



### Science Meeting – Scientific Report

**Scientific report (one single document in WORD or PDF file) should be submitted online within two months of the event. It should not exceed seven A4 pages.**

***Proposal Title: III Summer School on Statistical Physics of Complex and Small Systems***

***Application Reference N°: 4658***

#### 1) Summary (up to one page)

The summer school was oriented at providing a solid background on techniques of Statistical Physics to PhD students and young postdocs working on complex and small systems. It follows the two preceding Summer Schools held in Palma de Mallorca in 2011 and in Benasque in 2012.

Statistical Physics together with Dynamical Systems Theory has developed powerful tools to characterize and understand the properties of complex systems well beyond the traditional basic body of knowledge included in typical courses at undergraduate or master level. The school has given the opportunity to the participants to learn these advanced techniques and resources, so that they can make use of them in their research. The range of topics in the school was broad so that students can benefit from learning on topics that, beyond the immediate needs for their specific PhD research, do indeed contribute to have a solid and broad background.

The school took place at the Instituto de Física Interdisciplinar y Sistemas Complejos, IFISC, a joint research institute from the Spanish Consejo Superior de Investigaciones Científicas and the Universitat de les Illes Balears in Palma de Mallorca. It was attended by 43 students: 39 from Europe, one from Turkey, two from Brasil, one from USA and one from Mexico. Besides learning, the format of the school provided with the opportunity for the students to interact with the lecturers and with other students, probably were working on different topics.

Besides theoretical classes the school also included hands-on sessions on the different topics. Participants presented their work as posters and as a 4 minute talk to summarize the contents of their contributions.

## 2) Description of the scientific content of and discussions at the event (up to four pages)

The school included 6 courses, three per week.

First week:

- *Stochastic Aspects in Nonequilibrium Statistical Physics*, by Horacio Wio, Instituto de Física de Cantabria (CSIC-UC), Spain.
- *Computational Statistical Mechanics*, by Christoph Dellago, University of Vienna, Austria.
- *Statistical Physics of soft and Hard Interfaces*, by Rodolfo Cuerno, Universidad Carlos III de Madrid, Spain.

Second week:

- *Theory and Models of Molecular Evolution*, by Susanna Manrubia, Centro de Astrobiología (INTA-CSIC), Spain.
- *Complexity and Chaos*, by Antonio Politi, University of Aberdeen, United Kingdom.
- *Complex Networks and Network Inference*, by Roger Guimerà, Universitat Rovira i Virgili, Spain.

Each course included one session of 1h on Monday and one sessions of 1h.15 minutes from Tuesday to Friday for a total of 6h of lecture time. Besides each course included two 80 minutes hands-on sessions supervised by the lecturers which included traditional “paper and pencil” exercises as well as computer exercises and numerical simulations. Some of the exercises were presented by the students on the last day of the course. For hands-on sessions we made use of a computer classroom equipped with 28 PC and sitting for an additional 28 people in which the software required for the hands-on sessions was pre-installed and configured. Part of the students did prefer to use the desktops provided while others prefer to install the software in their laptops and use them for the hands-on sessions. During the sessions support from IFISC IT personnel was provided. Student's had WiFi access to internet thorough all the UIB campus.

Besides the 6 courses the school also included a keynote lecture on *Stochastic Thermodynamics* by C. van den Broeck, Universiteit Hasselt, (Belgium) and 4 seminars:

- *Competitive patterns of interacting random walkers*, by E. Hernández-García, Instituto de Física Interdisciplinar y Sistemas Complejos (CSIC-UIB).
- *Fluctuations and scaling in condensed-matter physics*, by J.M. Lopez, Instituto de Física de Cantabria (CSIC-UC), Spain.
- *Systemic delay propagation in the US airport network*, by J.J. Ramasco, Instituto de Física Interdisciplinar y Sistemas Complejos (CSIC-UIB).
- *Collective phenomena in populations of oscillators*, by D. Pazó, Instituto de Física de Cantabria (CSIC-UC), Spain.

The School also included two poster sessions to allow the participants to present their results. Posters which were on display for a whole week and the poster session was hold at the same location where cofee breaks took place to encourage discussion. The panels sessions turns out to be extremely succesful. Last but not the least the school also included 4 sessions for student's oral presentations allowing for each student to gave a 4 minutes talk to sumarize the work presented at the poster session. A list of the abstracts of the participants contributions attached at the end of

this report. Presentations were in general very good both in the contents and in the form.

The schedule was planned to encourage scientific discussions and the interaction among students and lecturers. Besides the coffee breaks hosted together with the posters, the organization also provided lunch for all the participants and lecturers, so that discussions could continue in a more informal environment. Lunch was held at a separated room in one of the UIB cafeterias. Interaction among student's was further promoted by hosting them at the UIB student residence where they also had breakfast and dinner. Being housed at the student residence, students had free access to UIB sports facilities, which are located next to the residence.

The program of the School and the abstracts of the student's contributions are given in Annex 4A.

### **3) Assessment of the results and impact of the event on the future directions of the field (up to two pages)**

The school has been an outstanding success. Participants come from very different fields and different backgrounds (including physics, biology and computer science) attracted by wide variety of topics that were covered at the school, the reputation of the lecturers and the success of the two previous editions. We got initially over 50 applications even that at that time the ESF funding was not secured and therefore we could not announce any grant for the students. Grants were announced as soon as the problem with the ESF funding was solved. Most of the applications were of very high quality. Selection was done on the basis of their motivation to attend the school, qualifications on the degree and Master, suitability of their studies to understand the topics to be tackled at the school and work done in their PhD as compared to the time since they started.

In informal conversations students let us know that they were very glad both with the topics of the school and the lecturers as well as with the organization of the event. Contrary to the opinion that people is interested only in the topics close to their work, student's valued extremely well the diversity of topics and the interaction with people working in other topics. The possibility to present a poster and give a 4 minute talk on their work was also evaluated very positively. In general student's prefer this double format to a simpler format we used in the first school in which student's could give a 10 minute presentation plus 5 minute discussion but no poster. The combined format allows for longer and more detailed discussions during the coffee breaks and also allows for the work to be presented in front of everybody. In general student's prepared excellent posters and they give very good talks. It should be remarked that it is not so easy to call the attention of people working in other topics on your work (which requires a broad-scope introduction) and to summarize it in just 4 minutes.

