the most important process during wound healing and it must be very effective, for the cells to know in which way and direction they have to migrate. Cells own different mechanisms, such as endogenous electric fields and mechanical forces, for them to sense and transmit movement signals. Endogenous generated electric fields are found to be one of the most important cues on cell migration. Thus, cell migration can be enhanced by the application of external electric fields. Current work is focused on the study of both cell monolayer impedance characterization and kinematic behavior influenced by induced electric fields. Moreover, a study of the effect of external electric fields on cells seeded on different substrates was also performed. Results have shown an enhancement of cell migration due to the effect that the mechanical properties of the substrates and the applied electric fields induced on them. In order to fully understand the mechanisms by which cells sense and transduce electrical and mechanical signals during migration in wound healing more studies should be performed.

Ensemble-Averaged and Deterministic Descriptions of Tumor-Driven Angiogenesis

F. Terragni,[1] M. Carretero,[1] V. Capasso,[2] and L.L. Bonilla[1]

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A stochastic model for the growth of blood vessels (angiogenesis) attracted by a tumor is discussed. According to this, tips of newly created capillaries feel a chemotactic force proportional to the gradient of a growth factor released by the tumor, thus they move, possibly branch out, and may melt with other vessels (anastomosis). Even though the latter process keeps the number of tips relatively low, a deterministic description of the vessel tip density can be found by means of ensemble averages over many replicas of the angiogenic process. A good agreement between the two models is achieved as far as the anastomosis rate is properly fitted. On the other hand, the average advance of vessel tips towards the tumor can be described by a soliton, whose features can be controlled in terms of few parameters.

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[1] L.L. Bonilla, V. Capasso, M. Álvaro, and M. Carretero. Hybrid modeling of tumor-induced angiogenesis. Physical Review E **90**, 062716 (2014).

[2] F. Terragni, M. Carretero, V. Capasso, and L.L. Bonilla. Stochastic model of tumor-induced angiogenesis: ensemble averages and deterministic equations. Physical Review E, to appear (2016).

[3] A. Carpio and G. Duro. Well posedness of an integrodifferential kinetic model of Fokker-Planck type for angiogenesis. Nonlinear Analysis: Real World Applications **30**, 184-212 (2016).

Diffusion of a hard colloidal tracer in a dense ideal gas

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We study the diffusion of a hard tracer in an ideal gas by means of simulations with microscopic Langevin dynamics. This system allows us to test the validity of low density theories of self-diffusion up to high densities of the bath, using tracer velocity and force autocorrelation functions. In particular, the use of a diffusion kernel vs. friction kernel, is discussed. Although at low density both approximations yield similar results, the validity of the latter is a key element for mode coupling theories.

Interacción efectiva de partículas autocatalíticas por flujos de Marangoni

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Una partícula autocatalítica genera gradientes de sustancias químicas en su entorno. Si está cerca de una interfase entre fluidos, estos gradientes provocan flujos de Marangoni que se manifiestan como una interacción efectiva entre las partículas y de éstas con la interfase. Presentamos un estudio teórico del modelo mínimo que describe esta fenomenología y una discusión de su relevancia para partículas coloidales.

The Origin of Long-lived Oscillations in electronic 2D-spectroscopy

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Recent observations of oscillatory features in the optical response of photosynthetic complexes have revealed evidence for surprisingly long-lasting electronic coherences which can coexist with energy transport. This observation has generated different questions like: Is quantum coherence responsible for the surprisingly high efficiency of natural light harvesters? If so, how do such systems avoid the loss of coherence due to interactions with their warm, wet and noisy environments? The answer to these important questions rests in the beneficial interplay between electronic and vibrational degrees of freedom.

