ECC15

15th Experimental Chaos and Complexity Conference

Book of Abstracts

4-7 June 2018 | Universidad Rey Juan Carlos | **Madrid** | Spain

World Scientific
Connecting Great Minds

URJC

Program at a Glance

	SUNDAY JUNE 3	MONDAY JUNE 4	TUESDAY JUNE 5	WEDNESDAY JUNE 6	THURSDAY JUNE 7
8:15		REGISTRATION	REGISTRATION	REGISTRATION	REGISTRATION
8:45		OPENING			
9:00		**Keynote Lecture** Kenneth Showalter	**Fluid Dynamics & Transport** J. W. Bush (I) P.Sáenz M. Bourgoin C. Quilliet A. Ortiz-Ambriz	**Systems Biology** J. García-Ojalvo (I) J. Magnes D. Míguez M. Stich C. Letellier	**Brain &Neuronal Dynamics** M. Sánchez-Vives (I) E. Moses (I) J. Soriano A. Camassa J.J. Torres
9:45		**Chemical Systems** O. Steinbock (I) F. Fenton S. Nkomo			
11:00		COFFEE BREAK	COFFEE BREAK	COFFEE BREAK	COFFEE BREAK
11:30		**Nonlinear Dynamics I** T. Kapitaniak (I) R. Stoop (I) T. Carroll E. del Río C. Evain	**Nonlinear Dynamics II** J. Rodríguez-García F. Petrelis R. Grigoriev J. Tiana E. Macau	**Cardiac & Wave Dynamics** S. Luther (I) C.Herndon A. Schlemmer S. Alonso N. Kourvaris V. Pérez-Muñuzuri	**Science of Cities & Human Mobility** M. Barthelemy (I) A. Díaz-Guilera M.P. Xochicale A.P. Muñuzuri D. Soriano Paños
13:30		LUNCH	LUNCH	LUNCH	LUNCH
15:00		**Data Analysis** N. Zafrir (I) M. Zanin (I) A. Partida M. Soriano D. Molina-García	**Optics & Lasers** I. Fischer (I) P. Suret (I) D. Lippolis M. Faggian A. Dolcemascolo S. Coulibaly		**Geophysics** A. Bracco (I) N. Boers (I) E. Bradley D. Zhilenko
17:00		COFFEE BREAK	POSTERS & WINE		CLOSING
17:30		**Ecology, Evolution & Epidemiology** S. Manrubia (I) U. Feudel (I) J.L. Herrera A. Welsh			
18:00	WELCOME RECEPTION				
18:30				SOCIAL EVENT	
19:00					
19:30					
20:00					
21:30				GALA DINNER	

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ECC15 2018

15th EXPERIMENTAL CHAOS AND COMPLEXITY CONFERENCE

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BOOK OF ABSTRACTS

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Welcome and Acknowledgments

Dear Colleagues,

We welcome you to the **15th Experimental Chaos and Complexity Conference** (ECC). The ECC conference is a biennial event that, since its first edition in 1991 in Crystal City (USA) has been held uninterruptedly in European and American cities gathering together researchers bringing their latest experimental results on diverse fields of nonlinear dynamics and complex systems.

We are now honored of hosting the 2018 edition of the ECC series in the Rey Juan Carlos University (URJC), the youngest university in the Madrid area. The initiative comes from two groups of researchers of the URJC, the Group of Applied Mathematics and the Complex Systems Group, active members of the nonlinear and network science communities, whose research projects are framed in the field of the Information and Communication Technologies (ICT) security and biomedical problems.

We are deeply grateful for the excellent response that our call has received, with the result of a program featuring 18 invited, 41 contributed talks and more than 60 poster presentations. The panel of invited speakers is of the highest level, with the outstanding presence of **Prof. Kenneth Showalter**, C. Eugene Bennet Chair in Chemistry at the West Virginia University (USA), keynote speaker and guest of honor for his long career and scientific contributions in the field of pattern formation in chemistry, who will open the conference with the lecture *Chimera and Chimera-Like States in Populations of Coupled Chemical Oscillators* on Monday June 4. Afterwards, thirteen thematic sessions will provide the international scientific community on experimental nonlinear dynamics and complex systems with a unique discussion forum.

In our endeavor, we have had the great support of the major Spanish research groups in nonlinear dynamics. Therefore we would like to thank the **ECC15 Scientific Advisory Board** for their contributions to the conference planning: **Javier Burguete** (Universidad de Navarra), **Blas Echebarria** (Universitat Politècnica de Catalunya), **Jordi García-Ojalvo** (Universitat Pompeu Fabra), **Emilio Hernández-García** (IFISC CSIC & Universitat de les Illes Balears), **Juan Manuel López** (IFCA-CSIC & Universidad de Cantabria), **Cristina Masoller** (Universitat Politècnica), **Diego Maza** (Universidad de Navarra), **Claudio Mirasso** (IFISC CSIC & Universitat de les Illes Balears), **Yamir Moreno** (Universidad de Zaragoza), **Miguel Angel Muñoz** (Universidad de Granada), **Alberto P. Muñuzuri** (Universidade de Santiago de Compostela), **Jordi Ortín** (Universitat de Barcelona), **Victor Pérez-García** (Universidad de Castilla La Mancha), **Anxo Sánchez** (Universidad Carlos III) and **Jordi Soriano** (Universitat de Barcelona).

We would like also to acknowledge the invaluable support of the Rey Juan Carlos University services and staff who made our work easier: **Maria Antonia Rodriguez Tato** and **Bernardino Tato** (Oficina de Proyectos Europeos); **Esmeralda García**, **Miguel Angel Sevilleja**, and **Susana Clarós** (Servicio de Gestión Económica); **Laura de la Cruz** (Servicio de Publicaciones); **Raquel Valor** (Servicio de Contabilidad y Presupuestos); **Natalia Fernández** (Gestión Economica Campus); **Lorena Fernández Martínez** (Secretaría del Rector); **Pedro Valero** and **Alicia Cermeño** (Servicio de Personal Docente e Investigador); **Juan Manuel Dévora Lorenzo** and **Juan Carlos Hernández** (Tecnologías de la Información); **José Manuel De León Ceano-Vivas** (Gerente Campus Madrid), and **Vicerrectorado de Extensión Universitaria**.

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Finally, we thank all the Attendees because all this organization is pointless without them. We look forward to provide the best interdisciplinary atmosphere to create new collaborations and synergies recognizing and exploiting common research interests.

Sincerely,

Irene Sendiña-Nadal
General Chair
Complex Systems Group, URJC

Regino Criado
Co-chair
Applied Mathematics Group, URJC

Inmaculada Leyva
Logistics Chair
Complex Systems Group, URJC

Javier M. Buldú
Scientific Chair
Complex Systems Group, URJC

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Juan A. Almendral (URJC), Miguel Romance (URJC), Alejandro García del Amo (URJC), Alex Tlaie (URJC), Ignacio Echegoyen (URJC), Antonino Giaquinta (BBVA), Ricardo Gutiérrez (URJC), and Jacobo Aguirre (CNB-CSIC).

EXTENDED PROGRAM

Registration 8.15–8.45 Library Hall

Opening 8.45–9.00 Auditorium

Keynote Speaker *Chair: Stefano Boccaletti* 9.00–9.45

Chimera and Chimera-Like States in Populations of Coupled Chemical Oscillators Auditorium
Kenneth Showalter

Session 1: Chemical Systems 9.45–11.00
Chair: Stefano Boccaletti Auditorium

1. **Will Chemical Self-Organization Revolutionize Micro-Engineering?** *Oliver Steinbock*
2. **Chimera states in 1D and 2D with mutliple co-existing solutions** *Flavio Fenton*
3. **Multistability in Globally Delay-Coupled Chemical Oscillators** *Simbarashe Nkomo*

COFFEE BREAK 11.00–11.30 Outdoors

Session 2: Nonlinear Dynamics I 11.30–13.30
Chair: Lou Pecora Auditorium

1. **Transitions between different ringing schemes of the church bell** *Tomasz Kapitaniak*
2. **Human sound sensations and emotions are not brain-generated, but the consequences of fundamental nonlinear cochlear physics** *Ruedi Stoop*
3. **Dimension from Covariance Matrices** *Thomas Carroll*
4. **Experimental confirmation of the new theory of noisy intermittency** *Ezequiel del Río*
5. **Control of a spatiotemporal instability affecting the relativistic electrons in synchrotron radiation facilities** *Clément Evain*

LUNCH BREAK 13.30–15.00 Canteen

Session 3: Data analysis 15.00–17.00
Chair: Ricardo Gutiérrez Auditorium

1. **Rethinking Cyber and the Role of AI** *Nadav Zafrir*
2. **Statistical physics in the realm of small data** *Massimiliano Zanin*
3. **A simulation of a Bitcoin blockchain based on a pseudo-randomly selected block** *Alberto Partida*
4. **Information processing by complex systems: the case of a single nonlinear node with delay** *Miguel C. Soriano*
5. **Measuring tumor complexity on magnetic resonance images: A robustness analysis points out the need for standardization** *David Molina-García*

COFFEE BREAK 17.00–17.30 Outdoors

17.30–19.30 **Session 4: Ecology, Evolution, and Epidemiology**
Auditorium *Chair: Jacobo Aguirre*

1. **On the architecture of genotype spaces and the dynamics of molecular adaptation** *Susanna Manrubia*
2. **Harmful algal blooms in spatially heterogeneous environments: biodiversity and transport** *Ulrike Feudel*
3. **Analyzing disease outbreaks by means of symbolic networks** *Jose Luis Herrera*
4. **Spatial Pattern Formation in Aggregations of Artemia Franciscana** *Andrea Welsh*

Registration 8.30–9.00 Library Hall

Session 5: Fluid Dynamics and Transport 9.00–11.00
Chair: Diego Maza Auditorium

1. **Pilot-wave hydrodynamics: from chaotic dynamics to quantum-like statistics** *John Bush*
2. **Spin lattices of macroscopic wave-driven particles** *Pedro J. Sáenz*
3. **Kolmogorovian Active Turbulence** *Mickael Bourgoin*
4. **Swimming through buckling** *Catherine Quilliet*
5. **Microrheology of compact colloidal clusters driven by optical tweezers.** *Antonio Ortiz-Ambriz*

COFFEE BREAK 11.00–11.30 Outdoors

Session 6: Nonlinear Dynamics II 11.30–13.30
Chair: Ulrike Feudel Auditorium

1. **Nonlinear dynamics in an experimental rotating split-cylinder flow** *Jesús Óscar Rodríguez-García*
2. **Fluctuations and transitions in turbulent flows** *François Pétrélis*
3. **Dynamics, geometry, and topology of fluid turbulence** *Roman Grigoriev*
4. **Experimental study of the optimal waveforms for entraining optical spikes** *Jordi Tiana-Alsina*
5. **Synchronization of phase oscillators with coupling mediated by a diffusing substance** *Elbert Macau*

LUNCH BREAK 13.30–15.00 Canteen

Session 7: Optics and Lasers 15.00–17.00
Chair: Jordi García-Ojalvo Auditorium

1. **Spatio-temporal chaos in semiconductor lasers with delayed feedback** *Ingo Fischer*
2. **Integrable Turbulence in the focusing regime: from optical fiber experiments to theoretical open questions** *Pierre Suret*
3. **Toward a test of the fractal Weyl law in an optical microcavity** *Domenico Lippolis*
4. **Evidence of a critical phase transition in a purely temporal dynamics with long-delayed feedback** *Marco Faggian*
5. **Experimental analysis and mean-field reduction of a large population of coupled semiconductor lasers** *Axel Dolcemascolo*
6. **Chimera states in coupled-waveguide Kerr resonators** *Saliya Coulibaly*

Poster and Wine Session 17.00–19.00 Lecture Building

8.30–9.00 **Registration**
Library Hall

9.00–11.00 **Session 8: Systems Biology**
Auditorium *Chair: Susanna Manrubia*

1. **Bacterial electrophysiology: Dynamics and functional implications** *Jordi García-Ojalvo*
2. **Nonlinear Time Series of Live Diffraction Signals in C. elegans** *Jenny Magnes*
3. **The influence of network topologies in drug treatment** *David Míguez*
4. **Modelling of supramolecular redox-mediated oscillations** *Michael Stich*
5. **Optimizing intermittent hormonotherapy after a prostatectomy by using individualized model** *Christophe Letellier*

11.00–11.30 **COFFEE BREAK**
Outdoors

11.30–13.30 **Session 9: Cardiac and Wave Dynamics**
Auditorium *Chair: Flavio Fenton*

1. **Electromechanical Vortex Filaments During Cardiac Fibrillation** *Stefan Luther*
2. **Not all heartbreak is the same** *Conner Herndon*
3. **Quantification of spatiotemporal complexity during ventricular fibrillation** *Alexander Schlemmer*
4. **Modeling reentry formation due to diffuse fibrosis in cardiac tissue: Effects of topological quantities** *Sergio Alonso*
5. **Traveling fronts and stationary patterns in complex bistable networks: Theory and applications to chemical reactions** *Nikos E. Kouvaris*
6. **Hemodynamics guided microparticles for drug delivery in atherosclerosis lesions** *Vicente Pérez-Muñuzuri*

13.30–15.00 **LUNCH BREAK**
Canteen

18.30–24.00 **SOCIAL EVENT**

Registration 8.30–9.00 Library Hall

Session 11: Brain and Neuronal Dynamics 9.00–11.00
Chair: Jenny Magnes Auditorium

1. **From cerebral cortex complexity to consciousness** *María Sánchez-Vives*
2. **Dynamics of a Brain: Oscillations and Synchronization in a Cultured Neuronal Network** *Elisha Moses*
3. **Connectivity and Dynamics in Neuronal Cultures: Experiments, Simulations, and Medical Applications** *Jordi Soriano*
4. **What does the complexity of the cerebral cortex network tell us about brain states?** *Alessandra Camassa*
5. **Complexity in Brain Structure and Functions** *Joaquín Marro*

COFFEE BREAK 11.00–11.30 Outdoors

Session 12: Science of Cities and Human Mobility 11.30–13.30
Chair: Massimiliano Zanin Auditorium

1. **Scaling in cities** *Marc Barthelemy*
2. **Synchronization in populations of moving oscillators** *Albert Diaz-Guilera*
3. **Quantifying the Inherent Chaos of Human Movement Variability** *Miguel P Xochicale*
4. **Modeling language competition: social networks and Turing structures** *Alberto P. Muñuzuri*
5. **Epidemic detriment driven by recurrent human mobility patterns** *David Soriano Paños*

LUNCH BREAK 13.30–15.00 Canteen

Session 13: Geophysics 15.00–17.00
Chair: Javier M. Buldú Auditorium

1. **Tropical teleconnections and model biases in the Community Earth System Model using network tools** *Annalisa Bracco*
2. **Complex networks and climate dynamics: from regional to global teleconnections** *Niklas Boers*
3. **Information dynamics of the paleoclimate** *Elizabeth Bradley*
4. **Influence of non-uniform rotation on turbulent spectra** *Dmitry Zhilenko*

Closing 17.00–17.15 Auditorium

POSTER LIST

- **P1** **Understanding the Some Aspects of Alternate Bearing Phenomenon** *Awadhesh Prasad*
- **P2** **A Tape Recorder is a Chaotic Dynamical System** *Ned Corron*
- **P3** **Simulation of atmospheric turbulence spectra in the flows in rotating spherical layer** *Olga Krivonosova*
- **P4** **Scaling Laws in the Energy Distribution for a Nonlinear Coupled System** *Meirielen Caetano de Sousa*
- **P5** **Exploring the route to measure synchronization in non-linearly coupled Hamiltonian systems** *Shraddha Gupta*
- **P6** **Continuous Wavelet Transform analysis of Partial and Complete Measure Synchronization in a system of three non-linearly coupled oscillators** *Shraddha Gupta*
- **P7** **Hybrid cellular Potts model for tumor-induced angiogenesis** *Rocío Vega-Martínez*
- **P8** **Solar-wind dynamics from Voyager 2 and New Horizons** *Elizabeth Bradley*
- **P9** **Chaotic behavior and coherence resonance in semiconductor superlattices at room temperature** *Emanuel Mompo*
- **P10** **The role of chaotic transients in Cardiac Dynamics** *Thomas Lilienkamp*
- **P11** **Waves and patterns in giant amoeboid cells: modelling and experiments** *Francesc Font*
- **P12** **Quantify the complexity of the spacing between surfaces: Applications to brain tumors.** *Julian Pérez-Beteta*
- **P13** **Dynamics and synchronization of delay-coupled networks with a fluctuating connectivity** *Otti D'Huys*
- **P14** **Bifurcation induced by the aspect ratio in a turbulent von Karman swirling flow** *Javier Burguete*
- **P15** **Cross predicting spatio-temporal chaos in excitable media using Echo State Networks** *Ulrich Parlitz*
- **P16** **Estimating model parameters from measured time series using attractor comparison** *Ulrich Parlitz*
- **P17** **Nonlinear graph-based assessment of network observability** *Christophe Letellier*
- **P18** **From Order to Disorder in Ensembles: Back and Forth. Localization and Pattern Formation in Hierarchies** *Michael G. Zeitlin*
- **P19** **Complex Quantum World on the Tower of Scales** *Antonina N. Fedorova*
- **P20** **Pyroelectric Detection near a Period Doubling Bifurcation** *Martin Diestelhorst*
- **P21** **Topological analysis of experimental recordings of ventricular fibrillation** *Daniel Gurevich*
- **P22** **Implementation of Chaos-Based Coded Modulations with Software Defined Radio** *Francisco J. Escribano-Aparicio*
- **P23** **Periodic and Quasiperiodic Dynamics of Optoelectronic Oscillators** *Lucas Illing*
- **P24** **Synchronization and Its Suppression in a Network of Networks of Bursting Oscillators** *Fabiano A.S. Ferrari*
- **P25** **Response to damage and recovering capability in perturbed cultured neuronal networks.** *Estefanía Estévez Priego*
- **P26** **Bioremediation techniques for carbamazepine elimination.** *Manuel Arrayás*
- **P27** **The Perron-Frobenius operator to calculate the reinjection probability density function in chaotic intermittency** *Sergio Elaskar*
- **P28** **Fast propagation regions causespiral wave in an excitable medium** *Vladimir Zykov*
- **P29** **Nonlinear Normal Modes in the Double and Triple Pendulum** *Cavendish McKay*