While this is in general a not easy job for a researcher, it is even more difficult for a PhD student. Nevertheless practically all the talks stay on time. Altogether, there was a very good atmosphere among the students.

Lecturers also were also quite satisfied on the organization and on the way the School develop as well as on the student's attitude.

The school had also an impact on the UIB campus. The Vicerector of the UIB for research and postgraduate students, come for the school inauguration to welcome the students and to give them some inspiring words.

The grant given by the ESF has been extremely important and decisive in achieving this results. It allowed to organize the school without any registration fee and also to offer grants that cover the lodging expenses of 27 students. Besides, is also covered the cost of the coffee breaks, meals and the cost of the lodging of the invited lecturers and contributed to cover the the cost of the travel of the invited lecturers and other administrative costs.

After three successful editions it is clear that the format of this School has a clear future and that it is clearly helpful in proving a way for PhD students and young postdocs to adquire a solid knowlegde on the forefront topics in the field of complex and small systems, as well as in creating links with researchers in other topics. Links of this sort have the potential to be very relevant in the future when the now PhD students become senior researchers applying for research projects that involve several groups with different expertise.

- 4) Annexes 4a) and 4b): Programme of the meeting and full list of speakers and participants**

Annex 4a: Programme of the meeting and abstract of the student's presentations.

Hours	Monday	Tuesday	Wednesday	Thursday	Friday			
<b>WEEK 1</b>								
9:00 - 10:15		<b>Stochastic Aspects in Nonequilibrium Statistical Physics</b>						
10:15 - 10:45		COFFEE BREAK						
10:45 - 12:00		<b>Computational Statistical Mechanics</b>						
12:00 - 13:00		<b>Statistical Physics of soft and Hard interfaces</b>						
13:00 - 13:15		LUNCH						
13:15 - 14:30	LUNCH							
14:30 - 15:00						LUNCH		
15:00 - 16:00	Stochastic Aspects ...	IFISC presentation Students 4 min. talks	C. van den Broeck	Students 4 min. talks				
16:00 - 16:10	BREAK							
16:10 - 17:10	Computational ...	Hands on Stochastic Aspects ...	Hands on Soft and Hard interfaces	Hands on Computational ...				
17:10 - 17:30	Soft and Hard interfaces ...							
17:30 - 18:10								
18:10 - 18:50		Hands on Computational ...	Hands on Stochastic Aspects ...	Hands on Soft and Hard interfaces				

<b>WEEK 2</b>						
9:00 - 10:15	Students 4 min. talks	<b>Theory and Models of Molecular Evolution</b>				
10:15 - 10:45	COFFEE BREAK					
10:45 - 12:00	Students 4 min. talks	<b>Complexity and Chaos</b>				
12:00 - 13:15	E. Hernández-García	<b>Complex Networks and Network Interference</b>				
13:15 - 15:00	LUNCH					
15:00 - 16:00	Theory and Models ...	J. M. López	J. J. Ramasco	D. Pazó		
16:00 - 16:10	BREAK					
16:10 - 17:10	Complexity and Chaos	Hands on Theory and Models ...	Hands on Complex Networks ...	Hands on Complexity and Chaos		
17:10 - 17:30	Complex Networks ...					
17:30 - 18:10						
18:10 - 18:50		Hands on Complexity and Chaos	Hands on Theory and Models ...	Hands on Complex Networks ...		

## **Student's Contributions. First Week.**

### **Granular media, colloids & interphases**

**G. Chamorro, Moises**

#### **On granular fluids driven by stochastic and drag forces**

*Moisés G. Chamorro, Francisco Vega Reyes, Vicente Garzó*

Departamento de Física. Universidad de Extremadura, E-06071, Badajoz, Spain

**Abstract:** The homogeneous state of a granular gas of smooth inelastic hard spheres fluidized by the presence of a random and a drag force described by the Enskog-Boltzmann equation is analyzed. The combined action of both forces tries to mimic the interaction of the set of particles with a surrounding fluid. This state is characterized by a scaled distribution function  $\varphi$  that does not only depend on the dimensionless velocity but also on the dimensionless driving force parameters. The dependence of  $\varphi$  and its first velocity moments  $a_2$  and  $a_3$  on both the coefficient of restitution  $\alpha$  and the driven parameters is investigated by means of the DSMC method. In addition, approximate forms for  $a_2$  and  $a_3$  are also derived from an expansion of  $\varphi$  in Sonine polynomials. The theoretical expressions of the above Sonine coefficients agree well with simulation data, even for quite small values of  $\alpha$ .

**Majka, Maciej**

#### **A model for environment induced interaction between colloid particles.**

*M. Majka, P. F. Góra*

Marian Smoluchowski Institute of Physics, Jagiellonian University, Reymonta 4, 30-059 Kraków, Poland

**Abstract:** The typical model of colloid is a system consisting of two particle species: one which can be observed and the other that acts as environment. The presence of environment results in the additional Effective Interaction (EI) between distinguished particles, which can lead to self-organization in the system. Standard theories can predict EI from various types of particle-environment interactions, but they neglect the influence of intra-environment interactions. We propose a new general model of EI, which includes both particle-environment and environment-environment interactions. The EI is expressed by a single compact-form formula combining the microscopic interactions. This result is not restricted to any specific potential type and can serve as a tool to design systems of desired characteristics. The theory is illustrated by several analytically or numerically solvable examples, including hard-sphere systems and the systems based on 'ion in the solution' interactions.

**Rimas, Zilvinas**

#### **Title: Condensation of liquid in porous media**

*Zilvinas Rimas, Sergei Taraskin*

Department of Chemistry, University of Cambridge, Cambridge, UK

**Abstract:** Using a lattice constructed on a network representation for real soil samples we analytically and computationally investigate capillary condensation in out-of-equilibrium regime. The expressions for the critical parameters marking the appearance of hysteresis have been derived and tested computationally. By detailed comparison of the dynamics in the real soil network topology and random network, we found that the effects of spatial heterogeneity in soil network for

the most part can be neglected. However the distribution of the vertexes with a particular coordination number and the disorder in structural parameters of the constructed lattice has an immense influence to the dynamics. Therefore we deduce that random network with given distribution in coordination number and structural properties could be used to model real material.