Superradiance at the localization-delocalization crossover in chlorosomes

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We study the effect of disorder on spectral properties of tubular chlorosomes, the main light-harvesting supramolecular structures in green sulfur bacteria. Employing a Frenkel-exciton Hamiltonian with diagonal and off-diagonal disorder consistent with spectral and structural studies, we analyze excitonic localization and spectral statistics of the chlorosomes. A size-dependent localization-delocalization crossover is found to occur as a function of the excitonic energy. The crossover energy region coincides with the more optically active states with maximized superradiance, and is, consequently, more conducive for energy transfer.

Emergent interactions in non-equilibrium suspensions

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We present a simple framework to compute the interactions between inclusions in different out-of-equilibrium solvents, i.e. suspensions of active particles and of granular particles. The character of the interaction between inclusions is of key importance in such systems thus it will determine the ability of the suspension to seggregate intrusive particles.

Firstly, we present a model of active, self-propelling and self-aligning, particles. The ability of the particles to align and swim is ubiquitous in bacterial or autophoretic suspensions. By trapping the inclusions we can measure the mean values of their effective interparticle force. A systematic exploration of the interparticle force as a function of the competition between propulsion and alignment allows us to identify three different regimes. We report a change in the qualitative behaviour of the forces, compared to thermal equilibrium. Specifically, tuning the particle activity we can go from atractive to repulsive and back to attractive effective forces.

Secondly, we present a simple model to simulate forced granular suspensions, as studied experimentally by C. Lozano *et al.* (Phys. Rev. Lett. **114**, 178002) in Navarra. The model takes into account the external forcing of a dense polydisperse mixture of disks, that model the poppy seeds in the experiment. In addition to the disks, we include two inclusions of greater mass and different behaviour under forcing to model the bronze spheres.

In our simulations we track the relative movement of the inclusions to extract the probability density $P(D)$, the probability to measure a distance D between the inclusions. For large values of the surface density, the probability distribution exhibits a nonmonotonic decrease as a function of the interparticle distance, implying that the two inclusiuons are more likely to be found at integer values of the diameter of the granular particles.

In both situations we report an emergent long-ranged interaction. This feature is of special interest since the interactions in the model are characterized by a finite range, the diametres of the particles. The origin of the interaction may be attributed to the out-of-equilibrium nature of the system; both the external forcing and the intrinsic difference in the mobilities of the particles.

Role of inelasticity in the symmetry of the Onsager matrix

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The role of energy exchange between a quantum system and its environment in is investigated from the perspective of the Onsager conductance matrix. We consider the thermoelectrical linear transport of an interacting quantum dot coupled to two terminals under the influence of an electrical potential and a thermal bias. We implement in our model the effect of coupling to electromagnetic environmental modes created by nearby electrons within the P(E)-theory. Our findings relate the lack of some symmetries among the Onsager matrix coefficients when a Zeeman field is applied with an enhancement of the maximum power efficiency and the occurrence of the heat rectification phenomenon.

Brain structure under a critical condition mediated by local currents

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The brain may be viewed as a complex network which, at the functional level, is highly heterogeneous and dissasortative, with scale-free distributed degrees [1]. This structure is known to improve both the robustness and efficiency of the network [2] and it is likely to be determined, at least in part, by a process of synaptic pruning. The latter is a physiological process which is known to take place in the brain of many mammals during infancy and which consists in an extensive activity-dependent elimination of synapses [1–3]. In this work, we study the correlation between the topological properties and the cognitive abilities of a neural network which evolves under a process of synaptic pruning. In accordance with previous studies, we seek for a deep correlation between neural network structure and brain activity patterns [4].

Previous studies [5] have analysed the topological process of synaptic pruning by assuming topological microscopic mechanisms for attachment and detachment of links. Here we propose a new model of evolving neural systems in which synaptic pruning is mediated by microscopic rules that depend on physiological information associated to the dynamic of both neurons and synapses. A preliminary study shows that only when the system reaches a memory phase there is a direct correlation between each neuron's degree and the synaptic current it is receiving. This, in fact, implies a strong correlation between the structural and functional topologies during memory and retrieval of information. Furthermore, the final state of the evolving network shows, in this memory regime, critical features such as a scale-free node degree distribution.