P30 Direct observation of the onset of a spatio-temporal instability in storage ring synchrotron radiation sources *Clément Evain*
P31 The acoustically forced, charged bubble in a liquid *Balakrishnan Ashok*
P32 Structural vs dynamical complexity in cultured neural networks *Alexander Tlaie*
P33 Measuring coordination with ordinal patterns *Ignacio Echegoyen*
P34 Connector Links Support Functional Centrality Distribution in Brain Hemispheres *Johann Martínez*
P35 A pre-crisis vs crisis analysis of peripheral EU stock markets by means of wavelet transform and a nonlinear causality test *Josué M. Polanco-Martínez*
P36 Spatial correlations in nonequilibrium reaction-diffusion problems by the Gillespie algorithm *José María Ortiz de Zárate*
P37 Classification of motor imagery in MEG recordings *Parth Chholak*
P38 Multiple scales in complex friction-induced disk brake vibrations *Merten Stender*
P39 Single-Point Multilayer Cluster *Santiago Moral Rubio*
P40 Extracting differential equations from measured vibro-acoustic impulse responses in cavity preparation of total hip arthroplasty *Sebastian Oberst*
P41 Coupling induced logical stochastic resonance *Manaoj Aravind*
P42 Forbidden and missing ordinal patterns in noisy chaotic time series *Felipe Olivares*
P43 Wave blocking and horizons in one-dimensional flows: theoretical and experimental aspects *Alberto Saa*
P44 Characterizing transitions between locking regimes in an optical system under weak periodic forcing *Jordi Tiana-Alsina*
P45 The impact of a memristive device onto Chua's Circuit *Tom Birkoben*
P46 Modeling Chemotatic Response and Interactions of Amoeboid Cells with a Phase Field Model. *Eduardo Moreno*
P47 Granular Convection of Horizontally Shaked Granular Layers *Diego Maza*
P48 Using order pattern recurrence plots to distinguish between chaos and noise *Shuixiu Lu*
P49 Spatial patterns in the emergence of violent conflicts *Gerardo Aquino*
P50 Controlling genetic and dynamic instabilities in synthetic microbial populations *Philip Bittihn*
P51 Relationship between vulnerabilities in heterogeneous information systems *Juan López-Ruiz*
P52 A nonequilibrium-potential approach to competition in neural populations *Nataniel Martinez*
P53 Manifold learning of ordinal pattern distributions for identification of individuality of human brain dynamics using EEG signals at rest *Hiromichi Suetani*
P54 Inertial wave attractors in rotating and stratified systems *Ilias Sibgatullin*
P55 Evolution and controlling of the Plykin - newhouse attractor by the Pyragas method *Sergey Belyakin*
P56 Magnitude and phase of the perturbation effects on the Hamiltonian dynamical system *Meziani Bachir*
P57 New tool for characterizing time series from non-modelled experimental systems based on histograms *Gerard Vidal*
P58 Photon Bubble Turbulence in Cold Atomic Gases *Joao Rodrigues*
P59 Universality in the Resonant Facilitation of the Inter-Separatrix Transport Onset *Riccardo Mannella*

ABSTRACTS

Keynote Speaker

Chimera and Chimera-Like States in Populations of Coupled Chemical Oscillators

Kenneth Showalter

West Virginia University, Morgantown, USA; kshowalt@wvu.edu

We have studied chimera and chimera-like states in populations of photochemically coupled Belousov-Zhabotinsky (BZ) oscillators. Simple chimeras and chimera states with multiple and traveling phase clusters, phase-slip behavior, and chimera-like states with phase waves are described. Simulations with a realistic model of the discrete BZ system of populations of homogeneous and heterogeneous oscillators are compared with each other and with experimental behavior. Spiral wave chimeras as well as chimera core instabilities are studied in large arrays of photochemically coupled oscillators [1, 2, 3, 4].

[1] M.R. Tinsley et al., *Nature Physics* 8, 662 (2012)
[2] S. Nkomo et al., *PRL* 110, 244102 (2013)
[3] S. Nkomo et al., *Chaos* 26, 094826 (2016)
[4] J.F. Totz et al., *Nature Physics* 14, 282 (2018)

Session 1: Chemical Systems

Will Chemical Self-Organization Revolutionize Micro-Engineering?

Oliver Steinbock

Department of Chemistry and Biochemistry, Florida State University, Tallahassee, USA;
steinbck@chem.fsu.edu

The rational design of systems that create complex materials and functional devices by externally controlled self-organization holds great promise for modern materials science. Progress toward this goal requires an understanding of how materials synthesis is affected by transport processes, steep concentration gradients, and other factors that arise from reaction conditions far from the equilibrium. This talk will focus on two experimental examples: smoothly curved, polycrystalline micro-structures called biomorphs and hollow tube structures known as chemical gardens. Both systems show hierarchical architecture that extends from the nanoscale into the macroscopic world and grow via the steady propagation of reaction fronts that form solid product. I will give a brief introduction covering the underlying qualitative mechanisms of these surprising structures and then discuss recent efforts to understand details of the growth processes that share many features with reaction-diffusion fronts in excitable systems. Time permitting, I will also highlight the relevance of these systems for the identification of microfossils and the origin of life.

Chimera states in 1D and 2D with mutliple co-existing solutions

Flavio Fenton[1] *and Andrea Welsh*[2]

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Most chimera states to date require global coupling to produce co-stable solutions. We present here a system that can lead to up to four different co-existing solutions in a system composed of identical oscillators only coupled by diffusion. The single oscillatory system is based on the saline oscillator. In this talk, we first demonstrate the bi-stability of this system experimental as a function of initial conditions and perturbations with a given strength and phase. Then create a mathematical model for this system that when coupled in 1 and 2D by just diffusion allows the existence of up to four different solutions co-existing in space at the same time.

Multistability in Globally Delay-Coupled Chemical Oscillators

Simbarashe Nkomo[1], *Mark Tinsley*[2] *and Kenneth Showalter*[3]

[1]Oxford College of Emory University, Oxford, USA; simbarashe.nkomo@emory.edu
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[3]West Virginia University, Morgantown, USA; kenneth.showalter@mail.wvu.edu

The coexistence of many dynamic states for the same system parameters has been theoretically studied in varying networks of coupled oscillators [1, 2]. Examples of experimental demonstrations of multistability include a two-coupled system of Rossler oscillators[3] and coupled chaotic opto-electronic oscillators [4]. Using a globally delay-coupled population of photosensitive Belousov-Zhabotinsky chemical oscillators, we demonstrate switching behavior between dynamic states for specific coupling strength and delay parameter values. The ZBKE model is used for the numerical investigation of the interplay between coupling strength and delay on the dynamic behavior of systems of coupled homogeneous and heterogeneous chemical oscillators. We discuss the existence of specific values of delay for which the incoherent state is significantly dominant and the connections to the likelihood of finding chimera states [2].

[1] R. Debalays, T. Coletta, and P. Jacquod, *Journal of Mathematical Physics* 58 032703 (2017)
[2] S. Nkomo, M. Tinsley, and K. Showalter, *Chaos* 26 094826 (2016)
[3] M.S. Patel et al., *PRE* 89 022918 (2014)
[4] J. Hart, K. Bansal, T. Murphy, and R. Roy, *Chaos* 26 094801 (2016)

Session 2: Nonlinear Dynamics I

Transitions between different ringing schemes of the church bell

Tomasz Kapitaniak

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We present a hybrid model of church bell. The dynamical system of yoke-bell-clapper is nonlinear and discontinuous. We use the Lagrange equations of the second type to derive formulas that describe the system's motion. The energy between the bell and the clapper is transmitted via impacts, here modeled using a coefficient of energy restitution. The values of the system's parameters have been determined basing on the measurements of the biggest bell "The Heart of Lodz" in the Cathedral Basilica of St Stanislaus Kostka, Lodz, Poland. Using the same bell we also validate the model by comparing the results of numerical simulations with experimental data. The presented results show that the described model is a reliable predictive tool which can be used both to simulate the behavior of the existing yoke-bell-clapper systems as well as to design the yokes and predict the motion of new bells.

Human sound sensations and emotions are not brain-generated, but the consequences of fundamental nonlinear cochlear physics

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For thousands of years, humans have wondered how the mammalian hearing system maps the world around us, and why hearing confronts us with a number of strange and puzzling phenomena. In the very recent past, the nature of most of these phenomena has now been revealed, exposing, in parallel, an immense success story of applied nonlinear dynamical systems. In this talk, we will outline how a nonlinear dynamical systems understanding of the nature of the mammalian hearing sensor, the cochlea, provides deep insight into the processes that before were largely believed to be the manifestations of cortical computation. We will see that a whole stunning network of nonlinear sensory nodes is at the origin of mammalian hearing [1] that has network properties that can be actively shaped in real-time by "listening". Using present day technical terms, the hearing network has the properties of a critical system in its relaxed state, whereas in the tuned state [2], this property is abandoned [3]. This, first of all, changes the view of hearing perception as a process occurring primarily at the level of the cortex, to one where the salient phenomena of hearing are established at the level of the sensor itself. Second, as the hearing system can be taken as a blueprint of sensory systems, it offers a novel approach for a modern understanding of sensors based on networks of nonlinear dynamical elements. In the case of hearing, this leads to an entirely different understanding of the origin of the mammalian hearing threshold [4]. Finally, we will expose some of our presently unpublished results regarding the preferability of standard Hopf systems in hearing , and we will discuss some results indicating that the human emotion of sound "pleasantness" can to a large extent, also be explained by the nonlinear processes taking place in the hearing sensor, the cochlea. Since the hearing system can be seen as a very ancient type of nervous system, we expect our insight to also provide more general guidelines for a coherent view, at a fundamental level, of the nature of biological information processing. In particular, we expect our results to offer a new perspective into the properties, the roles, and the nature of the different computations occurring within the brain.

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Dimension from Covariance Matrices

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I describe a method to estimate embedding dimension from a time series. This method includes an estimate of the probability that the dimension estimate is valid. Such validity estimates are not common in algorithms for calculating the properties of dynamical systems. The algorithm described here compares the eigenvalues of covariance matrices created from an embedded signal to the eigenvalues for a covariance matrix of a Gaussian random process with the same dimension and number of points. A statistical test gives the probability that the eigenvalues for the embedded signal did not come from the Gaussian random process.

Experimental confirmation of the new theory of noisy intermittency

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Intermittency is a specific route to the deterministic chaos when spontaneous transitions between laminar and chaotic dynamics occur. It was introduced by Pomeau and Maneville [1, 2, 3]. Later it has been found that transition to chaos through intermittency occurs in many phenomena. The main attribute of intermittency is the reinjection mechanism that maps trajectories of the system from the chaotic region into the local laminar phase. This mechanism can be described by the corresponding reinjection probability density. As analytical expressions for the RPD are available for a few problems only, the most common approximation used to obtain many classical results on intermittency theory have been considered the RPD uniform [2, 4]. Recently a generalization of the classical intermittency theory has been presented, where new methods to investigate the RPD in systems showing Type-I, II, or III intermittency are offered. The classical theory is included in this new framework as a particular case [5]. Tthe new theory has not been checked on continuous experimental systems. We present an experimental system based on an analog electronic circuit. The experimental results are in good agreement with the new theory. Noise has strong impact on the intermittency phenomena. The generalized RPD introduces a novel scenario. Whereas the uniform reinjection should remain constant under a wide class of noise, the new one is affected by the noise. Recently an analytical approach to the noisy reinjection probability density has been presented [6]. We are also focusing on the role of the noise in our experiment and we have found good agreement with the new noisy intermittency approachment. The (signal)/(internal noise) relation can be turned in the circuit. This fact is used to investigate the noise effect by using the natural noise in the circuit, without any external noise generator. It is also important to note that a complete description of the ideal noiseless system and the real noisy experiment can be obtained from experimental noisy data.

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Control of a spatiotemporal instability affecting the relativistic electrons in synchrotron radiation facilities

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Synchrotron radiation facilities are sources using the light emitted by relativistic electron bunches and dedicated to various users of Thz, VUV and X-ray radiation. The power delivered generally depends of the electron-bunch charge, and synchrotron radiation facilities tend to use electron bunches with the highest possible charge density. However, at high charge density, a spatio-temporal instability affects the electron-bunches in most facilities [1] (e.g. ALS in Berkeley, BESSY in Berlin, DIAMOND in UK, SOLEIL in France [2], etc.). This instability has a fondamental origin: it comes from the interaction of the electron bunch with its own radiated electric field. As a consequence, microstructures appear in the longitudinal direction of the bunch with a complex temporal evolution. Here, we present the first results on the control of those instabilities using a feedback method. The strategy is directly inspired from chaos control method (In particular from the OGY and Pyragas methods). The idea is to stabilized a pre-existing unstable periodic solution. A feedback system continuously applies small perturbations on one of accelerator parameters in function of the deviation between the unstable solution and the system state. After numerical studies on the system model , we succeeded to experimentally control this instability at synchrotron SOLEIL (France). To this purpose, we used a rather simple elecronic feedback system (base on a FPGA board). We will present the results as well as the open questions (from the dynamical point of view) raised by this study.

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Session 3: Data analysis

Rethinking Cyber and the Role of AI

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As reliance on computing, connectivity, interactions, networks, servers, automation and “smart” devices grew, companies lost order. To regain order, they centralized their network access, servers and databases. Unfortunately, what helped IT also helped attackers and as a result companies are inundated with the overwhelming number of alerts indicating anomalous activity in their networks. How can AI solve the alert fatigue problem?"

Statistical physics in the realm of small data

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Complex network theory and data mining share more characteristics than what may prima facie appear. Not only do both share the same general goal, that of extracting information from data to ultimately create compact and quantifiable representations; but they also often address similar problems too. At the same time, being based on different concepts and hypotheses, they provide complementary points of view, which may result in fresh perspectives to well-known problems. This talk will review an example of the synergies that can emerge from the convergence of both fields. Specifically, we will see how the data describing a biomedical prognosis problem can be synthesised into a network representation; and how the topology of the resulting network can help a subsequent data mining task. We will further see how this approach is especially efficient for small data sets, an important niche of many biomedical problems that is yet usually eclipsed by the celebrated big data concept.

A simulation of a Bitcoin blockchain based on a pseudo-randomly selected block

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The aim of this paper is to present an analysis of a blockchain implementation such as Bitcoin from a viewpoint based on a complex network model with the aim to identify an initial toy model to which Information Security measures could be applied. As it is known, blockchain finds its roots in cryptography and distributed systems. Those blockchain implementations using decentralised consensus have a simple motto i.e. "the longest chain wins". This technology can then be used, among many other user cases, to create a ledger book, i.e. A chain of blocks with records representing financial transactions. The most popular blockchain implementation is Bitcoin which appeared in 2008 [1]. Without mentioning the word blockchain at all, in [1] an ongoing chain of hash-based "proof of work" is described. In fact, this is the heart of Bitcoin, "a purely peer to peer version of electronic cash" [1]. It combines three powerful artifacts: the blockchain technology, a distributed peer-to-peer network and a fully decentralised consensus-based approach. The entire public Bitcoin blockchain, its distributed ledger, reached in January 2018 a volume over 100 GB. This database contains Bitcoin addresses, dates, transactions and bitcoin figures. In order to model this database as a complex network, our proposal is to start small and focus our attention first on a pseudo-randomly selected block. The only requirement to select a transaction block has been that one of the "richest" Bitcoin addresses, according to [2], participates in that block. The selected block records 2522 transactions. Initially we consider every different Bitcoin address present in the block as a node. The links between the nodes will be the transactions publicly available in [3]. Some measurements and properties of this network are analyzed: clustering coefficient, modularity, possible existence of motifs and communities. The attractiveness of this proposal is that algorithms and steps used to study this block escale and can be used to study each completed bitcoin block in the Bitcoin blockchain. It is remarkable that in [4] it is also suggested that there is no preferential attachment in the Bitcoin transaction network. The proposed initial link with Information Security is founded on anonymity, although in [1] it is concluded that anonymity in Bitcoin is not a pivotal design goal of the Bitcoin system.