**Tyukodi, Botond**

### **Depinning models and amorphous plasticity**

*B. Tyukodi, D. Vandembroucq*

[École Supérieure de Physique et de Chimie Industrielles de la Ville de Paris, laboratoire PMMH \(ESPCI - PMMH\), Paris, France](#)

**Abstract:** Recently, the study of the mechanical behavior of complex materials (ranging from soft foams, colloidal gels, pastes to the hard granular materials, structural glasses, porous or heterogeneous rocks) has attracted a growing number of physicists. Although very different regarding their typical length- or time scales, all of these materials share a common feature, the disorder of their structure and a common phenomenology: instead of breaking/sliding/flowing in a smooth way, they exhibit intermittent and heterogeneous dynamics over a wide range of time and length scales. In particular, recent efforts have been focused on the plasticity of dense amorphous solids and we intend to address this question. In this study we focus on developing a mesoscopic depinning-like model inspired by previous closely related models developed to describe the propagation of elastic lines in random media (crack fronts, contact lines, magnetic walls) and known to exhibit a (depinning) dynamic phase transition.

**Heinonen, Vili**

### **Bcc crystal-fluid interfacial free energy in Yukawa systems**

*V. Heinonen(1), A. Mijailovic(2), C. V. Achim(1,2), T. Ala-Nissila(1,3), R. E. Rozas(2), J. Horbach(2) and H. Lowen(2)*

(1) COMP Centre of Excellence, Department of Applied Physics, Aalto University, School of Science (2) Institut für Theoretische Physik II: Weiche Materie, Heinrich-Heine-Universität Düsseldorf (3) Department of Physics, Brown University

**Abstract:** We determine the orientation-resolved interfacial free energy between a body-centered-cubic (bcc) crystal and the coexisting fluid for a many-particle system interacting via a Yukawa pair potential. For two different screening strengths, we compare results from molecular dynamics computer simulations, density functional theory, and a phase-field-crystal approach. Simulations predict an almost orientationally isotropic interfacial free energy, which is independent of the screening strength. This value is in reasonable agreement with our Ramakrishnan-Yussouff density functional calculations, while a high-order fitted phase-field-crystal approach gives about 2-3 times higher interfacial free energies for the Yukawa system. Both field theory approaches also give a considerable anisotropy of the interfacial free energy. Our result implies that, in the Yukawa system, bcc crystal-fluid free energies are a factor of about 3 smaller than face-centered-cubic crystal-fluid free energies.

**Kallus, Yoav**

### **Pessimal shapes for packing and covering**

*Yoav Kallus*

[Princeton University](#)

**Abstract:** Shapes that tile space provide an obvious optimum for packing fraction and covering fraction among all shapes. The question of which convex shapes leave the most empty space in their densest packing is much less obvious and has been the subject of various mathematical conjectures. I show that the ball is a local pessimum among centrally symmetric 3-dimensional shapes and the regular heptagon is a local pessimum among 2-dimensional shapes. In 2 dimensions and in dimensions above 3 the ball is not a local pessimum, so the situation in 3 dimensions is exceptional despite what might be expected naively. For covering, the ball is a local pessimum in 2 and 3 dimensions, but not in 4 and 5 dimensions.

## *Work & fluctuations*

**Kuśmierz, Lukasz**

### **Heat and work distribution for mixed Gauss-Cauchy process**

*L. Kuśmierz(1), E. Gudowska-Nowak(1), J. M. Rubi(2)*

(1) Marian Smoluchowski Institute of Physics, and Mark Kac Center for Complex Systems Research, Jagellonian University, ul. Reymonta 4, 30--059 Kraków, Poland (2) Departament de Física Fonamental, Facultat de Física, Diagonal 647, 08028 Barcelona, Spain.

**Abstract:** We analyze energetics of a non-Gaussian process described by a linear stochastic differential equation. The process represents a paradigmatic model of a nonequilibrium system. We define thermodynamic quantities for trajectories of the process and analyze contributions to mechanical work and heat. As a working example we consider a particle subjected to a drag force and two independent additive Lévy white noises with stability indices  $\alpha=2$  and  $\alpha=1$ . Distributions of dissipated heat and work performed by the force acting on the system are addressed by examining contributions of Cauchy fluctuations to either bath or external force acting on the system.

**Kutvonen, Aki**

### **Dissipated work and fluctuation relations for non-equilibrium single-electron transitions**

*A. Kutvonen (1), J.P. Pekola (2), T. Ala-Nissilä (1,3)*

(1) COMP CoE at the Department of Applied Physics, Aalto University School of Science, Espoo, Finland (2) Low Temperature Laboratory (OVLL), Aalto University School of Science, Espoo, Finland (3) Department of Physics, Brown University, Providence, USA

**Abstract:** We discuss a simple but experimentally realistic model system, a single-electron box (SEB), where common fluctuation relations can be tested for driven electronic transitions. We show analytically and numerically that Jarzynski equality can be violated even if the system starts from equilibrium, the process in contact with only one heat bath and we perform no feedback. However, an integral fluctuation relation based on total entropy production works also in this situation.

**Mihelich, Martin**

### **Maximum entropy production and ASEP model**

*M. Mihelich(1), B. Dubrulle(1) and D. Paillard(2)*

(1) Service de Physique de l'Etat Condensé, Direction des Sciences de la Matière, CEA-Saclay, CNRS URA 2464, 91191 Gif-sur-Yvette cedex, France (2) Laboratoire des Sciences du Climat et de l'Environnement, CEA-CNRS Centre d'Etudes de Saclay, Orme des Merisiers Gif-sur-Yvette, France

**Abstract:** The Principle of Maximum Entropy Production (MEP) stipulates that a nonequilibrium stationary system selects the state which maximizes the entropy production taking into account constraints. Though many attempts to demonstrate this principle did not lead to convincing evidence, it has been used in many fields such as solid physics, electromagnetism, quantum physics or climate science. MEP is widely used because it permits to obtain a well fitted approximation without huge calculation. We will show how, in a simple model close to those used in climate science, the Maximum Thermodynamics Entropy Production Principle (MEP) and the Maximum Kolmogorov-Sinai Entropy Principle are equivalent. This result highlights an existing link between two empirical principles often used in nonequilibrium physics.