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[2] S. Nablakha, A. L. Barth, Z. Bar-Joseph, PLOS Computational Biology **11(7)**, 1004347 (2015).

[3] N. Gogtay et al., Proc. Natl. Acad. Sci U.S.A. **101**, 8174-8179 (2004).

[4] J.J. Torres and J. Marro, Scientific Reports **5**, 12216 (2015).

[5] S. Johnson, J.J. Torres and J. Marro, Journal of Statistical Mechanics **10**, 03003 (2010).

Chiral thermoelectrics

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Mesoscopic thermoelectrics has recently received great interest as it allows for powerful and highly efficient nanoscale heat engines [1]. In this talk, I will present a three-terminal energy harvester based on chiral quantum Hall edge channels which occur when a 2-dimensional electron gas is subject to a strong perpendicular magnetic field [2]. The chirality of the system gives rise to new contributions to the Seebeck and Peltier coefficient. These new terms allow for a finite thermoelectric response even in a left-right symmetric setup. Furthermore, they lead to an asymmetry between Seebeck and Peltier coefficient that can be controlled by gate voltages and offers the potential for increased thermoelectric efficiency. In addition, the chirality also gives rise to a modified Cuttler-Mott relation. Furthermore, I will show that the setup can also act as an efficient heat diode [3]. Finally, I will discuss a heat engine based on an electronic Mach-Zehnder interferometer where any ther moelectric response is of purely quantum-mechanical origin [4].

[1] [1] B. Sothmann, R. Sánchez, A.N. Jordan, Nanotechnology **26**, 032001 (2015).
[2] [2] R. Sánchez, B. Sothmann, A.N. Jordan, Phys. Rev. Lett. **114**, 146801 (2015).
[3] [3] R. Sánchez, B. Sothmann, A.N. Jordan, New J. Phys. **17**, 075006 (2015).
[4] [4] P. P. Hofer, B. Sothmann, Phys. Rev. B **91**, 195406 (2015).

High efficiency thermoelectric devices based on ferromagnet-superconductor quantum dots

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We study the linear response thermoelectric efficiency of a ferromagnetic-quantum dot-superconducting device. The spin polarized tunneling from the ferromagnet to a nearby quantum dot in combination with Zeeman field leads to large values of thermopower. Thermoelectric power can also be controlled by a back gate potential connected to the dot. Computed figure of merit of this device is very high due to the combined effects of external gate voltage, Zeeman splitting, and lead magnetization. Moreover, we find that spin Seebeck effect and magnetothermopower can vary dramatically, which suggests that spin currents can be tuned by thermal means only.

Theory of thermopower for spin-orbit coupled graphene and 2D spin transistors

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We investigate the transport properties in two 2D electron systems. The first system is composed by a graphene monolayer with a Rashba coupling localized around a finite region [1]. We calculate within the scattering approach the linear electric and thermoelectric conductance as well as the charge thermopower. We find that the junction thermopower is largely dominated by an intrinsic term independently of the spin-orbit potential scattering. We discuss the possibility of cancelling the intrinsic thermopower by resolving the Seebeck coefficient in the subband space. The second system consists on a spin-orbit-coupled two-dimensional electron system under the influence of a thermal gradient externally applied to two reservoirs [2]. We discuss the generated voltage bias (charge Seebeck effect), spin bias (spin Seebeck effect) and magnetization-dependent thermopower (magneto-Seebeck effect) in the ballistic regime of transport. We observe that, when the contacts are ferromagnetic, the thermopower can take positive and negative values. This is very interesting since depending on the position of the Fermi energy we may tune, with a fixed difference of temperature, the direction of the electric current.

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[1] M.I. Alomar and D. Sánchez, Phys. Rev. B **89**, 115422 (2014).
[2] M.I. Alomar, L. Serra and D. Sánchez, Phys. Rev. B **91**, 075418 (2015).