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Information processing by complex systems: the case of a single nonlinear node with delay

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The brain is a paradigmatic example of a complex system with efficient computational properties. With only 20W of approximate power consumption, the brain can stand a fight even against powerful supercomputers with a power consumption of about 10MW for certain cognitive tasks. This feat is achieved by the combination of a distributed network of interconnected units and adapted information coding. Several novel computational paradigms are inspired by the brain's information processing capabilities. Among those, Reservoir Computing stands out as a simple yet powerful approach to process sequential information. The design rules behind reservoir computing can be sketched as follows: a recurrent network (a.k.a reservoir) of nonlinear nodes is created with fixed connection weights, (ii) the input information is also injected into the reservoir with fixed connection weights, (iii) the output response of the reservoir is linearly combined via previously trained connection weights in order to meet the requirements of a targeted information processing task. Importantly, the lack of the requirements to define a specific network, or to train the reservoir facilitate the experimental implementation of this paradigm in analog hardware. A further conceptual and hardware simplification is even possible by using a single nonlinear unit subject to a delayed feedback loop as the reservoir. In this manner, "virtual" nodes that are defined as temporal locations along the feedback loop can emulate the properties of a reservoir with spatially distributed units. This minimalistic approach to information processing has already been demonstrated in electronic and optoelectronic implementations with state-of-the-art performances. In this talk, we illustrate how the experimental implementation of a single nonlinear node with delay fulfills the requirements to process sequential information, including memory and computational power. As a novel example of the advanced capabilities of this minimal approach, we demonstrate the possibility to generate several types of chaotic time-traces in an autonomous manner, i.e., without direct intervention on the system after it has been trained.

Measuring tumor complexity on magnetic resonance images: A robustness analysis points out the need for standardization

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Tumors appear due to the abnormal growth of groups of cells which may differ in their morphology, genetics and biological behavior. This biological complexity is referred to as "tumor heterogeneity". Heterogeneous tumors present high resistance under treatments as chemotherapy or radiotherapy [1]. Currently, it is not possible to assess microscopic heterogeneity present in tumors. However, imaging allows for the macroscopic monitoring of the tumor's complexity. The study of tumor heterogeneity from medical images is an active field and many quantitative features have been proposed [2], being the textural heterogeneity markers the most used [3]. These markers have a great potential as imaging biomarkers, having shown correlation with survival, tumor grade, tumor type, etc. However, these measures must be reproducible under image size changes for their clinical use. In this work, we studied the robustness of 16 3D textural heterogeneity markers of the most common types , providing regional (run-length based measures) and local information (co-occurrence matrices) on tumor complexity. We used high-resolution pretreatment magnetic resonance T1 sequences of 20 patients with glioblastoma, the most frequent malignant primary brain tumor and the most lethal type [4] and studied the feature robustness under different dynamic ranges and spatial resolutions using the coefficient of variation (CV). None of the textural features considered were robust under dynamic range changes. The textural co-occurrence matrix feature entropy was the only textural feature robust (CV The implications of this work go beyond the specific tumor type and MRI sequence studied here and pose the need for standardization in complexity quantification of general images. Our results point out the need for novel complexity measures for complex 3D structures obtained from medical images such as tumors [5].
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Session 4: Ecology, Evolution, and Epidemiology

On the architecture of genotype spaces and the dynamics of molecular adaptation

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Evolutionary dynamics is often viewed as a subtle process of change accumulation that causes a divergence among organisms and their genomes. However, this interpretation is an inheritance of a gradualistic view that has been challenged at the macro-evolutionary, ecological, and molecular level. Actually, the evolutionary dynamics of molecular populations shares deep qualitative and quantitative similarities with slowly driven physical systems, remarkably non-linear responses analogous to critical transitions, sudden state changes and hysteresis. Furthermore, the functional promiscuity inherent to genotypes transform classical fitness landscapes into multiscapes where adaptation may be instantaneous in response to an environmental change. The quantitative nature of adaptive molecular processes is deeply dependent on a multilayered network-of-networks structure of genotype spaces that we begin to unveil.

Harmful algal blooms in spatially heterogeneous environments: biodiversity and transport

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Harmful algal blooms are rare events which are characterized by a sudden large abundance of potentially toxic plankton species which can alter the dynamics of the whole ecosystem. Since as a consequence of climate change, the frequency of HABs is increasing, there is a strong need in understanding the possible causes for such bloom events. Based on experiments and model studies we discuss the emergence and transport of toxic blooms. We analyze the transport of toxic species in an experimental setup consisting of 5 microcosms connected with tubes. Those micro-ecosystems are exposed to a gradient of nutrient conditions to mimic a heterogeneous environment. We study under which conditions toxic species can develop blooms in competition to nontoxic species possessing a larger growth rate. Based on those experiments we use a network model to investigate the spread of toxic species in such patchy environments. In the real ocean those connections between different patches of environmental conditions are realized by hydrodynamic flows. Analyzing data from observations in the Southern California Bight we demonstrate, that particularly mesoscale hydrodynamic vortices are of crucial importance for the spread of HABs and provide hydrodynamic niches for HAB development. However, data analysis reveals that the impact of upwelling events as sources of heterogeneous nutrient conditions for the growth of plankton is not conclusive. We illustrate that mesoscale hydrodynamic structures responsible for the inhomogeneous distributions of nutrients are either boosting or suppressing plankton blooms.

Analyzing disease outbreaks by means of symbolic networks

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The understanding of disease outbreaks, as well the prevalence and lifetime of contagious diseases have become a challenge in biomedical sciences. The unavoidable difficulties in poorest populations to access valuable medical triages together with the lack of policies to inspect the reported cases in controlled populations, drive to a shortage of the quality of the recorded datasets. Although different interdisciplinary perspectives have been proposed to understand the dynamics of different diseases, recent advances in the understanding of complex systems dynamics suggest alternative viewpoints that may enhance our understanding of the problem. Under this framework, we propose an aggregated-data-based model that shows how the persistence of events in disease outbreaks follows specific progressions that can be identified and characterized thanks to the analysis of the temporal patterns encoded in the number of infected individuals. Our methodology considers aggregated data as the seminal information to extract either the level of complexity and entropy of the evolution of a disease, as well as the distribution of hidden temporal patterns. Beyond focusing on a single disease and, with the aim of gaining general intuition about the results of the proposed methodology, we consider different diseases and track their similarities and divergences. Additionally, we build up directed weighted networks associated to the disease dynamics, in which the nodes (edges) represent specific temporal events (progressions between consecutive events). This way, we can study the role of each node (pattern) in the diseases considered, as well as the structure of the complex network related to the disease temporal patterns and find, for instance, the existence of common persistent events (hubs). In this scenario, we identify similarities in the structure of networks associated to different outbreaks and make a dynamical and topological characterization of such networks. These results lead to the primary conclusion that, in general, disease outbreaks maintain specific ordinal patterns, which is translated to specific values of statistical complexity and permutation entropy, when the whole symbolic network is analyzed. Furthermore, there are particular nodes that have an important role in the system which depend on the particular disease considered. Lastly, we consider the possible relations between dynamical-topological-prevalence variables.

Spatial Pattern Formation in Aggregations of Artemia Franciscana

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Swarming is a ubiquitous self-organization phenomenon which occurs in many biological systems such as groups of the flocking of birds and insects, the schooling of fish, and the collection of bacteria. This sort of behavior is an emergent phenomenon as most of this behavior arising without any sort of centralized control or leadership. Swarming depends primarily on local interactions between individuals in the swarm. We will discuss the three-dimensional patterns that can be observed by the swarming of brine shrimp, specifically the Great Salt Lake strain of Artemia franciscana, at high concentration. These patterns can be easily observed with simple tabletop experiments; however, the causes of these patterns are unknown. We experimentally test the effects on certain physical parameters such as concentration, temperature, salinity, luminosity and the relationship of extended-area to depth on the phase separation that produces these patterns. We then develop a model for the shrimps' behavior which will also yield the same sort of patterns. We hope to model the basic length and times scales of the patterns, the patterns selected, the stability of those patterns, and the transitions that occur between patterns.

Session 5: Fluid Dynamics and Transport

Pilot-wave hydrodynamics: from chaotic dynamics to quantum-like statistics

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A decade ago, Yves Couder in Paris discovered that droplets walking on a vibrating fluid bath exhibit several features previously thought to be exclusive to the microscopic, quantum realm. These walking droplets propel themselves by virtue of a resonant interaction with their own wavefield, and so represent the first macroscopic realization of a pilot-wave system of the form proposed for microscopic quantum dynamics by Louis de Broglie in the 1920s. New experimental and theoretical results allow us to rationalize the emergence of quantum-like behavior in this hydrodynamic pilot-wave system in a number of settings, and explore its potential and limitations as a quantum analog.

Spin lattices of macroscopic wave-driven particles

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We present experiments that demonstrate the spontaneous emergence of collective behavior in spin lattices of droplets walking on a vibrating fluid surface. Circular wells at the bottom of the fluid bath encourage individual droplets to walk in clockwise or counter clockwise direction along circular trajectories centered at the lattice sites. A thin fluid layer between the wells enables wave-mediated interactions between neighboring walkers resulting in coherent rotation dynamics across the lattice. When the pair-coupling is sufficiently strong, interactions between neighboring droplets may induce local spin flips leading to ferromagnetic or anti-ferromagnetic order. Our results for different 1D and 2D lattice symmetries illustrate the effects of topological frustration.

Kolmogorovian Active Turbulence

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Active living organisms, such as bacterial suspension, birds, fishes, etc., tend to self-organize and to develop coherent collective motion, with important consequences in terms for instance of nutrient finding strategies or protection against predators. Such systems are intrinsically out of equilibrium as energy is constantly injected at the scale of the particles, and tend to exhibit fluctuations which are hard to model. The emergence of large scale motions with energy injected at small scale underlies the existence of multi-scale coupling mechanisms and correlations driven by inter-entities interactions. Such a scenario, with multi-scale interactions, resonates with the classical picture of the turbulent energy cascade in which energy is injected at large scale and dissipated at small scale, resulting in a kinetic energy spectrum following a power law with exponent $-5/3$. Here we examine possible connections between an experimental active system and fluid turbulence by investigating the dynamics of abiotic active matter (avoiding biological specificities), made of self-propelled camphor swimmers, in the light of classical statistical indicators (both from the Eulerian and Lagrangian points of view). The system is composed of an ensemble of agar gel disks (with radius 2.5 mm and height 0.6 mm) loaded with camphor, which are floating on a water surface while confined in a petry dish of radius 75 mm. When individually deposited at an air-water interface, the disks self-propel (with typical swim velocity 10 mm/s) by Marangoni effect arising from the camphor spreading at the interface, and have a collective dynamics which depends on the number of swimmers. Here we track the particles for a very long time using a camera operating at 30 Hz, so that their dynamics is fully resolved and their velocity and acceleration is computed by differentiation along particle trajectories. In agreement with previous observations, we find a transition between a continuous swim configuration for dilute systems and a denser regime with pseudo-periodic burst of high activity. Here we report results obtained in the moderatelly dense regime (particle area fraction of about 2 percent, corresponding to 20-50 swimmers) in which the dynamics of the particles are correlated, with a high level of fluctuations, but without any coherent motion nor large scale organization. In this regime, we observe the particles explore the water surface homogeneously, their Lagrangian velocity and acceleration having a nearly Gaussian Probability Density Function (PDF). Computing the second order velocity structure function of the particle pairs,

$$S_2(r) = \langle (\vec{v}(\vec{X}_j(t)) - \vec{v}(\vec{X}_j(t)) \cdot \vec{r}_{ij}/r_{ij}) \rangle, (\vec{r}_{ij} = \vec{X}_i - \vec{X}_j),$$

we find that this quantity increases as a power law $S_2(r) \propto r^{2/3}$ which is reminiscent of 3D turbulence, and corresponds to a Kolmogorovian kinetic energy spectrum $E(k) \propto k^{-5/3}$. All quantities (temporal or spatial correlations), estimated either by using the Eulerian view point or Lagragian view point are in good agreement with the scaling laws of classical turbulence. The investigation shows that the dynamics of the present system corresponds to moderate turbulence characterized by a Taylor scale Reynolds number $Re_\lambda \simeq 70$.

Swimming through buckling

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An elastic spherical shell that buckles then re-inflates during an overpressure cycleundergoes a net displacement. We studied experimentally thisdisplacement in liquids with viscosities varying on 4 decades, and for acentimetric shell buckling under overpressures of the order of theatmosphere we observed an optimum for viscosities around the glycerol's one. Through study of the external flow using PIV, plus forcequantization, shape recording and direct measurement of the displacementusing a frictionless rail, we could identify solid deformation andhydrodynamics features for the optimum regime and the referencesituation in water, at high Reynolds. With a very rough model for theshell dynamics, we were able to understand how the coupling betweenshell and flow dynamics may lead to an optimum in the displacement. Themodel was generalized for micronic shells, opening the route for thefabrication with high throughput of simple synthetic microswimmers,actuated by a scalar field such as the pressure in echographic devices. This work has been published last november with Editor's suggestion in Phys. Rev. Lett [1].

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Microrheology of compact colloidal clusters driven by optical tweezers.

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The classical many body behavior of confined particle systems under external driving is relevant to an extremely diverse array of phenomena, which ranges from the propagation of granular materials, polymeric solutions and emulsions, all the way to the governing physics of atomic friction. Here I will present a new model system to explore these dynamics, based on optically constructed colloidal corrals that can tightly confine collections of particles. With these corrals we have observed non-Newtonian velocity profiles, shear thinning and thickening and their relation with elastic radial deformations. We believe this system will be useful to develop the understanding of non-equilibrium many body systems, and their relation to rheological phenomena.

Session 6: Nonlinear Dynamics II

Nonlinear dynamics in an experimental rotating split-cylinder flow

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Rotation and turbulence are present in many natural or industrial flows. One example are geophysical flows where rotation is present in many scales creating lots of different instabilities. On the other hand, many industrial flows also have this kind of behavior like liquid mixing processes. All these situations can be considered as enclosed systems in which lots of questions remain unanswered yet. To have a better knowledge of these kind of systems, several experiments using a von Kármán flow driven by propellers have been performed in our group finding very rich phenomena. Now, we have developed a new experimental device motivated by different numerical simulations (see [1, 2, 3]). The new experimental setup consists in a horizontal split-cylinder in which each half is moved independently by two shafts. All the system is enclosed in a cell filled by the working fluid (typically water). Halves are moved by two different servomotors and they can rotate in co-rotation or counter-rotation with independent velocities. In this configuration, the internal radius of the cylinder R is fixed, but we can change the length L of both halves, so we can change the aspect ratio defined as $\Gamma = 2L/R$. With this setup we can study the regimes inside the flow and the different symmetry-breaking that should appear according to [1] and [2]. The velocity field developed inside the split-cylinder is measured using LDV. The first results have been obtained in co-rotation applying an asymmetric rotation velocity. We set a main rotating velocity Ω and a differential rotating velocity ω so right-half rotation velocity is $\Omega + \omega$ and left-half rotation velocity is $\Omega - \omega$. Assuming that ν is the kinematic viscosity of the working fluid, we characterize the flow inside the split-cylinder as function of the Reynolds number Re and the Rossby number Ro defined as follows

$$Re = \frac{\Omega R^2}{\nu}, \quad Ro = \frac{\omega}{\Omega}.$$

The basic state described numerically by [2] has been found inside the experimental split-cylinder among other interesting phenomena, like a complex behavior of the boundary layer. We have also observed an azimuthal mode $m = 2$ consisting in a pair of vortices rotating inside the bulk of the split-cylinder. Here, we will present the 2D spatial average flow and the time series of the behavior of the flow for the experimental parameters.

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Fluctuations and transitions in turbulent flows

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When a fluid flow is driven strongly enough, it becomes turbulent and its velocity field fluctuates in time and space. It is commonly believed that the system then explores all the accessible states. Yet there are examples in which a flow transitions from one solution to another one, which amounts to a breaking of ergodicity. I will present experimental results on such a transition in a two dimensional turbulent flow and discuss several properties close to the transition; in particular the appearance of 1/f fluctuations, that are commonly observed in the context of electronic transport in solid state physics but not in fluid dynamics [1, 2, 3].

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Dynamics, geometry, and topology of fluid turbulence

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Dramatic progress in understanding fluid turbulence, especially at moderate Reynolds numbers, has been made in the past decade using a deterministic framework based on the state space geometry of unstable solutions of the Navier-Stokes equation. Initial results obtained by restricting attention to minimal flow units capable of sustaining turbulence and imposing unphysical boundary conditions seemed to suggest that fluid turbulence is in many ways similar to low-dimensional chaos, with unstable periodic solutions forming the geometric skeleton for dynamics. However, extending these results to larger flow domains with physical boundary conditions both proved very challenging and produced a number of surprises. In particular, our experimental and numerical studies have shown that unstable equilibria, quasiperiodic states, and heteroclinic connections can play an equally important role. We have also demonstrated that unstable solutions can be used for forecasting the evolution of experimental turbulent flows.