**Tizón Escamilla, Nicolás**

### **Fluctuations in the Ising model**

*P.L. Garrido (1,2), P.I. Hurtado, (1,2) and N. Tizón (2)*

(1) Instituto Carlos I de Física Teórica y Computacional (Universidad de Granada, UGR), Granada, Spain. (2) Departamento de Electromagnetismo y Física de la Materia (Universidad de Granada, UGR), Granada, Spain

**Abstract:** Nonequilibrium phenomena characterize the physics of many natural systems. Despite their importance, no general theory exists yet capable of predicting nonequilibrium macroscopic behavior in terms of microscopic physics, in a similar way to equilibrium statistical physics. This is due to the difficulty in combining statistics and dynamics, which plays a major role out of equilibrium. However, during the last years, new advances made in the study of macroscopic fluctuations, with their statistics and associated structures, have improved our understanding of nonequilibrium behavior. The language of the fluctuations is the theory of large deviations, with large-deviation functions (LDFs) measuring the probability of fluctuations and optimal paths sustaining these rare events as central objects. In fact, LDFs play in nonequilibrium systems a role akin to the equilibrium free energy. Our aim is to show how we can study fluctuations in a particular system: the Ising model.

**Sartoretti, Guillaume**

### **Self-Organized mixed canonical-dissipative dynamics for Brownian planar agents**

*G. Sartoretti and M.-O. Hongler*

Laboratory of Microengineering for Manufacturing (STI/IMT/LPM), EPFL (Swiss Federal Institute of Technology in Lausanne), Switzerland

**Abstract:** We consider a collection of  $N$  homogeneous interacting Brownian agents evolving on the plane. The time continuous individual dynamics are jointly driven by mixed canonical-dissipative (MCD) type dynamics and White Gaussian noise sources. Each agent is permanently at the center of a finite size observation disk  $D$ , and counts the number of its fellows located in this disk to re-actualize control parameters entering into the MCD. Dissipation mechanisms together with the noise sources ultimately drive the dynamics towards a consensual stationary regime characterized by an invariant measure  $P_s$  on an appropriate probability space. Assuming propagation of chaos, a mean field approach enables to analytically calculate  $P_s$ . The MCD drift is derived from a Hamiltonian function  $H$  and incites the agents to follow one consensual orbit coinciding with a level curve of  $H$ . When  $H$  is the harmonic oscillator, we are able to analytically derive the consensual orbit as a function of the size of  $D$ .

## **Transport & Diffusion**

**Becker, Thijs**

### **Diffusion of interacting particles in discrete geometries**

*T. Becker (1), K. Nelissen (1,2), B. Cleuren (1), B. Partoens (2) and C. Van den Broeck (1)*

(1) Faculteit Wetenschappen, Universiteit Hasselt, Hasselt, Belgium (2) Departement Fysica, Universiteit Antwerpen, Antwerpen, Belgium

**Abstract:** A new model describing the diffusion of interacting particles is introduced. Exact analytical expressions for the self- and transport-diffusion are obtained when correlations are neglected. The effect of correlations is investigated by comparing the analytical expressions with results from simulations. The self-diffusion is found to exceed the transport-diffusion when particles cluster, explaining recent experimental findings published in Phys. Rev. Lett. by Chmelik et al. Finally, quantitative agreement with experiment is obtained.

**Ibrahim, Yahaya**

**Propulsion mechanisms of a phoretic-swimmer**

*Y Ibrahim (2), R Golestanian (1), T Liverpool (2)*

(1) Rudolf Peierls Centre of Theoretical Physics, University of Oxford, Oxford OX1 3NP, UK (2) School of Mathematics, University of Bristol, Bristol, BS8 1TW, UK

**Abstract:** Colloid particles have been shown experimentally to propel themselves in the presence of some gradient (e.g Electric field, chemical gradient) due to phoretic effects. We review the theory for such phoretic mechanisms and hydrodynamics responsible for the particle propulsion. Furthermore, reviewed here is a theoretical framework elucidating generic design paradigm for self-propelled particles capable of generating and sustaining such gradients - consuming the free energy in the ambient.

**Laenen, François**

**Heavy particle dynamics in random smooth flows by probabilistic method.**

*F. Laenen(1), J. Bec(2), G. Krstulovic(3)*

(1) Lagrange, UMR 7293, CNRS, Observatoire de la Côte d'Azur.

**Abstract:** Heavy particle dynamics plays an important role in nature, including pollutants suspension in water, water droplets formation and aerosols transport in atmosphere, as well as in the industrial world, including chemical reactions, combustion processes and others. By use of numerical simulation using smooth, homogeneous and isotropic flow, preferred concentration with multi-fractal clustering and Lyapunov exponents determination has been shown. The goal here is to prove the reproducibility of these results using a more probabilistic approach inspired from Lattice-Boltzmann modeling.

**Straka, Mika**

**Anomalous heat conduction in the one-dimensional FPU-alpha-beta chain**

*S. Lepri (1), R. Livi (2, 3), M. Straka (3)*

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**Abstract:** After more than fifty years, heat conduction in the one-dimensional FPU-alpha-beta chain still poses an open question. Recent studies challenge the generally accepted opinion of diverging thermal conductivity in the thermodynamic limit, suggesting its convergence. In our work we intend to clarify the basic assumptions of a theoretical hydrodynamic approach and to test the possibility of normal heat conduction.