Local currents in quasi-1D Majorana nanowires

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Majorana modes appear in quasi-1D wires as effectively charge-less, zero-energy eigensolutions. They arise from the splitting, through a phase transition, of bulk electronic states into pairs of quasi-particles on the wire ends, each one being its own antiparticle. Several experiments with hybrid superconductor-semiconductor nanowires using tunneling spectroscopy from a normal conductor to the nanowire have observed a zero bias peak consistent with a Majorana state. In order to relate this peak with the Majorana state it is necessary a better understanding of its transport properties and the location in the parameter space of the Majorana phase boundaries. We have investigated the role of the magnetic orbital motion on the Majorana states physics present in quasi-1D planar hybrid semiconductor-superconductor nanowires. We will show that in a planar nanowire the main effect of the orbital motion is to change the Majorana phase boundaries.

On the other hand, stationary Majorana states can sustain non-vanishing local quasi-particle currents that are altered by the kinetic orbital motion caused by the off plane components of the magnetic field. We will compare the quasi-particle current present in planar Majorana nanowires with and without magnetic field components perpendicular to the nanowire surface. This comparison will be performed also between closed and open nanowires attached to normal leads.

[1] J. Osca and L. Serra, Phys. Rev. B **91**, 235417 (2015).

[2] J. Osca and L. Serra, J. Phys.: Conf. Ser. **647** 012063 (2015).

Interference of real and virtual transitions in quantum dot chains

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We analyzed long-range transport through an ac driven triple quantum dot. Resonant transitions between separated and detuned dots are mediated by the exchange of n photons with the time-dependent field. An effective model is proposed in terms of second order (cotunneling) processes which dominate the long-range transport between the edge quantum dots. The ac field renormalizes the inter dot hopping, modifying the level hybridization.

With the same set-up and the intermediate dot also in photo assisted resonance among the edge quantum dots we get interference ects between the long-range transport, that only couples the edge dots, and the first order tunneling path where the central dot gets normally occupied. We find configurations where the two paths interfere destructively and totally blocks the current. This work enhances the value of AC fields in mesoscopic transport.

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[1] F. Gallego-Marcos, R. Sánchez and G. Platero. Journal of Applied Physics **117**, 112808 (2015).

[2] F. Gallego-Marcos, R. Sánchez and G. Platero. arXiv:1508.05943 (2015)

Non-local transport of strongly-interacting fermions via topological and Shockley edge states

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In recent years, scientists have simulated many theoretical quantum-mechanical models in cold atom experiments with the use of periodic drivings. The Harper-Hofstadter Hamiltonian, or the Haldane model for Chern insulators, are some of the latest examples of what has become known as Floquet engineered matter. The increasing precision and tunability of these experimental setups has allowed scientists to also directly measure topological quantities such as the Zak-phase in a dimer chain. Motivated by these advances we study the strongly-interacting limit of the Fermi-Hubbard model in the simplest system displaying a topological phase transition, the SSH model. We have found that the hybridization of the edge-states of the system in the topologically non-trivial phase permits the long-range transfer of doublons (slowly decaying excitations of the Fermi-Hubbard model). On the other hand, an ac driving is able to induce a different kind of edge modes similar to Shockley edge states, that also permit doublons to travel from one end of the chain to the other without occupying the intervening sites. These findings may be useful in the development of future applications in quantum information.

Generic helical edge states due to Rashba spin-orbit coupling in a topological insulator

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We study the helical edge states of a two-dimensional topological insulator without axial spin symmetry due to the Rashba spin-orbit interaction. Lack of axial spin symmetry can lead to so- called generic helical edge states, which have energy-dependent spin orientation. This opens the possibility of inelastic backscattering and thereby non-quantized transport. Here we find analytically the new dispersion relations and the energy dependent spin orientation of the generic helical edge states in the presence of Rashba spin-orbit coupling within the Bernevig-Hughes-Zhang model, for both a single isolated edge and for a finite width ribbon. In the single-edge case, we analytically quantify the energy dependence of the spin orientation, which turns out to be weak for a realistic HgTe quantum well. Nevertheless, finite size effects combined with Rashba spin-orbit coupling result in two avoided crossings in the energy dispersions, where the spin orientation variation of the edge states is very significantly increased for realistic parameters. Finally, our analytical results are found to compare well to a numerical tight-binding regularization of the model.