Experimental study of the optimal waveforms for entraining optical spikes

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The entrainment phenomenon, by which an oscillator adapts its natural rhythm to an external signal, has been observed in physics, chemistry, biology, etc. Recent attention has focused on determining the optimal conditions for entraining an oscillator to a weak external periodic signal. Here we use an experimental setup consisting of a semiconductor laser with optical feedback, as a testbed to study entrainment. The laser operates in the so-called low frequency fluctuations regime, in which the laser intensity displays apparently random dropouts [1]. Our goal is to experimentally find the most suitable waveform to entrain the intensity dropouts to a weak external periodic signal that modulates the laser pump current. To that end we analyze three waveforms (pulsed-up, pulsed-down and sinusoidal), as well as we analyze the role of the signal's parameters (amplitude and frequency) and of the laser's control parameter (the dc value of the pump current). We show that the waveform that produces widest regions of entrainment is the pulse-down waveform. We also find that it is not possible to ensure perfect entrainment as there are "extra" dropouts, which are not entrained to the external signal. However, three measures to quantify the entrainment quality are used, in order to determine the optimal entrainment parameters. In a second step, we use these optimized conditions to study experimentally how the laser responds when a non-periodic pulsed-down signal is applied to the pump current.

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Synchronization of phase oscillators with coupling mediated by a diffusing substance

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We investigate theoreticallyy and experimentally the transition to phase and frequency synchronization in a chain of phase oscillator “cells” where the coupling is mediated by the local concentration of a chemical which can diffuse in the inter-oscillator medium and it is both secreted and absorbed by the oscillator "cells", influencing their dynamical behavior. This coupling has the advantage of having a tunable parameter which makes it possible to pass continuously from a global to a local (nearest-neighbor) coupling form. We have verified that synchronous behavior depends on the coupling strength and coupling length. Our theoretical results are verify experimentally in yeast cell populations.

Session 7: Optics and Lasers

Spatio-temporal chaos in semiconductor lasers with delayed feedback

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Deterministic chaotic emission is ubiquitous in semiconductor lasers for various conditions, in particular when the lasers are experiencing delayed optical feedback, but chaotic emission also occurs in solitary devices with broad apertures. This is due to the characteristic nonlinear interaction between the optical laser field and the semiconductor as active medium. Consequently, the study of these phenomena in semiconductor lasers has been an intense and fruitful research field for more than 40 years. The motivation to study chaotic emission of semiconductor lasers has been threefold. First, the occurrence of chaotic dynamics has been detrimental for many applications of these lasers, second, these laser systems have become one of the most paradigmatic optical system to study nonlinear phenomena, and third, the manifold complex phenomena in semiconductor lasers have been utilized for novel applications. In this presentation, we concentrate on spatio-temporal chaotic phenomena. We provide an overview of the occurrence of such phenomena in high-power broad-area edge emitters with one transverse direction and broad-area VCSEL with two transverse directions. Moreover, already in the early 1990s, it has been recognized that lasers with delayed optical feedback show interesting analogies with spatially extended systems with one spatial dimension, when mapping the optical intensity in the feedback loop to the one that has emerged one delay time later. This so-called spatio-temporal representation has turned out to be very fruitful and interesting spatio-temporal phenomena have been identified. Recently, the idea of the equivalence of delayed feedback systems and 1D spatially extended systems was extended to 2D systems, when using two delayed feedback loops with delays acting on different time scales. We will show, that indeed this approach allows to experimentally study spatio-temporal chaos in semiconductor lasers with two transverse directions without fundamental limitations with respect to homogeneity and aspect ratio. We demonstrate that the wavenumber spectrum shows a transition from being exponential toward a power-law dependence. In this sense, this configuration might allow to study the transition to optical turbulence in 2D experimentally. Moreover, we will discuss implications for applications, since semiconductor lasers with delayed feedback have recently been employed as ultra-fast and energy-efficient information processing systems, based on neuro-inspired concepts of computation.

Integrable Turbulence in the focusing regime: from optical fiber experiments to theoretical open questions

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The complex phenomena arising from the propagation of *partially coherent waves* in a system described by the one dimensional nonlinear Schrödinger equation enter within the framework of *integrable turbulence*. This fundamental field of research first introduced by V.E. Zakharov relies on the analysis of complex phenomena found in nonlinear random waves systems described by an integrable equation [1, 2, 3]. The mechanisms found in integrable turbulence are of a profoundly different nature than those found in conventional turbulence [1]. We report optical experiments and numerical simulations devoted to the investigation of integrable turbulence in the focusing regime of 1DNLSE [2, 4, 3]. We present in particular direct single-shot recordings of both phase and amplitude of optical rogue waves (Rws) by using an original ultrafast measurement technique called Heterodyne Time Microscope (HTM) [3]. The key point of the experimental setup is a completely new combination of the heterodyne technique and of the so-called time lens strategy that provide large temporal windows [4]. Rws with time scale of the order of 500 fs are found to emerge from the propagation of partially coherent waves having initial time scale of 5ps. Using our HTM and another optical sampling setup, we measure precisely the probability density function (PDF) of optical power of the nonlinear random waves rapidly fluctuating with time. The PDF of optical power is found to evolve from the exponential distribution to a strong heavy-tailed distribution. The exponential distribution of the power corresponds to a Gaussian statistics for the field. Our experiments thus confirm the occurrence of extreme events (Rws) in integrable turbulence with a probability much higher than predicted by the normal law. The knowledge of the phase and of the amplitude of the experimental field now opens the way to a full comparison between experiments and theory. The HTM reveal for the first time the phase of nonlinear random waves propagating in optical fibers. By putting together the temporal signatures of phase and power profiles (and not only the power), our experiments definitively demonstrate the peculiar role played by the breathers-like structures in integrable turbulence. In particular we demonstrate that the Peregrine Soliton can locally emerge from the propagation of nonlinear random waves [3]. We show that our results can be interpreted in the framework of the semiclassical theory of 1DNLS in which it has been demonstrated that gradient catastrophe in the dispersionless limit of focusing 1DNLS is regularized by the emergence of the Peregrine soliton [5]. In this talk we also review existing theoretical approaches and open questions in the fundamental field of integrable turbulence.

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Toward a test of the fractal Weyl law in an optical microcavity

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The statistics of resonances is nowadays a topic of interest in several fields, ranging from acoustics, to nuclear, atomic, optics, and condensed matter physics. Counting eigenmodes can be often instrumental in characterizing the underlying classical dynamics (regular vs. Chaotic) of a quantum system from an experiment, as well as to identify quantum-to-classical correspondences. A milestone in this context is Weyl law, that predicts how the number of eigenstates supported on a certain volume of a bounded phase space scales with the energy (or typical action) of the system [1]. Weyl law takes an especially interesting form when applied to quantized open chaotic systems [2]: in that case, the number of resonances scales with the fractal dimension of the chaotic saddle (repeller). To date, there have been but few attempts to experimentally validate the fractal Weyl law, and none at optical frequencies. This experimental lag is mostly due to the difficulties of reading overlapping spectra, a common problem in open quantum systems, and of dealing with partial absorption, which would theoretically alter the fractal repeller, its dimensions, and therefore the Weyl scaling. In this talk, I will first outline the progress recently made to overcome the above obstacles and count statistics of chaotic resonances in a deformed dielectric microresonator [3], coupled with both infrared and visible light. Importantly, dynamical tunneling of the electric field between regular and chaotic regions of the phase space plays a key role in the success of our methods. Then, ongoing work will be presented on estimating the information dimension of a deformed optical microcavity from sole far-field measurements, as well as on the design of an experiment aimed at validating the fractal Weyl law, which employs the recently developed technique of chaos-assisted broadband momentum transformation [4].

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Evidence of a critical phase transition in a purely temporal dynamics with long-delayed feedback

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It is well known that complex dynamical evolution may originate from simple low dimensional dynamical systems when a time-delayed feedback mechanism is considered. These may typically happen in systems where the propagation time of a signal is not negligible with respect to the typical timescale of the local dynamics. Examples include many biological systems and laser physics, where a long delayed feedback may be easily obtained by optical or electronic device. In this latter case, it is well known that a deep analogy exists between delayed feedback and spatially extended dynamical systems [1]. In this work, experimental evidence of an absorbing phase transition is provided in a purely temporal optical system: a bistable semiconductor laser with long-delayed opto-electronic feedback and multiplicative noise, shows the peculiar features of a patio-temporal critical phenomenon belonging to the directed percolation class. DP is a prototypical non-equilibrium universality class so-far associated with spatio-temporal dynamics. These findings are confirmed by the numerical study of a simple, effective model for laser dynamics [2, 3], providing accurate estimates of the transition critical exponents. This result pushes forward an hard equivalence of non-trivial stochastic, long-delayed systems with spatio-temporal ones, opening the way for further experimental and theoretical investigations of non-equilibrium critical phenomena in purely temporal dynamics.

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Experimental analysis and mean-field reduction of a large population of coupled semiconductor lasers

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The dynamics of ensembles of coupled systems is a broad and fascinating topic which can be considered in many settings including neurosciences or social phenomena. In many cases this dynamics is analysed on the basis of simplified mathematical models and experimental descriptions large-ish networks are comparatively scarce. Here we discuss an optical experiment in which about 500 semiconductor lasers are coupled from one-to-all to fully connected network configurations. Instead of studying synchronization of optical fields, we analyse the chaotic dynamics of the light intensity which emerge when the intensity of the light emitted by a laser is re-injected into the laser control parameter via an optical to electrical converter and a nonlinear function [1]. In this configuration and in well chosen parameter regimes, a single laser can display chaotic spiking due to the presence of three different characteristic time scales, which span about five orders of magnitude. Here, we study the emergence of chaos and synchronization when the order parameter of one laser drives the whole population and when the sum of several or even all laser signals drives the common bifurcation parameter of the array. In particular, we analyse the statistical distribution of laser intensity of sub-ensembles of the whole array depending on the region of the chaotic attractor which is considered and on control parameters such as the coupling strength and the operating point of the whole array. The experimental results are reproduced by a detailed physical model of the laser network, where the dynamics of each node is described in terms of (single-mode) semiconductor-laser rate equations and the coupling mechanism is provided by a common AC-coupled nonlinear feedback loop. In particular, complex sequences of synchronized mixed-mode oscillations are observed and characterized. We discuss the reduction of the dynamics to that of a mean field model.

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Chimera states in coupled-waveguide Kerr resonators

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Chimera states are spatiotemporal patterns in which an array of oscillators splits into two domains: one coherent and phase locked, the other incoherent and desynchronized [1, 2]. A while after their discovery, the main ingredient to explain this counterintuitive state was the weakness or non-local nature of the coupling between the oscillators. However, recent works have reported on chimera states in globally [3] and, strong and non-locally coupled oscillators [4]. These works opened the possibility to generate a novel type of chimera state based on other type of oscillators coupling. Here, we study the case of the nearest neighbor local coupling, widely present in nature. To this end we consider an array of coupled-waveguides resonators. Coupled-waveguides play an important role in communication technologies, optical computing, and even quantum information processing. From a fundamental point of view, their dynamic behaviors exhibit interesting states like discrete solutions [5]. Based on a discrete model, we investigate the formation of complex spatiotemporal localized states in an array of coupled-waveguide resonators. The presented localized states correspond to the optical behavior equivalent to the chimera states. By means of the Lyapunov spectrum, we are able to characterize the spatiotemporal chaotic nature of these optical chimera states [6].

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Poster and Wine Session

Understanding the Some Aspects of Alternate Bearing Phenomenon P1

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Major plants which produce large seed crops usually show alternate bearing, i.e. A heavy yield year is followed by extremelylight ones, and vice versa. This causes the cascading effect throughout the ecosystem, and may cause the serious health problem for human beings. Therefore, it is very important to understand this natural phenomenon. In this poster we will discuss the resource budget model [1], which characterizes the ecological alternate bearing phenomenon in fruit crops, in which high and low yields occur in alternate years. We will attempt to understand some of the dynamical complexities [2] of this phenomenon. We will also discuss a new fruits production method to get constant fruits production from an orchard by enhancing alternate bearing of individual trees, based on the principles of synchronization of coupled oscillators and utilizing the existing models. The proposed method, using direct coupling [3], between plants show dominance of out-of-phase synchronization, even in the presence of indirect interactions , suggesting the possibility of controlling fruit production.

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P2 A Tape Recorder is a Chaotic Dynamical System

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We naively apply Koopman operator theory to yield a linear, infinite-dimensional representation of a chaotic one-dimensional iterated map. At first glance, our result appears pathologically simple and of little interest: it is mathematically equivalent to a tape recorder that provides storage and playback of the chaotic time series. However, the result does not explicitly depend on the particular iterated map, and we find the same Koopman operator dynamics can model any iterated map, including higher dimensional systems and even random signals. We then make a connection to the mathematical oddity of linear chaos, with the surprising result that a tape recorder, when viewed as a dynamical system, is provably chaotic. That is, a storage-and-playback system formally satisfies the three conditions in Devaney's definition of chaos: a transitive orbit, dense periodic orbits, and sensitivity to initial conditions. We conclude by clarifying the meaning of chaos in a tape recorder, which is not simply a restatement of chaos in the original iterated map. Rather, the Koopman operator works in an immense function space comprising all possible waveform recordings, and its chaoticity provides the flexibility to playback anything, including chaos.

Simulation of atmospheric turbulence spectra in the flows in rotating spherical layer P3

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Large scale flows in the atmosphere are usually explained within the concept of ôtwo-dimensionalö turbulence with two inertial intervals corresponding to energy transfer at low wave numbers and enstrophy transfer at high wave numbers. Energy and enstrophy supply to a flow occurs owing to external forces with wave numbers between these intervals. The dependence of the energy spectrum $E(k)$ on the wave number k has the slope -5/3 in the inertial interval of energy transfer from high to low wave numbers , the same as in the Kolmogorov relation describing three-dimensional turbulence. In the inertial interval of enstrophy transfer from low to high wave numbers (direct cascade) the slope is -3. The direction of the cascade is also determined by the sign of the third order longitudinal velocity structure function D_{LLL}. The negative and positive signs of D_{LLL} correspond to the direct and inverse cascades, respectively. Conclusions of the theory of two-dimensional turbulence were confirmed in numerous studies. At the same time, long-term measurements of the horizontal velocity of the wind in the upper layers of EarthÆs atmosphere, reveals an anomalous location of spectral regions. Both, viscous dissipation and vertical motions, which are components of large-scale circulation inherent to the atmospheric flows, prevent two-dimensional turbulence. Large-scale circulation also exists in turbulent flows induced by the rotation of the boundaries of the spherical layers, responsible for the motion of viscous incompressible fluid sandwiched between them. This is why the flow of a viscous incompressible fluid in a layer between rotating concentric spheres is studied in this work with the aim to qualitatively simulate corresponding processes in the atmosphere. Transition from the periodical to turbulent flows driven by the action of the modulation of the velocity of one of the spheres, have been studied experimentally and numerically. The form of spectra of turbulent pulsations of the azimuthal velocity depends on the sphere whose rotational velocity is modulated, as well as on the amplitude and frequency of modulation. We have established a possibility of the formation of turbulence with spectra qualitatively similar to the spectra obtained during the measurements in the upper atmosphere: with the slope close to -3 at low frequencies, close to -5/3 at high frequencies, and with the negative longitudinal velocity structure function of the third order. The obtained results demonstrate that such spectra are formed in the regions of a flow that are strongly synchronized under the action of the modulation of the rotational velocity.
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P4 Scaling Laws in the Energy Distribution for a Nonlinear Coupled System

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Nonlinear coupled systems are present in many areas, such as physics, engineering, biology, neuroscience, social sciences, etc. Coupled systems usually have properties that are not found in the individual subsystems. The new properties depend on the nonlinear coupling and the energy exchange it causes among the subsystems. We propose a new approach to investigate the energy distribution in nonlinear coupled systems, and how it varies according to the parameters. The method consists in writing the total energy of the system, and identifying the energy terms associated with each subsystem and their coupling. To illustrate the procedure, we work with a spring pendulum, which represents a paradigm for the study of coupled systems, and is used as a model for several systems. For the spring pendulum, we identify three energy terms associated with the spring-mass and pendulum like movements, and their coupling. The expression we obtain for the coupling energy term accurately describes the energy exchanges between the spring and pendulum motions for different configurations of the system (low and high energy, regular and chaotic orbits). We also calculate the average energy terms for a great number of trajectories throughout the phase space to obtain global characteristics of the spring pendulum dynamics. We verify that the average energy terms vary regularly with the total energy and the parameters of the system. We obtain scaling laws that describe different aspects of the average energy distribution, including the parameters that lead to strong or weak coupling, and the subsystem that dominates the dynamics of the coupled system. The approach we propose provides a new way to investigate internal energy exchanges, and how the coupling regulates the dynamics and properties of nonlinear coupled systems.