**Suñé, Marc**

**Anomalous transport and diffusion of Brownian particles**

*M. Suñé and J.M. Sancho*

Departament d'Estructura i Constituents de la Matèria (UB), Barcelona, Spain

**Abstract:** We present a numerical study, through simulation of the Langevin equation, of the anomalies in transport and diffusion of overdamped Brownian particles in totally disordered potential landscapes either in one and two dimensions. In particular, the effects of three different disorder correlations or spectra have been analyzed. The anomalous regimes are characterized by the time exponents of the power law relation carried out both by the mean and the variance. Though the anomaly in transport is always of subtransport type, diffusion exhibits more anomalies: both subdiffusion and superdiffusion are indeed reached. In two dimensions we present a mixed anomaly: subdiffusion in the perpendicular direction to the force and superdiffusion in the parallel one. We have recently observed some novel properties of diffusion of infradamped Brownian particles which are still under discussion.

## **Student's Contributions. Second Week.**

### ***Biological & ecological systems***

**Barardi, Alessandro**

#### **Phase-coherence transitions in the gamma range between delay-coupled neuronal populations**

*Alessandro Barardi, Belen Sancristobal, Jordi Garcia-Ojalvo*

Department of Experimental and Health Sciences, Barcelona Biomedical Research Park, Universitat Pompeu Fabra, Barcelona, Spain  
Departament de Física i Enginyeria Nuclear, Universitat Politècnica de Catalunya, Terrassa, Spain

**Abstract:** In neuronal systems, firing synchronization is of great importance in information transmission between brain areas. In the last decades, several studies have reported various examples of synchronization among neurons, such as chaos synchronization in a large ensemble of HH neurons. It is known that synchronized spikes increase their impact to a given target neuron. Analogously, synchronized electrical oscillations emerging from the activity of thousands of neurons can increase the functional connectivity between neural assemblies by coherently coordinating their firing dynamics. We have studied, using conductance-based models, the influence of the synaptic delay on the synchronization of neural populations oscillating in the gamma range. We examined how different ranges of synaptic delays give rise to in-phase/out-of-phase transitions at different frequencies and show this behavior is related to the level of coherence achieved by the two signals.

**Camilo Luna, Juan**

#### **Study of competition in intercellular signaling in extended dynamical systems**

*J. C. Luna, P. Formosa-Jordan and M. Ibanes*

Departamento de Estructura y Constituyentes de la Materia, Universitat de Barcelona (ECM - UB), Barcelona, Spain

**Abstract:** Cell to cell communication involves the binding of a ligand with a receptor anchored in the cell membrane of neighboring cells, such that from this interaction is triggered a signal that regulates gene transcription inducing cell-fate commitment. Lateral induction and lateral inhibition are two main processes mediated by intercellular signaling. In the former the ligand activates the formation of the signal, which in turn activates the transcription of the ligand, while in the later the ligand activates the formation of the signal, but the signal represses the transcription of the ligand. Lateral induction and lateral inhibition have opposite functional responses. In this work we have studied the response of a system when there are two molecular mechanisms acting simultaneously. We have found that the competition between the ligands for the receptor induce change in the topology of the mechanisms and favors transitions between lateral induction and lateral inhibition in a robust manner.

**Catalán, Pablo**

#### **toyLIFE: a new framework for the study of gene network evolution**

*Pablo Catalán, Clemente Fernández-Arias and Jose A. Cuesta*

Grupo Interdisciplinar de Sistemas Complejos (GISC), Departamento de Matematicas, Universidad Carlos III de Madrid, 28911 Leganés, Madrid, Spain

**Abstract:** Genes affect the expression of other genes, creating a complex network of regulating

interactions that determines the way a cell will function through its life. These networks are called gene regulatory networks (GRNs). Many models have been proposed for the study of GRN evolution, but most of them model mutation as direct changes in the topology of the network. However, real mutational changes occur on the DNA, and there are several levels of redundancy before these mutations get translated into actual changes in the topology of the GRN. These changes can be small or have a large impact on the GRN. We present here toyLIFE, a new framework designed to study the evolution of GRNs. toyLIFE contains analogs of genes, aminoacids and proteins, which interact through well-defined physical laws to produce “toyGRNs”. This simple framework allows us to study how the effects of mutation at the “toyDNA” level are carried to higher levels, leading to new insights on the evolution of these systems.

**Ebadi, Haleh**

### **Identification of biological control networks from dynamics**

*H. Ebadi, K. Klemm*

Bioinformatics Group, Computer Science Department, Leipzig University, Germany

**Abstract:** An observation of a state transition provides partial information on the interactions constituting a high-dimensional deterministic system. Here we strive to quantify how the number of observed single state transitions and/or short trajectories reduces the number of interaction matrices consistent with the set of observations. As a test-bed, we use several established Boolean (threshold unit) models of cell cycle control in living organisms. The numerical study also uses ensembles of randomly reshuffled matrices as a null model. We find that the original interaction matrices are easier to reconstruct than the shuffled surrogates.

**Martinez Garcia, Ricardo**

### **Optimizing the search for resources by sharing information: Mongolian gazelles as a case study.**

*R. Martinez-Garcia (1), J.M. Calabrese (2), T. Mueller (2),(3), K.A. Olson (2), C. Lopez (1).*

(1) Instituto de Física Interdisciplinar y Sistemas Complejos (CSIC - UIB), Palma de Mallorca, Spain. (2) Ecology Center, Smithsonian Conservation Biology Institute, Front Royal VA, USA. (3) Behavior, Ecology, Evolution, and Systematics Program, University of Maryland, College Park MD, USA.

**Abstract:** We propose a model of Brownian searchers which are able to perceive the quality of the environment at its location, and with a long-range pairwise interaction that provides information on the habitat in far away regions of the space. First, we study the efficiency of the search depending on the range of the communication from a temporal and a spatial point of view measuring the population mean searching time and the spatial distribution of individuals in the long time limit. Our results point out that the search is optimal at intermediate scales of communication. Finally, we study the foraging in Mongolian gazelles coupling the model with remotely-sensed data on resource quality in the Steppe of Mongolia and show that at intermediate lengths of communication gazelles optimize the search. Finally, the optimal communication range and frequency obtained with our model are in good agreement with experimental results.