Dissipative state preparation and phase transitions in quantum dots

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Most quantum systems are "open" in that they suffer from dissipation and decoherence due to coupling to uncontrolled environmental degrees of freedom. Recently it was appreciated that under certain conditions this coupling can also be exploited to perform quantum information tasks and can drive phenomena such as dissipative quantum phase transitions. We explore these effects in the context of (electron and nuclear) spins in quantum dots, in particular concerning dissipative generation of entanglement between quantum dots and the occurrence of dissipative phase transitions in dynamical nuclear polarization.

Quantifying spatial correlations of general quantum dynamics

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Understanding correlated dynamics in quantum systems out of equilibrium is both a fundamental challenge as well as of high practical relevance for the control of multi-particle quantum systems. In this contribution, we present a general and rigorous method to quantify the amount of correlations in the dynamics of quantum systems. Using a resource-theoretical approach, we introduce a suitable quantifier and characterize the properties of correlated dynamics in both closed and open quantum systems. Furthermore, we benchmark our method by applying it to the paradigmatic case of two atoms weakly coupled to the electromagnetic radiation field, and illustrate its potential use to detect and assess spatial noise correlations in quantum computing architectures.

Slow relaxation in electron glasses

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The problem of strongly disordered systems where electrons are localized and interactions between them are important has been under intensive study for some decades, both because of its complexity and because of fundamental interest. These systems are called electron glasses and represent many different physical materials, like: granular metals, amorphous solids, disordered thin films. A common feature to these systems is the phenomenon of slow relaxation, where d.c. conductance evolves logarithmically with time. The form of the relaxation scales with the duration of the excitation, a phenomenon called aging. We review experiments on slow relaxation and aging in electron glasses as well as theoretical approaches to explain them.

We also present recent AFM experiments on conducting polymers and granular metals showing slow relaxation, aging and a microscopic domain structure in the surface potential compatible with electron glasses predictions.

Fluctuation-dissipation relations in finite dimensional spin glasses

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We will review analytical, numerical and experimental studies regarding the fluctuation-dissipation relations out of equilibrium in spin glasses. In particular we will address the connection between the out of equilibrium dynamics and the static. Finally, we will present recent numerical results obtained using the JANUS-2 dedicated computer.

Effect of inelastic boundaries on the steady state flows in a dilute granular gas

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We introduce lateral boundaries on which granular particles collide inelastically. We will show how these boundaries drastically change the properties of the steady flows of driven granular gases, and give a theoretical explanation for a novel granular convection mechanism.

Análisis del comportamiento de un modelo de gas granular casi-bidimensional vibrado

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Los gases granulares están intrínsecamente fuera del equilibrio debido a la inelasticidad de las colisiones. Aquí se considera un gas granular de esferas duras confinado a una geometría casi-bidimensional, mediante dos placas vibrantes paralelas separadas una distancia menor que dos diámetros. El sistema alcanza eventualmente un estado estacionario homogéneo, aunque para ciertos valores de los parámetros exhibe una rica fenomenología.

Para describir la dinámica efectiva en el plano de estos sistemas, se ha propuesto un modelo cinético en el que se sustituye la verdadera regla de colisión por una en el plano que intenta incluir el efecto del vibrado sobre la dinámica bidimensional. Dicho modelo predice un estado estacionario homogéneo y a una hidrodinámica homogénea donde se observan efectos no lineales de memoria, análogos al llamado efecto Kovacs. Se han calculado los coeficientes de transporte y estudiado la estabilidad lineal de la hidrodinámica homogénea. Los resultados, junto a simulaciones tanto del sistema real como del modelo, se utilizan para discutir la validez del modelo.