Exploring the route to measure synchronization in non-linearly coupled Hamiltonian systems P5

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Synchronization, in the original sense of the term, refers to two or more trajectories asymptotically approaching each other and following a single identical trajectory. It plays a major role in natural and scientific processes. Dissipative systems are known to exhibit such synchrony. Measure Synchronization is a generalisation of the termśynchronization' extended to coupled Hamiltonian systems. Hamiltonian systems find wide applications in modeling of both quantum and classical systems. They were found to exhibit weak synchronization by Hampton and Zanette (in [1]) wherein they share the same phase space domain. Route to measure synchronization in a system of two non-linearly coupled one-dimensional oscillators is investigated on the basis of numerical computation. This system finds applications in the modeling of regular and chaotic magnetic fields in plasma [2, 3]. The potential of the system is represented by the Pullen-Edmonds Potential [4] which has applications in modeling of molecular systems [5] and in stellar astronomy [4, 6]. The Hamiltonian, $H = \frac{1}{2}\left(p_x^2 + p_y^2\right) + \frac{\beta}{2}\left(x^2 + y^2\right) + \frac{\gamma}{2}x^2y^2$, is similar to that of a classical SU(2) Yang-Mills-Higgs (YMH) system [7, 8], a toy model in classical nonlinear dynamics. Transitions to measure synchronization and unsynchronization, both quasiperiodic and chaotic, are investigated and distinguished on the basis of the variation of average bare energies, average interaction energy, root-mean-square value of oscillations, phase difference, and frequencies with the coupling strength. A suitable order parameter to identify and characterize both quasiperiodic and chaotic measure synchronous states is sought, and drawbacks of the various order parameters, suggested previously, are discussed [9].

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P6 Continuous Wavelet Transform analysis of Partial and Complete Measure Synchronization in a system of three non-linearly coupled oscillators

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Measure Synchronization is the generalization of synchrony to Hamiltonian Systems. Partial measure synchronization (PMS) and complete measure synchronization in a system of three non-linearly coupled one-dimensional oscillators have been investigated on the basis of numerical computation. The governing Hamiltonian of this system is the classical SU(2) Yang-Mills-Higgs (YMH) Hamiltonian with three degrees of freedom [1, 2], $H = \frac{1}{2}\left(p_x^2 + p_y^2 + p_z^2\right) + \frac{1}{2}\left(x^2 + y^2 + z^2\right) + \frac{1}{2}\left(x^2y^2 + y^2z^2 + z^2x^2\right)$, the potential also being significant as a local galactic potential used to describe motions in the central regions of a galaxy [3]. Different initial conditions denoting various total energies of the system have been investigated with. Similar to the three body problem in mechanics, the coupled three-oscillator system exhibits richer dynamics than the two-oscillator case [4], showing various transitions in the average bare energies, average interaction energies and the root-mean-square (RMS) values of the amplitude of oscillations, as the coupling strength is varied. When the system is quasiperiodic (QP), transitions namely, QP unsynchronized to PMS, PMS to PMS and PMS to chaos is observed. Transition from quasiperiodicity to chaos is seen to be associated with a gradual transition to complete chaotic measure synchronization (CMS) which in turn gives in to the chaotic unsynchronized states, which seems to be the most stable state in this case. The analyses illustrate the dependence on initial conditions. The explanation of the behaviour in the quasiperiodic regime is sought from the dominant frequency components of the oscillators obtained from the power spectra. An alternative approach to MS in the form of Continuous Wavelet Transform (CWT) analysis not only maintains the inferences drawn previously but also helps understand the dynamics with an unprecedented outlook. The study of wavelet coefficient spectra sheds new light on the relative phase information of the oscillators in the QP PMS regions, also highlighting the intertwined role played by the various frequency components and their amplitudes as they vary temporally. Further, this technique helps to draw a sharp distinction between CMS and chaotic unsynchronized states. Based on the CWT coefficients of the three oscillators, an order parameter M_{wav} is defined to indicate the extent of synchronization of the various scales (frequencies) for different coupling strengths in the chaotic regime. The technique serves as a potential tool to identify, quantify and analyse both partial and complete MS. Finally, the existence of PMS is verified using the order parameter M_2 (for different combination pairs of oscillators; same as M in [4]) and the definition is extended to obtain a new order parameter, M_3, aiding to distinguish complete MS of three oscillators from other forms of motion.

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Hybrid cellular Potts model for tumor-induced angiogenesis P7

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Angiogenesis, the formation of new blood vessels from existing vasculature, is the basis of organ growth and repair in healthy conditions and of pathological developments such as cancerous tumors. Angiogenesis is a multiscale process, ranging from gene transcription and protein synthesis, through the cell dynamics and right up to the level of organization of tissues and organs. In this poster, we present a cell-based model structured in terms of these multiple scales by incorporating extracellular and cellular levels as well as the results of simulations. At extracellular level, the model considers chemotaxis and durotaxis by adding an equation for the Vascular Endothelial Growth Factor and Finite Element computational model for the compliant extracellular matrix, respectively. At the cellular level, a cellular Potts model considers cell migration, growth, proliferation, cellular adhesion, distinction between tip and stalk phenotypes, sprout branching and anastomosis. The extracellular and cellular level are coupled giving rise to a model that incorporates biomechanical and biochemical mechanisms allowing to simulate branching based on purely biological properties.

Solar-wind dynamics from Voyager 2 and New Horizons P8

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One of the important problems in planetary science is to understand the dynamics of the solar wind: the stream of charged particles emitted by the sun. A specific question that is of particular interest is whether those dynamics are stationary. Sensor data from the Voyager 2 and New Horizons missions — launched in 1977 and 2006, respectively—allow us to address this question. In this work, we consider time-series data of solar wind properties collected at the same heliospheric distance by both missions, roughly 20 years apart. We present a comparative analysis of these properties using nonlinear time-series analysis and information-theoretic techniques. Our findings suggest that the Lyapunov exponents of the density and temperature dynamics are higher in the New Horizons data and lower in the velocity dynamics at the time of the Voyager mission.

P9 Chaotic behavior and coherence resonance in semiconductor superlattices at room temperature

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Random number generators are key in many areas: data security, numerical simulations, online games of chance, etc. Classical generators can be either insecure or slow. Recent solutions that avoid both problems include doped weakly coupled semiconductor superlattices which, operated at room temperature [1] can produce spontaneous chaotic oscillations. This can be exploited to generate true random numbers fast enough and with little post-processing. Under DC voltage bias, idealized superlattices [2] show self-sustained chaotic behavior for certain voltage intervals. If external and internal noise is taken into account, these voltage intervals can be made broader and the chaotic response enhanced. Thus, establishing superlattices as a robust physical entropy source. Another feature seen both in experiments [3] and numerical simulations [4] is coherence resonance: external band limited voltage noise of sufficient amplitude induces regular current self-oscillations in states that are stationary in the absence of noise. Furthermore, when a weak AC voltage signal is applied, coherence resonance triggers a stochastic resonance. That is, the current response is both phase locked to the AC signal and amplified, in the sense of a higher signal to noise ratio.

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The role of chaotic transients in Cardiac Dynamics P10

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The complex spatio-temporal dynamics during cardiac arrhythmias is determined by spiral and scroll waves. We simulate this chaotic spiral wave dynamics using numerical simulations of cardiac tissue and observe that the dynamics is often transient rather than persistent. We investigate the underlying mechanisms which lead to self-termination of the chaotic dynamics and discuss interpretations and implications for the understanding of cardiac arrhythmias in real hearts [1]. Furthermore, we show for the investigated cardiac models and other spatially extended systems (e.g. Morris-Lecar neuron model) which exhibit chaotic transients that the state space structure nearby the “exits” of the chaotic dynamics is significantly different from the region a typical trajectory passed before. Thus, we demonstrate that in principle precursors which predict the self-termination of the dynamics already a reasonable amount of time before may exist. This effect can also be reproduced and understood (semi)-analytically in more detail in simple low-dimensional maps [2]. Exploiting the knowledge about the state space structure it can be shown that an efficient control of the spatio-temporal chaotic dynamics is possible using spatially localized perturbations. Novel defibrillation strategies could benefit from these insights about the efficient control of high-dimensional chaotic dynamics.

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P11 Waves and patterns in giant amoeboid cells: modelling and experiments

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Spiral waves and complex patterns have been observed in the interior of Dictyostelium discoideum cells. The amoebas have typically around 10 μm length, and the waves are on the similar scale than the cell size. Recent experiments have shown that a set of similar Dictyostelium discoideum cells can fuse into a single, larger cell when exposed to repeated electric pulses [1, 2]. These cells, typically referred to as giant cells, present excitable waves with similar velocities and widths to those generated in normal-sized cells. The relatively large size of the giant cells permits a clearer observation of the wave dynamics and pattern formation within the cell domain [2]. For a systematic characterization of the internal waves in giant amoeboid cells, we present a mathematical model of pattern formation in the amoeboid interior that combines noisy excitable kinetics with a mass-conservation constrain, along with a dynamic phase field for the cell shape. The characteristic stochasticity observed in amoeboid cells is accounted for by means of a classical Ornstein-Uhlembeck process. The mass-conservation constraint together with the effect of the dynamical phase field and the interaction of the waves with the moving boundary give rise to new mechanisms of pattern formation including spiral wave generation and break-up. The present model represents an extension of a simplified model previously developed by our group that has been successful in describing experimental cell trajectories and pattern formation in motile amoeboid cells [3]. We compare the numerical simulations of our model with experiments with the giant amoeba Dictyostelium discoideum. We satisfactory reproduce the main biochemical dynamics observed inside the living cells and the shape deformations due to the internal forces. We conclude with a discussion of the biophysical implications of the model in the different mechanisms of pattern formation.

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Quantify the complexity of the spacing between surfaces: Applications to brain tumors. P12

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Measuring the properties of the region contained between two surfaces is of interest in different disciplines and applications [1, 2, 3]. In our case, we are interested in quantifying the differences between two surfaces related to a growth process. Thus one of the surfaces S_1 (internal) is enclosed in the other S_2 (external) but there is no a priori mapping between the points of S_1 and S_2. Thus, the question is given, how can we quantify the differences between these surfaces? Our specific goal is to quantify tumor growth data obtained from MRI images. Inner parts of the tumor are necrotic and active tumor areas appear as complex 3D rim-like structures. However there are other potential applications of the methodology. To characterize the space between the surfaces we have first generated a set of distances between them and then characterized this set using different statistical measures, leading to a set of quantifiers of the rim shape complexity (RSC). We have quantified RSC for 311 brain tumors called glioblastomas, that are the most malignant and prevalent brain tumors. Theoretical predictions [4] and limited studies have pointed out that geometrical variables obtained from MRI could be biomarkers of patient survival [5, 6]. We computed our RSC measures for the tumor images and found some of them to be associated to the patient prognosis and tumor properties. Thus, the spatial complexity measures defined here can be useful in oncology to classify tumors and predict patient survival from medical images.
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P13 Dynamics and synchronization of delay-coupled networks with a fluctuating connectivity

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Interaction delays are ubiquitous in many real-life networks: it takes time for information to travel in communication networks, or between coupled optical elements. In the brain a coupling delay between interacting neurons arises from the conduction time of an electric signal along the axon. Delayed interactions appear as well in traffic dynamics, genetic transcription circuits, social networks and population dynamics. Here, we study the effect of a topology that changes over time in such delay-coupled networks. Network fluctuations are essential features of, for instance, interacting neurons, where synaptic plasticity continuously changes the topology, or networks modeling social interactions. We concentrate on a numerical study of the synchronization properties of chaotic maps, coupled with an interaction delay T_d. The coupling topology fluctuates between an ensemble of directed small-world networks, while keeping the mean degree constant. These network fluctuations are random, and not adaptive, i.e., the network evolution is not linked to the state. The dynamics is characterized by three timescales: the internal time scale of the node dynamics T_{in}, the connection delay along the links T_d, and the timescale of the network fluctuations T_n. When the network fluctuations are much faster than the coupling delay and the internal time scale the synchronized state can be stabilized by the fluctuations: synchronization can be stable even if most or all temporary network topologies are unstable. When we increase T_n, the synchronized state destabilizes as both time scales collide ($T_n \approx T_d$). Synchronization is more probable as the network time scale increases further. However, in the slow network regime ($T_n \ll T_d \ll T_{in}$) we find that the long-term dynamics is desynchronized whenever the probability of reaching a non-synchronizing network is finite. We provide a theoretical explanation for these synchronisation properties: we develop a Master Stability Function approach for time-varying networks with delayed connections, in which the "effective" connectivity can be expressed as function of the three time scales T_{in}, T_n and T_d. Two limit cases are analytically investigated: When the network fluctuations are much faster than the internal time scale and the coupling delay ($T_n \ll T_{in}, T_d$), the effective network topology is the average over the different topologies. When coupling delay and network fluctuation time scales collide ($T_{in} \ll T_n = T_d$), the effective topology is the geometric mean over the different topologies (adjacency matrices).

Bifurcation induced by the aspect ratio in a turbulent von Karman swirling flow P14

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Two counter-rotating propellers are used to develop turbulence in a cylindrical cavity filled with water. The counter-rotating swirling flow can be the place of multistability, memory effects, and long time dynamics. De la Torre and Burguete [1] observed a symmetry breaking of the mean flow where the shear layer between the two counter-rotating cells of the flow does not remain in the middle of the cavity. Moreover, this shear layer can spontaneously jump from one side of the cavity to the other with a long residence time (typically 1000 s) compared to the turbulent time scales. But what is/are the problem parameter(s) which fix(es) the position of the shear layer and the spontaneous reversals? Here we analyze this bifurcation: It appears modifying the aspect ratio $\Gamma = H/D$. Whereas for low Γ the shear layer position has a smooth evolution when turning the asymmetry between the rotation frequency of the propellers, for high Γ the transition becomes abrupt and a symmetry breaking appears. Secondly we observe that the spontaneous reversals with large residence times exist only in a narrow window of aspect ratio. We present a phenomenological model that describres these features.
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Cross predicting spatio-temporal chaos in excitable media using Echo State Networks P15

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If for a given dynamical process some but not all of its state variables can be measured, the unknown variables can often be estimated from the available time series by means of cross prediction. This task can efficiently be solved using Echo State Networks providing dynamical state observers exploiting generalized synchronization. We present an application of this kind of dynamical modelling to spatio-temporal chaotic excitable media, given by the (cubic) Barkley model and the Bueno-Orovio-Cherry-Fenton model describing chaotic electrical wave propagation in cardiac tissue [1]. As a crucial concept for coping with the high dimensionality of the underlying chaotic dynamics of these spatially extended systems, only time series from nearby sampling sites are fed into the Echo State Network for cross predicting unobserved variables at some reference locations.

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P16 Estimating model parameters from measured time series using attractor comparison

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Time series based methods for estimating parameters of dynamical models are presented that are based on a comparison of the asymptotic dynamics given by the observed data and those generated by the model. Using delay coordinates the attractor of the observed process and a correspondingly reconstructed attractor of the model are compared in terms of the shape and distribution of the sets of reconstructed states in delay embedding space. Deviations between both attractors are quantified with different measures of "distance" that may serve as cost functions for optimization methods aiming at estimating proper model parameters reproducing the observed signal. We present different implementations of this approach for parameter estimation and evaluate their performance with several dynamical examples.

Nonlinear graph-based assessment of network observability P17

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Attempting to describe the functioning of a complex dynamical network is a challenging task. A full description of its state would require measuring a large amount of variables unless the network dynamics is observable. The observability of a system is a property that quantifies how reducible the system is by just measuring a limited set of its variables to describe the whole state. There are two relevant ingredients to take into account: i) the nature (linear or not) of the coupling between the nodes and ii) the node dynamics to select the best variable to measure in the selected node. Some attempts have been made by Liu and coworkers [1], who constructed a so-called inference graph, and introduced a technique to select the candidate sensors to provide full observability. However, it has been found that in some cases, their results do not match with those derived from a rigorous analytical analysis of the corresponding observability matrix [2, 3]. By means of a symbolic approach to assess the set of variables to measure (together with the Lie derivatives to reconstruct the whole state space), we improved their graph-based approach. We construct a pruned fluence graph in which only linear couplings are retained, that is, those allowing a full observability [4, 5] and discarding those nonlinear links responsible for introducing a lack of observability. We thus show that the sink strongly connected components allow in a very reliable way to determine the reduce set of variables to measure. We also developed a Matlab algorithm that allows to automatically determine the reduced set of variables by comparing the weakly and the strongly connected components. By just using the linear links of the network considered, and not treating all links on a equal footing, the key sensors to measre are thus reliably selected.

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P18 From Order to Disorder in Ensembles: Back and Forth. Localization and Pattern Formation in Hierarchies

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We present universal framework for generation, analysis and control ofnon-trivial states/patterns in the complex systems like kinetichierarchies describing general set-up for non-equilibrium dynamics andtheir important reductions. We start from the proper underlying functionalspaces and their internal hidden symmetries which generate all dynamicaleffects. The key ingredients are orbits of these symmetries, theirrepresentations, and Local Nonlinear Harmonic Analysis on these orbits.All that provides the possibility to consider the maximally localizedfundamental generic modes, non-linear and non-gaussian, which are not so smooth asgaussians and as a consequence allowing to consider fractal-like imagesand possible scenarios for generation chaotic/stochastic dynamics on thelevel of representation theory. As a generic example we consider themodeling of fusion dynamics in plasma physics.