**Nogueira de Souza Medeiros, Bruno**

### **Title: Use of electronic circuits in the study of collective neuronal phenomena**

*Bruno N. S. Medeiros, Mauro Copelli*

Departamento de Física, Universidade Federal de Pernambuco, Recife, PE, Brazil

**Abstract:** We make use of electronic devices that mimics the behavior of sensory neurons and chemical synapses to study collective neuronal phenomena. The devices are designed to be as simple as possible while still retaining physiological similarity with their biological counterparts. This allows for scalability, simple mathematical modeling and real-time parameter scanning. With these building blocks, we are able to investigate most types of network configuration and, therefore, phenomena such as Coherence Resonance, optimal dynamical range and short-term synaptic plasticity leading to self-organized criticality.

## *Social & Economical systems*

**Ashcroft, Peter**

### **Pattern formation in individual-based systems with time-varying parameters**

*P. Ashcroft and T. Galla*

[The University of Manchester, Manchester M13 9PL, United Kingdom](#)

**Abstract:** We investigate pattern formation in discrete systems driven by sweeping the system through a symmetry-breaking bifurcation at a finite rate. It is this rate which determines the typical length-scale of the resulting patterns. This is known as the Kibble-Zurek (KZ) theory of defect formation. The Turing picture of pattern formation has been studied in stochastic systems, but the KZ picture has so far been restricted to continuous systems. We study discrete, individual-based models where pattern formation is driven by intrinsic so-called demographic noise. We display results for a model of opinion dynamics, a model of evolutionary dynamics, and a model of cellular decision making with time-dependent lateral inhibition. Analytical descriptions of patterns formed in these models are derived through the linear-noise approximation. Further numerical work shows similar results in the case where the symmetry breaking bifurcation is triggered by population growth.

**Bustos, Ricardo**

### **On the distribution of per capita Gross Domestic Products**

*R. Bustos-Guajardo, C. F. Moukarzel*

[CINVESTAV, Departamento de Física Aplicada, Mérida Yucatán, México](#)

**Abstract:** World per capita Gross Domestic Products have been customarily assumed to have a log-normal distribution in many macroeconomic studies. This is only justified if the most relevant part of the dynamics can be seen as locally-acting random multiplicative noise, for each country independently. This simplification neglects the importance of exchange processes like international commerce, so it is not surprising that the log-normal hypothesis fails to fit the available data for per capita GDP. We have been able to analytically calculate the distribution of per capita GDP for a model that involves both commerce, in the form of Random Multiplicative Exchange, and local Multiplicative Noise for each country. Our analytic expressions provide greatly improved fits to per capita GDP data and allow us to estimate the relative importance of exchange versus local noise. Contrary to the implicit assumptions in some earlier models, we find that commerce cannot be neglected.

**Carro, Adrián**

### **Network effects on the local and dynamic properties of an agent-based herding model**

*A. Carro, R. Toral, M. San Miguel*

[Instituto de Física Interdisciplinar y Sistemas Complejos \(CSIC - UIB\), Palma de Mallorca, Spain](#)

**Abstract:** Some of the stylized facts of financial time series have been addressed as macroscopic patterns, emerging from herding interactions among groups of agents with heterogeneous trading strategies and a bounded rationality. These approaches focus on the processes of social interaction among agents, which can be described within a network framework whose structural effects upon the relevant macroscopic properties become crucial. We analyze the microscopic implementation of a simple stochastic herding formalism introduced by A. Kirman to model decision making among financial agents. By means of suitable approximations, we are able to derive closed-form solutions for the steady state of the order parameter, as well as the variance and the autocorrelation of the global state variable as functions of the degree distribution of the underlying network. We also show that it is possible to infer some characteristics of the underlying communication structure by measuring only global variables.

**Nyczka, Piotr**

### **Phase transitions in the q-voter model with two types of stochastic driving**

*Piotr Nyczka, Katarzyna Sznajd-Weron, Jerzy Cislo*

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**Abstract:** We study a nonlinear  $q$ -voter model with stochastic driving on a complete graph. From a social point of view, it is very important to distinguish between two types of nonconformity: anticonformity and independence. A majority of work has suggested that these social differences may be completely irrelevant in terms of microscopic modeling that uses tools of statistical physics. In this paper we clarify the concept of social temperature and show that different types of noise may lead to qualitatively different emergent properties. In particular, we show that in the model with anticonformity the critical value of noise increases with parameter  $q$ , whereas in the model with independence the critical value of noise decreases with  $q$ . Moreover, in the model with anticonformity the phase transition is continuous for any value of  $q$ , whereas in the model with independence the transition is continuous for  $q < 6$  and discontinuous for  $q \geq 6$ .

**Pace, Bruno**

### **Voter model with surface tension**

*B. Pace and K. Klemm*

[Bioinformatics group of Leipzig University](#)

**Abstract:** Spin systems are very central in the context of statistical physics for their simplicity and generality. But also, any process out of the realm of physics that shares some intrinsic properties and symmetries will inherit some of their characteristics such as the phase transitions or scaling properties. There is a well-known comparison between the Voter Model and the Ising Model at zero temperature. In the latter, however, curvature-driven surface tension orders the system. Here we propose a different microscopic mechanism for the emergence of surface tension with some different macroscopic behaviour and we compare the three models.

**Valverde , Pablo**

### **Effect of size of groups in an Optional Public Good Game model.**

*P. Valverde, S. Gonçalves, J.C. González-Avella, J.R. Iglesias*

[Instituto de Física, Universidade Federal do Rio Grande do Sul, Caixa Postal 15051, 90501-970 Porto Alegre RS, Brazil.](#)

**Abstract:** We study under which conditions cooperation can emerge in a type of social dilemma dynamics known as Optional Public Good Game (OPGG). We consider  $N$  agents, which can be in one of three possible states: cooperator (C), defector (D) or loner (L). In order to study the global properties of the OPGG in a mean field and a two-dimensional network, we have used the subset  $S$  of players chosen to play OPGG, the  $r$  parameter, the multiplication factor of OPGG and the probability  $p$  which defines the disorder degree in the network. Through the systematic study of those parameters, the system displays two different dynamics: i) convergence to an absorbing state, and ii) evolution to a state of coexistence in which the three strategies coexists. In the coexistence state and for some values of those parameters, the dynamics of the system exhibits a cyclic behavior among the three states.