Exact solution of the HCS in a 1d lattice model of granular media

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We present a simple one-dimensional lattice model which provides the typical phenomenology observed in granular media. Momentum conservation and energy dissipation due to collisions between nearest neighbours are the main signature of the system [1, 2].

The *Homogeneous Cooling State* (HCS) arises when periodic boundary conditions are considered. Not only do we solve the evolution of temperature and all two-velocities correlation functions in the hydrodynamic limit, but also exactly. This allows us to better understand this state: finite size effects in the cooling rate and the instability of the HCS are investigated [3].

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Chaotic current self-oscillations in weakly coupled semiconductor superlattices for true random number generation

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A weakly coupled semiconductor superlattice (SSL) represents an almost ideal one-dimensional nonlinear dynamical system with a large number of degrees of freedom. The strong nonlinearity in a doped, weakly coupled SSL originates from sequential resonant tunneling between adjacent quantum wells. Growth imperfections and various fluctuations of the layer thicknesses, electron density, energy levels, and inter-well coupling transform a weakly coupled SSL into a complex nonlinear system, in which the electron transport is strongly dissipative. During the last two decades, a great richness of nonlinear transport behavior has been observed in weakly coupled SSLs, including the formation of stationary electric-field domains, periodic as well as quasi-period current self-oscillations, and even driven as well as undriven chaos [1]. The oscillatory behavior is attributed to the localized, oscillatory motion of the domain boundary, which separates the high from the low electric-field domain. All experimental observations of these phenomena were confined to temperatures below 100 K until very recently, when spontaneous chaotic [2] and quasi-periodic [3] current self-oscillations were observed at room temperature in GaAs/(Al,Ga)As SLs using an Al content of 45%. This Al content results in the largest direct barrier for the GaAs/(Al,Ga)As materials system.
Based on these weakly coupled GaAs/$Ga_{0.55}Al_{0.45}$As SLs operating at room temperature, an all-electronic true random number generator (TRNG) has been demonstrated [4]. The spontaneous chaotic current self-oscillations with large amplitudes characterized by a bandwidth of several hundred MHz do not require external feedback or conversion to an electronic signal prior to digitization. The method is robust and insensitive to external perturbations, and its fully electronic implementation suggests scalability and minimal post processing in comparison to existing optical implementations. The achievable bit rates of up to 80 Gbit/s are very competitive, being about two orders of magnitude larger than typical bit rates for currently available all-electronic TRNGs. Even more recently, the synchronization of chaos based on room temperature spontaneous chaotic current self-oscillations in a weakly coupled GaAs/$Ga_{0.55}Al_{0.45}$As SL has been demonstrated as a useful building block for various tasks in secure communications, including a source of all-electronic ultrafast TRNG [5]. The emergence of several types of chaos synchronization has been experimentally demonstrated, in particular leader-laggard, face-to-face, and zero-lag synchronization in networks of coupled SSLs consisting of unidirectional and mutual coupling as well as self-feedback coupling. The realization of chaotic SSLs without external feedback and the synchronization among different structured SSLs open up the possibility for advanced secure multi-user communication methods based on large networks of coupled SSLs.

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Spontaneous chaotic oscillations and noise in a semiconductor superlattice model

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Fast spontaneous chaotic oscillations are used to generate high-quality true random sequences in random number generators. Using fast practical sources of entropy to produce true random sequences is crucial to make storage and transfer of data more secure at very high speeds. Secure communications and e-commerce come to mind. While the first high-speed devices were chaotic semiconductor lasers, the discovery of spontaneous chaos in semiconductor superlattices at room temperature [1, 2] provides a valuable all-electronic nanotechnology alternative.