P19 Complex Quantum World on the Tower of Scales

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We present a family of methods which can describe complex behavior in quantum ensembles. We demonstrate the creation of nontrivial stable states (patterns), localized, chaotic, entangled or decoherent, from the basic localized modes in various collective models arising from the quantum hierarchy described by Wigner-like equations. The advantages of such an approach are as follows: i) the natural realization of localized states in any proper functional realization of (Hilbert) space of states; ii) the representation of hidden symmetry of a chosen realization of the functional model describes the (whole) spectrum of possible states via the so-called multiresolution decomposition. Effects we are interested in are as follows: 1) a hierarchy of internal/hidden scales (time, space, phase space); 2) non-perturbative multiscales: from slow to fast contributions, from the coarser to the finer level of resolution/decomposition; 3) the coexistence of the levels of hierarchy of multiscale dynamics with transitions between scales; 4) the realization of the key features of the complex quantum world, such as the existence of chaotic and/or entangled states with possible destruction in "open/dissipative" regimes due to interactions with quantum/classical environment and transition to decoherent states. The numerical simulation demonstrates the formation of various (meta)stable patterns or orbits generated by internal hidden symmetry from generic high-localized fundamental modes. In addition, we can control the type of behavior on the pure algebraic level by means of properly reduced algebraic systems (generalized dispersion relations).

Pyroelectric Detection near a Period Doubling Bifurcation P20

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Pyroelectric detection is widely used to characterize infrared radiation. Fields of application are gas analysis, flame detection, contactless temperature measurement. Especially the latter application is exploited in infrared cameras for building inspection, medicine, and predictive maintenance etc. We present a new principle of pyroelectric detection based on the effect of small signal amplification near period doubling bifurcations in nonlinear dynamical systems. While the effect of small signal amplification can be understood without reference to a concrete dynamical system, for a practical application we had to look for a suitable realization of a dynamical system, which is sensitive to modulations through infrared radiation. We use a series resonance circuit consisting of a linear inductance and a ferroelectric capacitance. It can be driven to period doubling bifurcations by AC voltage of sufficiently high amplitude and suitably chosen frequencies. As ferroelectric material we chose triglycine sulfate because of its good pyroelectric properties. The perturbation may be introduced into the system by periodic infrared irradiation of the ferroelectric. This leads to a resulting periodic modulation of the temperature of the TGS-crystal and yields an electrical signal via the pyroelectric effect, which can be amplified near a period doubling bifurcation. Detailed investigations were performed to optimize this effect.

Topological analysis of experimental recordings of ventricular fibrillation P21

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Spiral wave breakup caused by dispersion of tissue refractoriness has long been believed to play a key role in maintaining complex cardiac rhythms such as atrial and ventricular fibrillation. To test this hypothesis, we have developed a level-set based method that can accurately and reliably extract the temporally and spatially resolved positions of wavefronts, wavebacks, and phase singularities from noisy optical mapping data. The utility of this method was illustrated by analyzing optical mapping voltage data during ventricular fibrillation in a Langendorff-perfused pig heart. A recent topological analysis of a two-dimensional model of atrial tissue has shown that there are four distinct mechanisms that increase the complexity of the excitation pattern and two distinct mechanisms that decrease its complexity. This analysis predicted that wave coalescence plays a more important role in maintaining fibrillation than wave breakup. A similar topological analysis of our experimental recordings provides supporting evidence for this theoretical prediction in ventricular tissue as well, which is essentially three-dimensional.

P22 Implementation of Chaos-Based Coded Modulations with Software Defined Radio

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Chaos-based coded modulation systems have been shown to be competitive against important wireless channels impairments, such as flat fading [1]. These techniques, working at the waveform and coding level, have been explored theoretically and numerically in different typical setups. Nonetheless, tests in real-world scenarios are necessary to validate the results. In this proposal, we take advantage of the availability of Software-Defined Radio (SDR) hardware and open source GNU Radio software libraries to carry on a full proof-of-concept. The implementation issues and trade-offs for such CCM systems are addressed and detailed [2]. The performance results, compared against classical counterparts, validate experimentally what had previously been shown by simulation, and exhibit gains against classical counterparts in fair conditions of comparison.

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P23 Periodic and Quasiperiodic Dynamics of Optoelectronic Oscillators

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We present a detailed study of instabilities that arise in optoelectronic oscillators with a single narrowband time-delayed feedback loop. Such optoelectronic oscillators produce periodic solutions and may be useful as high-purity signal generators but their nonlinear dynamics sets limits on available signal amplitudes. Starting from an integro-differential model, we utilize approximate analytic solutions to find the stability boundaries of the periodic solutions as well as regions of multistability. Our analytical predictions are confirmed by numerical simulations and experiments.

Synchronization and Its Suppression in a Network of Networks of Bursting Oscillators P24

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The brain is composed of a huge amount of neurons coupled through a non-trivial pattern of connectivity. Diffusion tensor tractography can be used to identify patterns of connectivity on real human brain [1]. In this work, we use a network of networks approach to describe the connection of neurons in the cerebral cortex. The cerebral cortex is considered as a network and the cortical areas as subnetworks. Every cortical network is composed of coupled Rulkov bursting neurons [2]. In order to make the model closer to real brain, chemical and electrical connections were considered [3]. As the intensity of connections is increased, the neurons suffer a transion from the asynchronous state to a partial synchronized state [4]. Synchronization is related to healthy and unhealthy conditions of the brain. For Parkinson's Disease, for example, the synchronization is related to motor impairments [5]. The synchronization can be suppressed applying external signals in the network [6]. In our case, the mean field of a cortical network was stored for a time τ and reinjected in the cortical network with an intensity ε_F, to cause suppression of synchronization [4]. The suppression in one single cortical network is not sufficient to cause suppression in the whole cortex network. To observe suppression of synchronization is necessary to apply external signal in several cortical networks. Besides, the results show that the success of synchronization suppression depends on time delay and signal intensity.
We thank UFVJM for partial financial support.

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P25 Response to damage and recovering capability in perturbed cultured neuronal networks.

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In the absence of adhesive proteins to fixate cells to a plating surface, neurons are given full freedom of movement and tend to form aggregates of neurons and glia, called clusters. Neuronal activity in clustered networks is obtained by means of calcium imaging techniques, which requires fluorescence microscopy. When applying a controlled perturbation to the network, changes in neuronal dynamics are expected, and the adaptive response of the network can be measured and analysed. Different types of perturbations may involve different responses in the system. Hence, we study both global attacks which gradually weaken structural connectivity, and targeted attacks directed to a single node of the network.
The latter demand high accuracy, therefore the use of precise instrumentation as a laser is essential. An infrared femtosecond laser, enabled for ablation to minimize collateral damage, is chosen to perform the nano-surgery in the neuronal culture. Our goal is to understand how these networks react towards a disturbance, and uncover the mechanisms of recovering, as well as the interplay between the structural and the effective connectivity. In such a way, the study of the resilience of neuronal networks is helping to develop models to quantify damage upon network degradation, with promising applications for the study of neuronal disorders in vitro.

Bioremediation techniques for carbamazepine elimination. P26

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We have isolated and identified a new microbial consortia to degrade pharmaceuticals and personal care products. In particular we have studied and modelled the degradation of carbamazepine by a microbial strain. We present the experimental method and procedure followed to obtain the data. in order to predict the outcome of future experiments we model the kinetics of the bacteria-drug reaccions. We propose a set of nonlinear ordinary differential equations which describes the bacteria-drug kinetics. We fit the model by optimizing the the Picard integral operator associated to the differential equations. The techniques presented here can be used in the study of other processes involving microorganism in bioreactors and sewage biodiscs in order to achieve the total elimination of water contaminants, such as naproxen, ibuprofen, etc, found in drinking water.

The Perron-Frobenius operator to calculate the reinjection probability density function in chaotic intermittency P27

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In several experiments the obtained data show intermittency. Therefore, to describe correctly the phenomenon it is necessary to evaluate the statistical properties of intermittency. Here, the Perron-Frobenius operator is applied to study the reinjection process in chaotic intermittency [1]. By mean of this operator, the theoretical expressions for the reinjection probability density function and the probability density of the laminar lengths for several maps can be obtained [2]. To validate the new expressions, the analytical functions are compared with numerical data. A high accuracy between theoretical equations and numerical simulations was found. Also, comparisons between the new expressions with those obtained using the M(x) function methodology are carried out [3, 4]. The results show that the RPD can acquire a richer and broader behavior than those given by the classical theory. Finally, the advantages and difficulties of both methodologies are described.

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P28 Fast propagation regions causespiral wave in an excitable medium

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Spiral waves represent a very famous example of spatio-temporal patterns in excitable media. These nonlinear distributed dynamical systems play important role in chemistry, biophysics and medicine. In the present talk we demonstrate that a self-sustained spiral wave can be easy created in a nonuniform excitable media where a wave break takes place due to sufficiently strong jumps in the propagation velocity. Our analytical and numerical results indicate that in a one-dimensional medium such an inhomogeneity can result in a unidirectional propagation block. It is also illustrated how this phenomenon can be used to create spiral wave in a two-dimensional medium with a specific size and geometry of the inhomogeneity. It is important to stress that following this way the spiral wave is created simply after a single excitation stimulus.

P29 Nonlinear Normal Modes in the Double and Triple Pendulum

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We apply the method of nonlinear normal modes to the double and triple pendulum, mechanical systems which exhibit complicated nonlinear behavior but are straightforward to realize experimentally. For carefully chosen values of the pendulum masses and lengths, the symmetric linear eigenmode generalizes to a similar nonlinear normal mode. Dissimilar NNMs, which are the more generic case and do not correspond to linear phenomena, are also presented. The triple pendulum serves as an example of how this work can be extended to higher dimensionality systems, such as chains and cables. Some connections with the control of chaotic oscillations in crane loads will also be discussed.

Direct observation of the onset of a spatio-temporal instability in storage ring synchrotron radiation sources P30

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Synchrotron radiation emitted by relativistic electron bunches, are used worldwide to produce light from Terahertz to hard-Xrays. In these source, a spatio-temporal instability is omni-present when electron bunch with high-charge density are used. This so-called micro-bunching instability is characterized by the spontaneous apparition of micro-structures in the bunch, more precisely in the 2-dimension longitudinal phase-space of the bunch. In storage rings, where the electron-bunches circulate in a pseudo-circular orbit, these micro-structures have often a deleterious effect (in particular they degrade the bunch properties), but they are also used to produce strong coherent synchrotron radiation in the THz range (at the micro-structure wavelength). However, until recently the evolution of the THz pulses, and the electron bunch dynamics were observed only by indirect means. Thanks to a special designed electro-optic system based on Electron-Optic-Sampling and on photonic time-strech [1], we manage to observe for the first time the onset of the instability [2]. As a remarkable fact, the spatio-temporal dynamics form some very regular patterns at the onset of the instability. These experimental observations can be in a large part reproduced by the numerical integration of the Vlasov-Fokker-Planck equation, which enables in addition to have access to the evolution of the 2d phase-space.

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P31 The acoustically forced, charged bubble in a liquid

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We present some results of theoretical studies [1, 2, 3, 4, 5] of a charged bubble undergoing radial oscillations in a liquid due to the application of a periodic, external forcing in the form of an ultrasonic acoustic wave. That bubbles in water are not neutral but actually carry a charge attributed to dissociated ions in the liquid has been known since the early decades of the twentieth century. We use a modified Rayleigh-Plesset equation for the bubble to incorporate the effects of charge, and assume that an adiabatic equation of state is obeyed by the gas within the bubble. The nonlinear oscillations of the bubble give rise to distinct oscillatory and chaotic regimes, and the electric charge crucially affects the dynamics. Bifurcation diagrams are obtained with charge, amplitude of the applied pressure and the driving frequency as control parameters. The presence of charge is seen to advance bifurcations. Charge and pressure thresholds are calculated for the system.The expansion-compression ratio $\zeta = (R_{max} - R_0)/(R_{min} - R_0)$ we have introduced enables us to predict, as a function of the pressure amplitude, the regime of instability for the oscillating bubble, lying between the Blake and upper transient pressure thresholds. Largest Lyapunov exponents for the charged bubble oscillator are calculated across a range of driving frequencies. The effect of bubble size is studied and the regime where violent implosion of the bubble cannot occur is obtained. We believe our results to have important, practical implications in medical diagnostics, especially in the context of defining mechanical indices for medical ultrasound and in engineering applications, both in large scale marine machinery and in microfluidic applications.

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Structural vs dynamical complexity in cultured neural networks P32

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In this line of research, we try to know if there is any relationship between the topological position a node occupies in a complex network and its dynamical state. Furthermore, it would be interesting to determine whether it is possible to infer a node's topological place from its individual dynamics. We work with the Morris-Lecar (M-L) model [1], which is a tool for modeling the electrical potential of a neuron's membrane. We will be comparing two types of networks (while maintaining the M-L model in each node): an artificial and an experimental one. We will see if we can distinguish any topological property of each network from individual dynamical measurements of its nodes.

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P33 Measuring coordination with ordinal patterns

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Any synchronization measure depending on Fourier analysis, such as Spectral Coherence and variations on it, demands the time series to be stationary and the correlation between spectra to be linear. Phase Indexes (i.e PLV or PLI), require, in addition to stationarity, that instantaneous phases of the signals follow a Von Mises distribution (the analogous of the Normal distribution in polar co- ordinates). Measures based on Information Theory entail large datasets, to estimate properly the underlying distribution of values, and the procedure to construct the bins from which to build distributions is not trivial [1]. Most dynamical systems, are strongly non-linear, nonstationary, and, in many cases, with short length time series [2]. Thus, synchronization analysis based on these procedures could potentially yield to misleading results [3]. Here we propose Ordinal Synchronization (OS) as a new measure of synchronization, based on the correlation of temporal ordinal patterns extracted from any pair of time series, in a natural development from Bandt and Pompe's method [4]. We test the performance of OS with datasets coming from unidirectionally coupled electronic Lorenz oscillators, coupled Rössler oscillators, and brain imaging datasets obtained with magnetoencephalographic (MEG) recordings. OS seems to provide a fast and robust-to noise tool to assess synchronization, without any implicit assumption about the distribution of data nor its dynamical properties. Nonetheless, as it ranges from $[-1, 1]$, it captures anti-synchronization, where two coupled nodes act synchronously in an inverse fashion, a plausible mechanism in the brain, neglected in many cases. To assess the validity of the measure, and to unveil which is the best length of the ordinal patterns extracted to quantify synchronization, two Lorenz oscillators were studied (in Master-Slave configuration), varying the strength of the coupling and perturbing the system with different noise signals in different conditions: equal noise in both oscillators, noise in the Master node, and noise in the Slave node. Comparisons with Spectral Coherence (SC), Mutual Information (MI), Phase Locking Value (PLV) and Pearson Correlation (Rho) will be provided, to assess the extent to which OS is related to all these classical measures of synchrony. We were especially concerned about the application of OS to the analysis of brain imaging and studied resting state MEG datasets, both at broad-band and filtered in the most common frequency bands: θ, α_1, α_2, β_1 and β_2. We will show that OS is in good accordance with other sync measures and it captures the increasing coupling strength between oscillators.

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Connector Links Support Functional Centrality Distribution in Brain Hemispheres P34

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In the last decade, Network Science has been shown to be a powerful tool to characterise brain organisation under different conditions, from cognitive processes, or motor tasks to the emergence and evolution of neurodegenerative diseases. The fact that brain networks are spatially embedded and each brain region has a precise spatial position results in useful information that it is not always accessible in other kind of real networks. In particular, the human brain consists of two large modules , which usually exhibit different but complementary functions. To better understand the role of the functional interactions between brain hemispheres, we adopted a network approach aimed to evaluate to what extent they engage a competitive behaviour in terms of centrality distribution or, conversely, wether they are close to a balance state. Specifically, we studied the brain as a system composed of two sub-networks, i.e. the left (L) and right (R) hemispheres, which may vie to maximise centrality of their nodes. Centrality C, i.e., the importance of the network nodes, was quantified by means of the eigenvector associated to the largest eigenvalue of the connection matrix, which is known as the eigenvector centrality. Resting state brain activity of 54 healthy adults was recorded by means of electroencephalography (EEG). Then, the imaginary coherence was used to construct the functional links between 48 cortical regions (24 in the left hemisphere and 24 in the right one) in the alpha (8-13 Hz) frequency band. We differentiated between intra-links (inside each hemisphere) and inter-links (between hemispheres) and analysed their distribution. Likewise, we quantified the centrality of the nodes inside each hemisphere and studied what rules constrain the distribution of centrality among the whole functional networks-of-networks (NoN). We then allowed both sub-networks to modulate their centrality through a pruning-link mechanisms. Finally, we investigated the robustness of functional NoNs when facing node failures and discovered how, depending on the number of inter-hemispherical links, the hemispherical robustness could be highly sensitive to failures, in contrast to other network metrics such as the clustering coefficient or the average shortest path. These results open the way to a new characterisation of the interactions between the two hemispheres that can be used to better understand organisational mechanisms in healthy and impaired brain networks.