## **Complex Networks**

**Bianco Martinez, Ezequiel**

### **Determining functional and physical connectivity in complex time-series**

*E. Bianco-Martinez, C. Antonopoulos and M.S. Baptista*

[Institute for Complex Systems and Mathematical Biology, University of Aberdeen, King's College, Aberdeen, UK](#)

**Abstract:** The study of the way information is exchanged between nodes in complex networks is of primordial importance for understanding its functionality. A quantity known as Mutual Information Rate (MIR) can quantify the exchange of information between nodes in a pair-wise fashion and is well defined for systems with memory or that presents non-zero correlation. Its calculation involves probabilities which requires a proper definition of a partition. Here, we show that there is a finite partition with equal-sized cells that optimally approximates a Markov partition, allowing for the accurate estimation of many dynamical invariants (Lyapunov exponents, Expansion rates, MIR, etc).

**Ferdinandy, Bence**

**HIV competition dynamics over sexual networks**

*B. Ferdinandy(1), E. Mones(1), T. Vicsek(1) and V. Müller(2)*

(1) Department of Biological Physics, Eötvös Loránd University, Budapest, Hungary (2) Research Group of Theoretical Biology and Evolutionary Ecology, Eötvös Loránd University and the Hungarian Academy of Sciences, Budapest, Hungary

**Abstract:** The global phylogeography of HIV is characterized by compartmentalized local epidemics that are typically dominated by one subtype, which indicates strong founder effects. We developed a stochastic modelling framework to simulate HIV epidemics over dynamic contact networks, parameterized based on empirical data. We simulated epidemics in which the second strain was introduced into the population with varying time lags after the first. With strains of equal transmission efficiency, the second strain was unable to invade on a time scale relevant for the history of the HIV pandemic. To become dominant over a time scale of decades, the second strain needed considerable advantage in transmission efficiency over the resident strain. Our simulation confirmed asymmetrical competition dynamics of HIV at the population level, with an advantage of the first successful strain in the population. The modelling framework also allows us to make predictions on the future evolution of the pandemic.

**Jiménez Martín, Manuel**

**The influence of network topology on the existence of spatially asymmetric retrieval states in binary attractor neural networks**

*Manuel Jimenez-Martin, Elka Koroutcheva*

Departamento de Física Fundamental, Universidad Nacional de Educación a Distancia (UNED) Senda del Rey 9, 28080 Madrid, Spain

**Abstract:** Neocortical neural networks can be understood as autoassociative networks with spatially dependent connectivity and they exhibit localized regions of activity during memory operations. These 'bumps' of activity are called Spatially Asymmetric States (SAS). The SAS have been shown to occur spontaneously in binary attractor Hopfield neural networks when asymmetry between the retrieval and the learning is imposed. The conexión between the SAS and some topological features of the network such as modularity is the topic of current research.

**Rodríguez Méndez , Victor**

**Inference in networks embedded in metric spaces**

*Victor M. Rodriguez, José J. Ramasco, Victor M. Eguíluz*

Instituto de Física Interdisciplinar y Sistemas Complejos (CSIC - UIB), Palma de Mallorca, Spain

**Abstract:** We have introduced a method to infer significant structure in networks based on Expectation Maximization, with the aim of applying it to networks whose nodes are embedded in a metric space. The method is used on different benchmark networks produced with a prior probability of connection between the nodes  $i$  and  $j$ . This probability is a function of the position coordinates of the nodes. By combining Expectation Maximization and Metric Multidimensional Scaling, we have recovered the given connection probability functions, the position of the nodes and the dimension of the underlying metric space from the benchmark networks. The quality of the inference is measured using the Pearson Correlation to compare the inferred and the original connection probabilities. The results are shown for different number of links in the networks.

**Vallès-Català, Toni**

**Identifying significant node groups in complex networks**

*Toni Vallès-Català, Marta Sales-Pardo, Roger Guimerà*

Departament d'Enginyeria Química, Universitat Rovira i Virgili (DEQ - URV), Tarragona, Catalonia, Spain

**Abstract:** Complex networks enable an accurate representation of a large amount of information, with which a wide variety of problems can be solved. For instance, the spreading of a disease can be studied with the worldwide air transportation network, and metabolic networks provide methods to

uncover novel drug targets within the every-increasing amount of biological data available. By studying the structure of a network we can extract all the information that can be used in the process of decision making. A good approach to unravel the characteristics of a structure is to group nodes into stochastic block models, where nodes with the same pattern of connections are grouped together. Trying to capture all the characteristics in one stochastic block model will produce a lack of information, since some properties of the structure would not be distinguishable. Our method provides all the characteristics of the structure in separately stochastic block models.

## *Nonlinear Dynamics*

**Abolaffio, Milo**

### **Excitable systems in two dimensional flows**

*G. Boffetta, F. Delillo, M. Abolaffio*

[Univesità degli studi di Torino](#)

**Abstract:** Recently was studied, for the first time, an excitable system in bidimensional turbulence, and the result is that the mean scale and the mean velocity of the characteristic patterns are renormalized by the turbulent diffusion. Stimulated by this work, we perform numerical simulations, validating numerically the results of the experiment and reaching region of parameters never joined by the experiment. We found that the crucial parameter for this system is the Damköhler number, the ratio between the correlation time of the velocity field and the time of the reaction, as expected by analogy with turbulent flame combustion theory.

**Escalona, Miguel**

### **Complexity, information transfer and collective behavior in chaotic dynamical networks**

*M. Escalona-Morán(1), G. Paredes (2) and M. G. Cosenza(3)*

[\(1\) Instituto de Física Interdisciplinar y Sistemas Complejos \(CSIC - UIB\), Palma de Mallorca, Spain](#) [\(2\) Laboratorio de Física Aplicada y Computacional, Universidad Nacional Experimental del táchira, San Cristobal, Venezuela](#) [\(3\) Centro de física Fundamental, Universidad de Los Andes, 5101 Mérida, Venezuela](#)

**Abstract:** We investigate the relationship between complexity, information transfer and the emergence of collective behaviors, such as synchronization and nontrivial collective behavior, in a network of globally coupled chaotic maps as a simple model of a complex system. Our results show that the emergence of nontrivial collective behavior is associated to higher values of complexity. Little transference of information from the global to the local level occurs when the system settles into nontrivial collective behavior while no information at all flows between these two scales in a synchronized collective state. As the parameter values for the onset of nontrivial collective behavior or chaos synchronization are approached, the information transfer from the macroscopic level to the local level is higher, in comparison to the situation where those collective states are already established in the system.