Spontaneous chaos at room temperature has been observed in models for idealized superlattices for voltage ranges where sharp transitions between different oscillation modes occur [3]. In this contribution we will present results showing that we can create non periodic signals by adding noise to a specific external voltage. In addition, we will discuss different superlattices configurations that may enhance chaotic behavior.

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Non-stationary and noise properties of molecular junctions in the polaronic regime

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Localized vibrations (phonons) may have an important impact in the transport properties of nanoscale conductors [1]. Such effects have been observed in many different systems such as atomic chains, semiconducting quantum dots, carbon nanotubes and other molecular junctions. In spite of this variety, from a theoretical point of view all these situations can be qualitatively described by the rather simple Anderson-Holstein model. This model considers a single resonant level coupled to fermionic reservoirs and to a localized phonon mode. While the stationary properties of this model have been extensively analyzed, by many approximations, the way the system reaches the steady-state is not yet well understood.

In this work we focus in the so called polaronic regime, where the coupling between electrons and phonons is strong, compared with the coupling of the level to the electrodes. In order to study the transient regime properties of the system we use an approximation studied in a previous work, based on on a resummation of the dominant Feynman diagrams from the perturbation expansion in the coupling to the leads [2].

Using this approximation we are able to analyze the evolution of the current and the average population of the level, observing long transient behavior when increasing the electron-phonon coupling and no bistability at long time. These results are compared with numerical exact results obtained from path-integral Monte Carlo [3], showing a good agreement for different range of parameters and initials preparations of the system. Using the expressions developed by Mukamel *et al.* [4], we are able to evaluate the single electron probabilities transfer through the junction and the evolution of the current cumulants, showing an universal oscillatory behavior for higher order cumulants.

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Self-assembly in rotating magnetic colloids

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The collective motion of structures formed by aligned rotating magnetic colloids has been recently studied (Phys. Rev. Lett. **115**, 138301). In this talk, we will present the three necessary elements for the formation of such structures: the rotation inducing mechanism, which in this case is obtained applying an oscillatory magnetic field; the hydrodynamic interactions, both with an interface, capable of transforming rotation into translation, and with other particles that enhance the effect, and cohesive interactions, which are the magnetic dipole-dipole interaction between particles to keep them united, and the gravity to keep them at a constant distance from the wall.

Taking into account these elements, we can write the dynamic equations of the system, which show a competition between hydrodynamic forces, the magnetic dipolar force and gravity. Once identified the characteristic forces that measure each of those contributions, we can tune them to observe the formation of new structures via Lattice-Boltzmann simulations.

Geometrically induced complex tunnelings for ultracold atoms carrying orbital angular momentum

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Controllable complex tunneling amplitudes have been induced for ultracold atoms in one dimensional (1D) optical lattices either by a suitable forcing of the optical lattice [1] or by a combination of radio frequency an d optical Raman coupling fields [2]. We demonstrate [3] that complex tunneling amplitudes appear naturally in the dynamics of orbital angular momentum states for a single ultracold atom trapped in two dimensional (2D) systems of sided coupled cylindrically symmetric identical traps.

Specifically, we consider two 2D in-line ring potentials and three 2D rings in a triangular configuration. The full dynamics Hilbert space consists of a set of decoupled manifolds spanned by ring states with identical vibrational and orbital angular momentum quantum numbers. Recalling basic geometric symmetries of the system, we show that the tunneling amplitudes between different ring states, named cross-couplings, with (without) variation of the winding number, are complex (real). Moreover, we show that a complex self-coupling between states with opposite winding number within a ring arises due to the breaking of cylindrical symmetry induced by the presence of additional rings and that these complex couplings can be controlled geometrically. Although for two in-line rings, the complex cross-coupling contribution is shown to give a non-physically relevant phase, we demonstrate that, in a triangular ring configuration, it leads to the possibility of engineering spatial dark states, which allows manipulating the transport of angular momentum states via quantum interference. This triangular trapping configuration may open a myriad of possibilities when assumed to be the unit cell of a 2D lattice.

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