P35 A pre-crisis vs crisis analysis of peripheral EU stock markets by means of wavelet transform and a nonlinear causality test

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This work presents an analysis of EU peripheral stock market indices and the S&P Europe 350 index (SPEURO), as a European benchmark market, over the pre-crisis (2004–2007) and crisis (2008–2011) periods. We computed a rolling-window wavelet correlation for the market returns and applied a non-linear Granger causality test to the wavelet decomposition coefficients of these stock market returns. Our results show that the correlation is stronger for the crisis than for the pre-crisis period. The stock market indices from Portugal, Italy and Spain were more interconnected among themselves during the crisis than with the SPEURO. The stock market from Portugal is the most sensitive and vulnerable PIIGS member, whereas the stock market from Greece tends to move away from the European benchmark market since the 2008 financial crisis till 2011. The non-linear causality test indicates that in the first three wavelet scales (intraweek, weekly and fortnightly) the number of uni-directional and bi-directional causalities is greater during the crisis than in the pre-crisis period, because of financial contagion. Furthermore, the causality analysis shows that the direction of the Granger cause–effect for the pre-crisis and crisis periods is not invariant in the considered time-scales, and that the causality directions among the studied stock markets do not seem to have a preferential direction. These results are relevant to better understand the behaviour of vulnerable stock markets, especially for investors and policymakers [1].

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Spatial correlations in nonequilibrium reaction-diffusion problems by the Gillespie algorithm P36

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We present [1] a theoretical and computational study of the two-spatial-points equal-time correlation function of concentration fluctuations in a one-dimensional reaction-diffusion system, comparing both equilibrium and out of equilibrium situations. As a representive example of equilibrium we choose a simple association-dissociation chemical reaction, while to obtain a non-equilibrium steady state we break detailed balance by adopting the WOH kinetics [2]. For the numerical simulations we have employed the Gillespie algorithm, dividing the 1D system into cells to treat diffusion as a chemical process between adjacent cells. We find that the spatial correlations are spatially short ranged in equilibrium, but become long ranged out of equilibrium. These computational results results are in good agreement with theoretical predictions from fluctuating hydrodynamics for a one-dimensional system and periodic boundary conditions. These simple results add to the growing evidence of generic long-ranged spatial fluctuations in non-equilibrium steady states.

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Classification of motor imagery in MEG recordings P37

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The understanding of the neurophysiological mechanisms responsible for performing motor imagery is essential for the development of Brain-Computer Interfaces (BCI). Our magnetoencephalographic (MEG) experiments with eight voluntary participants confirm the existence of at least two types of motor imagery: kinesthetic imagery (KI) and visual imagery (VI). While neurophysiological brain activity corresponding to KI is similar to real movement because it implies muscular sensation when performing an imaginary moving action, VI refers to the self-visualization of the corresponding action. KI is usually observed in specially trained subjects or professional sportsmen. These two types of motor imagery are distinguished by the activation or inhibition of different brain areas in Mu (Alpha and Beta) frequency regions. In particular, event-related synchronization analysis shows that VI activates Mu waves in the Occipital and Precuneus region, whereas KI inhibits Mu activity in motor-associated structures and the inferior parietal lobule.

P38 Multiple scales in complex friction-induced disk brake vibrations

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Brake system vibrations are of major concern for the automotive industry. The prominent example of high frequency vibrations in the audible range is caused by friction-induced instabilities and internal energy transfer to sound-radiating components such as the brake disk. The present work studies experimental vibration data gathered from accelerometers and laser vibrometer on a commercial disk brake system during dynamometer testing. High sampling rates are employed to allow for high temporal resolution. Qualitatively different system responses, i.e. Squealing and non-squealing configurations, are studied. Using Wavelet and Hilbert-Huang transforms for time scale separation the multiscale nature of brake squeal is shown. Different time scales are characterized by linear spectral methods, phase-space methods from nonlinear time series and recurrence plot analysis. Results indicate qualitatively different dynamics, i.e. Regular, chaotic and stochastic shares, at different time scales of the vibration signal. This work aims at better understanding of the excitation mechanisms and component interaction during operation.

Single-Point Multilayer Cluster P39

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For the purposes of this poster, a temporary event without context is considered as an event for which only its value and the time in which it occurred are available. As a difference to the field of time series, where the evolution of a value over time is studied, temporal events without context are a collection of observable events that should not necessarily have any relation between them. Examples might be payments made to a bank account if we only have the amount and day, or connections to a system if we only have information about the duration of the connection and when it was initiated. Identifying the payments on bank accounts in consecutive months of the electricity and gas bills, making a distinction between them, is a clear example of the problem that this poster addresses. First step: Determine the frequencies of occurrence of the events. In the case of bank account payments, we will have inputs and outputs that are repeated every week, month, quarter or year. For each of the identified occurrence frequencies, the following steps must be repeated from the second to the fourth. Second step: A multi-layer network is created where each frequency is one of the layers. For example, in a data set of one year we will have twelve monthly layers. Third Step: Single-point multilayer cluster. The layer with the least number of points is selected. For each point of this layer: 1) One point, and only one point, is selected from each of the other layers. 2) The selection of the single points of each layer should be the one that conforms to the cluster that minimizes the cohesion function. 3) The proposed way to measure it is the sum of the squares of each element to the centroid of the cluster. 4) One way to reduce the computational complexity of the model is to take as centroid the point of the layer with the least number of events. Fourth step: Collision elimination. In the creation of each of the clusters associated with each of the events of the layer with fewer events, there will be points that will belong to several clusters. But each point can only belong to one cluster. The Cluster Evaluation Function must be defined to determine in which cluster each event should remain, minimizing the total value of the cohesion function for all clusters. Fifth Step: Eliminate collisions between frequencies. Different events will have been part of different clusters in different layers: Interfrequency Collisions. The General Function of Cluster Valuation must be applied to determine in which cluster each event remains. The objective is to minimize the total value of the cohesion functions of all the clusters of all the frequencies of occurrence. At the end of the Correas-Moral Method we will have as many clusters as repetitive events have been identified and a collection of events that will not belong to any cluster. If this process were to become supervised, it would make it possible to find optimal values for the Valuation Functions.

P40 Extracting differential equations from measured vibro-acoustic impulse responses in cavity preparation of total hip arthroplasty

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Extracting features from experimental time series , especially for nonlinear systems, using nonlinear time series analysis (NTSA) has largely been neglected in the past. Brunton et al. [1] have shown that it is possible to extract a set of differential equations (DE) describing a steady-state using a phase space reconstruction of a scalar time series. Here, we apply this method for the first time to a clinically relevant problem in orthopedics, the prediction of the transients due to hammer blows during femoral cavity preparation in total hip arthroplasty. Results indicate that after an initial settling in period the coefficients remain constant describing a first order differential equation with strong coupling betweeen x- and y-direction; towards the end of impacting the first broach a change in the coefficients becomes visible, its meaning, however, remains yet unclear, which needs to be studied on the remaining five broaches.

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Coupling induced logical stochastic resonance P41

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It has been shown that a single bistable system, when driven by the sum of two external signals, can consistently work as a logic gate in a window of moderate noise [1]. This phenomenon, termed *Logical Stochastic Resonance*, has drawn wide-ranging research interest. Over the years it has been successfully realized in systems that include electronic circuits [2], synthetic genetic networks [3], optical systems [4] and nanomechanical devices [5]. Here we report our recent work [6], that goes beyond a single bistable system and demonstrate the following result: when we have two coupled bistable sub-systems, each driven separately by an external logic input signal, the coupled system yields outputs that can be mapped to specific logic gate operations in a robust manner, in an optimal window of noise. So, though the individual systems receive only one logic input each, due to the interplay of coupling, nonlinearity and noise, they cooperatively respond to give a logic output that is a function of both inputs. Thus the emergent collective response of the system, due to the inherent coupling, in the presence of a noise floor, maps consistently to that of logic outputs of the two inputs, a phenomenon we term *coupling induced Logical Stochastic Resonance*. Further, we show that the constant bias in this coupled system can act as a morphing control to robustly map to different logic truth tables, thus implementing a flexible logic gate. Lastly, we demonstrate our idea in proof of principle circuit experiments.

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P42 Forbidden and missing ordinal patterns in noisy chaotic time series

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For deterministic one-dimensional maps, Amigó et al. Have conclusively demonstrated that not all possible ordinal patterns can effectively materialize into orbits, which in a sense makes these patterns forbidden [3, 2]. On the other hand, for stochastic processes the probability of observing individual patterns depends not only on the time series length but also on the correlations' structure [3]. Then, the existence of a non-observed pattern does not qualify it as forbidden but only as missing. A similar observation also holds for the case of real data that always possess a stochastic component due to the omnipresence of observational noise. Thus, the existence of missing patterns could be either related to stochastic processes (correlated or uncorrelated) or to a deterministic nature. In this context, some open questions hold, how do forbidden/missing patterns behave in continuous systems, where the sampling time plays a crucial role? Which is the optimal sampling time to not over or under estimate the number of forbidden patterns? In order to answer these questions, we have initially analyzed the existence of forbidden/missing patterns from the well-known Mackey-Glass equation [4], operating in a high-dimensional chaotic regime contaminated with different amounts of observational noise. We found that in a noisy environment the number of forbidden patterns related to the ideal free noise chaotic dynamics goes to zero. We showed the decay of missing patterns as a function of the time series length for different samplings, i.e. Missing Patterns Spectrum, permits us to distinguish at what time scales the deterministic and stochastic features dominate the dynamics. On the other hand, we showed that the number of missing patterns as a function of the sampling time for a fixed length, reaches a maximum at a given time scale, which is a necessary condition for the presence of an intrinsic chaotic nature [**?**]. Based on experiments of a paradigmatic opto-electronic oscillator [6], we demonstrated our previous hypotheses. In addition, numerical simulations of our experiment support our results.

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Wave blocking and horizons in one-dimensional flows: theoretical and experimental aspects P43

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We consider the scattering of surface waves by an obstacle in one-dimensional shallow-water flows. We are mainly interested in the flow configurations involving horizons and exhibiting the so-called wave blocking behavior. The pertinent wave equation is written in the framework of Finsler geometry, where several properties of the scattering phenomena might be geometrically interpreted. Some predictions will be experimentally tested in a water channel specifically constructed for this purpose. Some technical details of the experimental apparatus are presented. Suggestions and ideas for future collaboration will be greatly appreciated!

P44 Characterizing transitions between locking regimes in an optical system under weak periodic forcing

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An autonomous oscillator can accommodate its intrinsic rhythm to an external weak periodic signal. The synchronization between the oscillator and the external input is known as entrainment and it is a universal phenomenon in nature. Recent attention has focused on the optimal conditions for entraining an oscillator to a weak external periodic signal. Here we use an experimental setup consisting of a semiconductor laser with optical feedback, as a testbed to study entrainment phenomena. The laser operates in the so-called low frequency fluctuations regime, in which the laser intensity displays apparently random spikes. [1]. The experimental control parameters are the amplitude of the weak signal, its frequency, and the control parameter of the laser (the dc value of the pump current, which controls the natural frequency of the spikes). Our goal is to experimentally identify and characterize the transitions between different locking regimes, when a weak periodic signal modulates the laser current. We investigate the transition between 1:1 locking (the frequency of the optical spikes is equal to the modulation frequency) and 2:1 locking (the spike frequency is half the modulation frequency), as well as higher order, noisier locking regimes. [2]. We use the ROC curves in order to characterize and quantify the effects of the control parameters on the entrainment performance as well as to identify the boundaries of the different locking regimes.

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The impact of a memristive device onto Chua's Circuit P45

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Chua's Circuit has attracted considerable interest during the last decades. A Chua Circuit consists of three energy-storing components, a locally active resistor and at least one nonlinear electronic device. The circuit exhibits a classical period-doubling route to chaos as well as a chaotic double-scroll attractor [1]. The Chua circuit can easily be built with standard electronic devices and allows likewise an appropriate mathematical description [2]. Here we present experimental results of a Chua circuit including an additional storage element in form of a memristive double barrier device. This quantum mechanical device consist of an Nb/Al/Al2O3/NbOx/Au layer sequence [3]. The devices are forming free and the I-V curves show an analog switching mechanism with a typical high resistance state (HRS) to low resistance state (LRS) ratio of about 100 (RHRS/RLRS) at 0.7 V. The dynamics of the system are characterized by chaotic oscillations interrupted by multiple qualitative changes in the system dynamics. These transient states are defined through damping and suppressing of the intrinsic chaotic oscillations. First experimental and numerical results will be presented and discussed.

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P46 Modeling Chemotatic Response and Interactions of Amoeboid Cells with a Phase Field Model.

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In general, individual cells respond first chemically and second mechanically (locomotion) moving in the direction of the food, enemy or target. For this, a cell needs the formation of an axis head/tail to define the direction of motion. The polarization is the needle of the compass needed for the cell to move. Without external signal the needle may randomly swing producing a random dynamics. However, under a chemical gradient the directional sensing of the cell produces a persistent motion in the direction of the gradient. We apply a phase field for the description of the interior (where the polarization processes takes place) and the exterior of the cells (where the biochemical species diffuse) to model the interaction of both environments at the membrane of the cell. We tune different parameters of the biochemcial reaction rates to compare the resulting dynamics of the computer model with experimental results of the motion of Dictyostelium discoideum in absence and presence of a linear chemical gradients of the chemo-attractant cAMP (cyclic adenosine monophosphate). Furthermore, we add to the model the contact interaction among cells under confinement and in absence of chemical gradient. Such interactions may play a role in some functions and development of multicellular organisms.

P47 Granular Convection of Horizontally Shaked Granular Layers

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Granular convection is a controversial topic due to the variety of mechanisms proposed to justify the experimental observations. To bring some light to this problem, we study a setup which shakes a single layer of spherical beads horizontally. We found that global collective movements can be induced if break the symmetry of the applied excitation signal. Nevertheless, advective transport can also be observed even if symmetric perturbations are used. Although the origin of both dynamics seems to be the same, the role of the boundary condition effects and the external forcing can be isolated.

Using order pattern recurrence plots to distinguish between chaos and noise P48

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The common features of the stochastic systems and chaotic systems (deterministic, low dimensional) hinder discrimination between the two distinct processes [1] especially for experimental, real-world signals. Order pattern recurrence plots (OPRP) [2], which visualise and quantify the recurrence pattern of the ordinal patterns is introduced to detect determinism from time series with the noise. We apply Bandt-Pompe methodology [3], which compares the relative value of the neighbours with d consecutive elements and symbolise the elements in the neighbours through d codes with $d!$ symbols, to encode the time series to the ordinal patterns. Then we analyse the recurrence of the ordinal patterns through the OPRP. Our numerical experiments examine the logistic map with and without noise when it exhibits periodic dynamics and chaotic dynamics, the henon map and fractional Brownian motion. Our results show that apart from the discrimination between chaos and noise, the OPRP is robust to the noise and can identify determinism from a noisy, chaotic time series by studying the number and the length of the diagonal lines which are longer but disrupted for chaotic system as known for conventional recurrence plot (RP) analysis. Through the transitive recurrence matrix in theOPRP we interpret the recurrence quantification analysis (RQA) of the OPRP. We find that an optimal dimension exists which preserves high levels of the properties of checkerboard texture in a chaotic times series with noise and which is unsusceptible to the interference of noise. A noise driven logistic map ($r_{t+1} = 3.91r_t(1 - r_t) + 2.5\eta_t$, where η_t is an iid uniform white noise), embedded with 6 dimensions, can retail enough periodic order patterns with infinitesimal noise patterns for the study of the chaotic dynamics.

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P49 Spatial patterns in the emergence of violent conflicts

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Human progress and development is often costly limited by persistent violence. Previous quantitative research has mainly focused on temporal [1, 2] and other statistical patterns in warfare [3] but relevant progress on characterization of its general spatial patterns is still lacking. While the importance of topology in geostrategical policies has long been acknowledged [4, 5], the role of spatial distributions and properties of cities and urbanization in determining a region's vulnerability to violent conflicts has largely gone unexplored. Using geographical data of cities and records of terror attacks in the past decade, we show that global patterns in conflict and peace are closely related to the relative position of cities in a global interaction network. We find that areas with betweenness centrality above a certain threshold are often the center of persistent conflict, while a high degree correlates with peace. In fact, betweenness accounts for over eighty percent of the variance in number of attacks. This metric is also a good predictor of the distance to a conflict zone and can estimate the risk of conflict. We conjecture that a high betweenness identifies areas with fuzzy cultural boundaries [6], whereas high degree cities are nested in areas where peace is more easily maintained. This is supported by a simple agent-based model in which cities influence their neighbors, which exhibits the same threshold behavior with betweenness observed in conflict data. These findings not only shed new light on the possible causes of violence, but can be used to estimate the risk associated with such actions as infrastructure development, the merging of cities or interventions in trade or migration patterns and therefore in informing more effective political decisions.