**Löber, Jakob**

### **Controlling the position of a front**

*Jakob Löber, Eckehard Schöll, Harald Engel*

[Institute for Theoretical Physics, TU Berlin, Germany](#)

**Abstract:** We present a method to control the position as a function of time of traveling front solutions to reaction-diffusion systems according to a pre-specified protocol of movement. Given this protocol, the control function is found as the solution of a perturbatively derived integral equation. Two cases are considered. First, we derive an analytical expression for the space and time dependent control function that is valid for arbitrary protocols and many reaction-diffusion systems. Second, for stationary control of traveling waves, the integral equation reduces to a Fredholm integral equation of the first kind. In both cases, the control can be expressed in terms of the uncontrolled wave profile and its propagation velocity, rendering detailed knowledge of the reaction kinetics unnecessary.



**Manzano Paule, Gonzalo**

**Title: Synchronization and quantum correlations in networks**

**Authors:** *G. Manzano(1), F.Galve(2), G. Giorgi (2), P.Colet(2), E. Hernández(2), R. Zambrini(2)*

**Affiliations:** (1) Departamento de Física Atómica, Molecular y Nuclear, Universidad Complutense de Madrid, Madrid, Spain. (2) Instituto de Física Interdisciplinar y Sistemas Complejos (CSIC - UIB), Palma de Mallorca, Spain

**Abstract:** Synchronization is one of the paradigmatic phenomena in the study of complex systems. Although several mechanisms and conditions for synchronous behavior in spatially extended systems and networks have been identified, the emergence of this phenomenon has been largely unexplored in quantum systems until very recently. Here we discuss synchronization in quantum networks of different harmonic oscillators relaxing towards a stationary state, being essential the form of dissipation. By local tuning of one of the oscillators, we establish the conditions for synchronous dynamics, in the whole network or in a motif. Beyond the classical regime we show that synchronization between (even unlinked) nodes witnesses the presence of quantum correlations and entanglement. Furthermore, synchronization and entanglement can be induced between two different oscillators if properly linked to a random network.

**Martínez-Llinàs, Jade**

**Tuning the period of square-wave oscillations in two delay coupled systems with delay feedback**

*Jade Martínez-Llinàs (1), Pere Colet (1) and Thomas Erneux (2)*

(1) Instituto de Física Interdisciplinar y Sistemas Complejos (CSIC - UIB), Palma de Mallorca, Spain (2) Université Libre de Bruxelles, Belgium

**Abstract:** Time delays are a source of instabilities and complex dynamics. Delays arise in optical and optoelectronic systems with feedback, where the feedback time is usually larger than the intrinsic time scale, and in coupled systems where delay is due to the finite propagation time from one system to another. An example of dynamical regime that can arise through time-delayed feedback is square-wave switching. The generation of tunable pulsating dynamics has been studied during the past few years, motivated by fundamental interest and also towards applications such as optical clocks and other binary logical applications, generation of stable microwave signals or optical sensing. Here we focus on the dynamics of two optoelectronic oscillators, each one with intrinsic delay, which are mutually coupled with delay. Optoelectronic oscillators exhibit a rich variety of dynamical regimes with different potential applications, including chaos generation and production of ultra-pure microwaves.

**Sonnenschein, Bernard**

**Title: Dimensionality reduction for stochastic Kuramoto oscillators**

*B. Sonnenschein and L. Schimansky-Geier*

Department of Physics, Humboldt-Universität zu Berlin, Newtonstrasse 15, 12489 Berlin, Germany; Bernstein Center for Computational Neuroscience Berlin, Philipstrasse 13, 10115 Berlin, Germany

**Abstract:** A highly influential model describing the phenomenon of synchronization is due to Kuramoto. It is concerned with the competition between diversity, which hinders synchronization, and couplings, by which the phase oscillators tend to synchronize. Here we consider all-to-all coupled oscillators, where diversity purely comes from noise acting on the frequencies. In the noise-free case the Ott-Antonsen theory provides an exact dimensionality reduction. No such stochastic counterpart has been found yet. However, one can derive an approximate theory within the framework of the so-called "Gaussian approximation". We obtain thereby a solution for the time-dependent order parameter, which measures the synchronization between the oscillators. We show that the analytical results are very accurate below and sufficiently above the exact critical value. We furthermore discuss the asymptotic behavior of the order parameter, which suggests a new tight upper bound for the corresponding scaling.

## Annex 4b: Full list of speakers and participants

### 1. Lecturers and speakers:

- Horacio Wio, Instituto de Física de Cantabria (CSIC-UC), Spain.
- Christoph Dellago, University of Vienna, Austria.
- Rodolfo Cuerno, Universidad Carlos III de Madrid, Spain.
- Susanna Manrubia, Centro de Astrobiología (INTA-CSIC), Spain.
- Antonio Politi, University of Aberdeen, United Kingdom.
- Roger Guimerà, Universitat Rovira i Virgili, Spain.
- C. van den Broeck, Universiteit Hasselt, (Belgium).
- Emilio Hernández-García, Instituto de Física Interdisciplinar y Sistemas Complejos (CSIC-UIB).
- Juan M. Lopez, Instituto de Física de Cantabria (CSIC-UC), Spain.
- Jose Javier Ramasco, Instituto de Física Interdisciplinar y Sistemas Complejos (CSIC-UIB).
- Diego Pazó, Instituto de Física de Cantabria (CSIC-UC), Spain.

Besides, Miguel A. Rodríguez (Instituto de Física de Cantabria [CSIC-UC], Spain) and Pere Colet (IFISC, CSIC-UIB, Spain), members of the organization, participated in the School.

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