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Controlling genetic and dynamic instabilities in synthetic microbial populations P50

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One promise of synthetic biology is that it enables the rational engineering of microbial populations for industrial and medical applications [1]. Many of these applications require synthetic microbial organisms to carry out their engineered task and maintain functionality over extended periods of time once they have been deployed to their target environment. However, this long-term viability is threatened by several instabilities, two of which we investigate here in order to reduce or eliminate their impact. Firstly, programming cells with additional behavior by introducing artificial gene regulatory networks increases the demand for cellular resources and therefore likely reduces their growth rate. At the population level, this creates evolutionary pressure towards deactivation or impairment of the engineered function. We show that the impact of this severe genetic instability can be limited by periodic reductions in population size [2]. By suppressing beneficial mutations, undesired evolutionary adaptation is slowed down, extending the average lifetime of the desired function. We derive quantitative estimates for the suppression factor using two different analytical approximations to cover the full range of possible population dynamics and selective advantages. We find that the suppression factor depends non-trivially on the growth rate increase of the mutant, leading to the selective elimination of mutations with certain selective advantages. In addition to synthetic biology, these results can also be applied more broadly to correctly design and interpret experimental and directed evolution studies. A second, dynamic, instability occurs when multiple microbial strains are placed in the same finite environment to construct synthetic ecologies for more complex tasks: In the long run, the fastest-growing cell type will displace less competitive strains, disrupting any synergistic function. We theoretically explore gene regulatory networks which employ quorum sensing based on diffusible signaling molecules to autonomously limit population growth. We show that a range of different population dynamics from steady states to oscillations can be achieved, consistent with experimental observations in controlled microfluidic environments. Equipping two strains with orthogonal quorum-sensing systems, such synthetic population control can stabilize a co-culture of two strains, increasing robustness to differences in growth rates [3]. Depending on the individual parameters and cross-talk between the quorum-sensing systems, we find distinct multi-strain dynamics that could be useful for a variety of applications.

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P51 Relationship between vulnerabilities in heterogeneous information systems

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This poster analyzes the existing mathematical relationship between vulnerabilities in heterogeneous information systems and their possible application to risk analysis. All information systems contains vulnerabilities that make it susceptible to receive attacks, a correct identification of them and their potential impact allows to improve the defense strategies of the system. In a traditional way, vulnerabilities are studied differentiated in silos defined by the different types of systems, but an attacker is able to use the vulnerabilities of several different systems to make a successful attack. Through parenclitic networks, the aim is to identify the underlying relationships between different vulnerabilities and in this way create a risk network that allows identifying different levels of risk within a network of systems.

P52 A nonequilibrium-potential approach to competition in neural populations

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Energy landscapes are a useful aid for the understanding of dynamical systems, and a valuable tool for their analysis. Here we derive a global Lyapunov function for a broad class of rate models of neural networks, which provides an energy landscape without any symmetry constraint. This newly obtained "nonequilibrium potential" predicts with high accuracy the outcomes of the dynamics in the globally stable cases studied here. Common features of the models in this class are bistability - with implications for working memory and slow neural oscillations - and "population bursts" also relevant in neuroscience. Instead, limit cycles are not found. Their nonexistence can be proven by resorting to the Bendixson-Dulac theorem, at least when the NEP remains positive and in the (also generic) singular limit of these models. Our finding opens the door to the use of generic rate models in gradient descent methods, a widely employed technique in deep learning and artificial neural network training.

Manifold learning of ordinal pattern distributions for identification of individuality of human brain dynamics using EEG signals at rest P53

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Human beings show their own genetic and habitual traits in vitro such as the faces, the iris of eyes, the fingerprints, the voice, and the gaits. Not only their appearances, physiological signals in vivo also reflects individuality. In this study, we propose an approach to identify individuality that appears in human brain dynamics and visualize inter-individual variations in low-dimensional space. To this end, we first introduce a distance measure based on information geometry for quantifying the similarity between the ordinal pattern distributions of the 63-ch electroencephalography signals recorded from 100 volunteers while they close their eyes at rest. Then, we apply manifold learning, which is a general framework of nonlinear dimensionality reduction in unsupervised ways, to a set of the ordinal pattern distributions for visualizing the relationship between them in a low-dimensional space. In the analysis, we employ several state-of-the-art algorithms of manifold learning including ISOMAP (isometric feature map), LLE (locally linear embedding), and t-SNE (t-distributed stochastic neighbor embedding) as well as the conventional methods such as PCA (principal component analysis) for comparisons. We show that using t-SNE, the proposed approach successfully identify individuality in EEG signals as isolated “islands” of items in a 2D space. Not only individuality, the propose approach also arrange such islands with appropriate locations according to the similarities measured in the original ordinal pattern distributions. We also give a appropriate way to tune the parameter of the cost function for t-SNE.

P54 Inertial wave attractors in rotating and stratified systems

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Internal (inertial) waves in a uniformly stratified (rotating) fluid obey a highly specific dispersion relation that admits their propagation in form of oblique beams, which preserve their inclination to a particular direction (prescribed by gravity for internal waves and the angular velocity vector for the inertial waves) upon reflection. In confined domains with sloping walls, repeated reflections of the wave beams lead to concentration of the wave energy at closed loops called wave attractors. The dynamics of wave attractors is best studied in essentially two-dimensional problems (plane or axisymmetric), progressing from the ideal-fluid concept to more realistic ones, with consideration of viscous effects, energy balance and cascades of wave-wave interactions. Development of fully three-dimensional highly nonlinear regimes has not yet been explored. The present paper considers direct numerical simulations of inertial wave attractors in an axisymmetric rotating annulus having a trapezoidal cross section and a vertical axis of revolution. The rotating fluid volume is confined between two vertical co-axial cylinders, with truncated cone as a bottom surface. The large-scale forcing is applied to the fluid volume by specific motion of the upper lid. The spectral element method is used to solve the Navier-Stokes equations in rotating fluid, with the non-slip boundary conditions at all rigid walls, and a prescribed vertical velocity field at the upper lid. We consider two types of forcing. The first one simulates a small-amplitude nutation (Euler-disk-type motion) of the rigid lid, where the vector normal to the lid undergoes precession in such a way that the tip of the vector describes a horizontal circle of small radius around the axis of rotation of the annulus. This motion is modeled by prescribing the vertical velocity field with cosine-shaped running wave in azimuthal direction and linear variation in the radial direction. The response to such forcing mimics some essential features of tidal excitation. We show that attractors are formed only when the sense of nutation in azimuthal direction (in rotating coordinate system) is opposite to the sense of the background rotation (in a fixed laboratory system). In a horizontal cross-section of the flow we see then a rotating pattern with 'Yin-Yang' interplay in laminar mode, and when instability occurs with growth of the amplitude of external forcing, we see the interplay between the large- and small-scale "Yin-Yang" patterns. The second type of forcing is purely axisymmetric. At the upper lid we prescribe the vertical velocity profile in radial direction, with the amplitude in form of half-wave of the Bessel function, and simple harmonic time dependence. Such forcing excites a purely axisymmetric motion in linear regime. As the forcing increases, the axial symmetry of the inertial-wave motion is broken: in the horizontal cross-section we observe the development of fine-scale 'Mandala' patterns possessing rotational symmetry whose complexity grow with time. In both cases of forcing the triadic resonance is responsible for development of instability, and at sufficiently large forcing, we observe a transition to three-dimensional wave turbulence. We show thus for the first time that fully three-dimensional simulations are necessary to capture the essential features of nonlinear regimes in inertial wave attractors in a rotating fluid annulus.[1, 2, 3, 4, 5, 6]

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Evolution and controlling of the Plykin - newhouse attractor by the Pyragas method P55

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In the present contribution consideration is being given to an autonomous physical system which is characterized by the presence of the attractor of a hyperbolic type. We study the possibility of evolution the Plykin and Newhouse attractor [1] of this type by the Pyragas method [2]. The choice of the method of control. As such it is possible to use an external signal or the introduction of additional delayed feedback. (Both methods can be realized primarily during the schematic simulation then in a real experiment). It might also be interesting to think about the realization of a more complicated scheme of control of the type suggested in the work for the stabilization of unstable periodic orbits belonging to the attractor.

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Magnitude and phase of the perturbation effects on the Hamiltonian dynamical system P56

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The phase space of non-integrable Hamiltonian systems is neither completely regular nor completely chaotic. Both dynamical regimes are connected by a complicated system where regular and irregular movements may or may not mix, depending on freedom system number, as well as properties limiting surface itself. We will show each systems behavior via a numerical study which consists of an application of the perturbed pendulum model and see the perturbation parameter impact on the structure of phase space. The numerical solution of the equations, governing the dynamics, allow us to see the structure of perturbed pendulum phase space and detect the presence of regular behavior (stability island) and chaotic depending on the perturbation parameter. Comments and discussions of the results obtained allow us to see how clear the mixed system (chaotic evolution and stability islands). Keywords: Hamiltonian system; Perturbation; chaos.

P57 New tool for characterizing time series from non-modelled experimental systems based on histograms

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Characterizing the system with their Fourier Transform is extremely useful in Linear Time Invariant systems. Knowing their frequency response and its frequency spectrum helps to modelate and control systems as a black-boxes. This technique has been used in engineering process during last decades. However, Fourier Transform does not gives the same amount of information in high dimensional complex systems. For instance, characteristic times do not arise as easily than in LTI systems. Here we propose a method based on histograms that allows to find with are the resonance frequencies in a highly complex dynamical system, by analyzing a time series. Our simulations show how systems can be controlled, i.e. their dynamics are modified, by using a small input signal. This technique is remarkable to control experiments without prior modelling but with access to an output time series.

P58 Photon Bubble Turbulence in Cold Atomic Gases

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Turbulent radiation flow is ubiquitous in many physical systems where light-matter interaction becomes relevant. Photon bubble instabilities, in particular, have been identified as a possible source of turbulent radiation transport in many astrophysical objects, such as massive stars and black hole accretion disks. Here, we report on the experimental observation of a photon bubble instability in cold atomic gases, in the presence of multiple scattering of light. Two different regimes are identified, namely the growth and formation of quasi-stationary structures of depleted atom density and increased photon number, akin to photon bubbles in astrophysical objects, and the destabilization of these structures in a second regime of photon bubble turbulence. A two-fluid theory is developed to model the coupled atom-photon gas and describe both the saturation of the instability in the regime of quasi-stationary bubbles and the low frequency turbulent phase associated with the growth and collapse of photon bubbles inside the atomic sample. We also employ statistical dimensionality reduction techniques to describe the low-dimensional nature of the turbulent regime and discuss the reconstruction of the phase space trajectories, together with the possible existence of chaos and/or strange attractors governing the system dynamics.

Universality in the Resonant Facilitation of the Inter-Separatrix Transport Onset P59

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Many real systems may be approximated, at least qualitatively, by a one-dimensional Hamiltonian dynamics with two or more separatrices [1]. A time-periodic perturbation causes a chaotic *inter-separatrix transport* if the perturbation amplitude h exceeds a critical value h_{IST} which is a function of the perturbation frequency ω_f. The IST plays an important role in many processes. Thus, its onset marks a sharp decrease of an amount of matter transported along a meandering jet, e.g. the Gulf Stream [2, 3, 4] or the high atmosphere jet stream [5], - the IST in these cases is often called the *cross-jet transport*. The IST onset may play a crucial role in a collapse of a magnetic confinement of plasma [6]. If the inter-separatrix energy range is narrow, the IST onset is strongly facilitated as ω_f approaches a local maximum $\omega_{\max}$ of frequency of eigenoscillation ω as function of energy E between the separatrices or its multiples $n\omega_{\max}$ [7, 8]. The facilitation is due to a resonant transport threading almost the whole inter-separatrix range and thus connecting chaotic layers replacing the separatrices. This resonant transport is so strong because, as $\Delta E \to 0$, the function $\omega(E)$ asymptotically approaches a rectangular form i.e. $\mathrm{d}\omega/\mathrm{d}E \approx 0$ almost everywhere. The explicit asymptotic theory for the minima of $h_{IST}(\omega_f)$ in the model of a classical 2D electron gas in a magnetic superlattice perturbed by the alternating magnetic or electric force [9, 7, 8] was developed in [10]. It was found that, in the leading-order approximation, the shape of $h_{IST}(\omega_f)$ near the minimum can be scaled so that the result is independent of any parameter. However it was not clear whether this universality is valid only for the considered model or generally. The present work resolves this problem in a very general form. The results are of big fundamental and practical importance. The latter means that our explicit formulas allow us to immediately predict $h_{IST}(\omega_f)$ with a reasonable accuracy practically for any relevant system while computer simulations, conventionally used for this, last a few days for each set of parameters. A comparison of our explicit results with the simulations for the kinematic model of a meandering flow with the perturbed amplitude of the travelling wave [2, 3] demonstrate a good agreement.

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Session 8: Systems Biology

Bacterial electrophysiology: Dynamics and functional implications

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Ion channels are fundamental components of cells that regulate the potential difference across the cellular membrane, which is in turn crucial for energy production, signaling, and communication with other cells. While the roles of ion channels in neurons and other excitable cells in animals has been known and studied for decades, their function in simpler cells such as bacteria has remained elusive so far. In this talk I will overview our recent work showing membrane potential dynamics and electrical signaling in bacterial biofilms, and discuss their role in ensuring the notorious resilience of these cellular populations to external attacks and stress. I'll show that this resilience relies on a careful spatiotemporal regulation of the metabolic activity of the bacterial cells forming the biofilm, orchestrated by electrical signaling.

Nonlinear Time Series of Live Diffraction Signals in C. elegans

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Microorganisms locomotion is presently understood by taking a video of a moving microorganism under a microscope, then performing video analysis on the collected data. This method is time-consuming, computationally heavy and omits subtle components of the motion. Time dependent diffraction signals are a complimentary method that speeds up aspects of the data collection and analysis. It maintains an accurate worm structure and reduces user error. Caenorhabditis elegans nematodes, or C. Elegans, were used to generate motion data. These nematodes are a model organism with a simple, bilaterally symmetrical structure that makes them ideal for the analysis of microscopic locomotion. A mutant "Roller" OH5747 with a restricted range of motion was selected for further simplification, as its oscillating motion tends to be confined to one side. A spectral analysis of diffraction patterns generated by directing laser light at C. Elegans in a cuvette has been conducted. A nonlinear time series analysis of nematode diffraction data is presented for mutant and non-mutant (wild type) C. Elegans. The Largest Lyapunov Exponents of roller and wild type C. Elegans are found to be 1.56 ± 0.64 and 0.91 ± 0.42 (base e) respectively, which indicates that motion of these nematodes is chaotic.

The influence of network topologies in drug treatment

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An accurate prediction of the outcome of a given drug treatment requires quantitative values for all parameters and concentrations involved as well as a detailed characterization of the network of interactions where the target molecule is embedded. We present a high- throughput in silico screening of all potential networks of three interacting nodes to study the effect of the initial conditions of the network in the efficiency of drug inhibition. Our study shows that most network topologies can induce multiple dose-response curves, where the treatment has an enhanced, reduced or even no effect depending on the initial conditions. The type of dual response observed depends on how the potential bistable regimes interplay with the inhibition of one of the nodes inside a nonlinear pathway architecture. We propose that this dependence of the strength of the drug on the initial state of activation of the pathway may be affecting the outcome and the reproducibility of drug studies and clinical trials.

Modelling of supramolecular redox-mediated oscillations

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In natural systems, supramolecular oscillators have been observed, for example, in the polymerization of actin filaments and microtubules. Here, we present experiments and modelling of a supramolecular pathway based on a perylenediimide derivative in aqueous solution. In this polymerization system, we observe autocatalytic growth and redox-mediated oscillations using UV-vis and fluorescence spectroscopy, complemented by dynamic / static light scattering and colorimetric measurements. Modelling is based on a moment-equation approach for the number and mass of polymers, as well as a redox-couple of monomers. We discuss different temporal and spatiotemporal patterns.

Optimizing intermittent hormonotherapy after a prostatectomy by using individualized model

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The prostate adenocarcinoma is the most frequent cancer affecting the eponym walnut-size gland in the male reproductive system. The tumor is graded according to the Gleason score based on a biopsy. For score less than 6, the tumor is not considered as a cancer. For a score equal to 6, the cancer has a very slow progression. Contrary to this, the prognostic is "dark" when the score is equal to 10, meaning that tumor cells are spreading very quickly. Prostate adenocarcinoma has at least two specificities. I) It is hormone-dependent and, consequently, hormonotherapy is a possible treatment. Ii) The rate of PSA is a rather reliable marker of the evolution of the cancer. Since few years, hormonotherapy started to be provided by intermittences, to reduce cardio-vascular risks, delay the occurrence of hormone independent tumor cells and, as a result, increase the survival rate as well as the quality of life by reducing side effects. Today, durations of on- and off-treatment periods are still chosen in a rather random way; such an approach most likely explain why there is no clear benefit from the survival point of view when patients receive an intermittent treatment rather than continuous one. Consequently physicians clearly need helps to optimize these parameters for each of their patients. In order to do that, we started by developing a model for describing the interplay between the tumor micro-environment (host cells), hormone dependent and hormone independent tumor cells, and the rate of prostate specific androgens. The rate of PSA - the single variable easily measured in patients - is directly correlated to the number of tumor cells. Model parameters were identified using a genetic algorithm applied to PSA time series for a few patients, who initially received prostatectomy, and then treated by intermittent hormonotherapy (LHRH analogue and anti-androgen). It is thus shown that our model can accurately reproduce the collected PSA time series by free runs over few years. Model parameter values allow distinguishing different types of patient (age and Gleason score). It was possible to show that the microenvironment plays a significant role in the evolution of the cancer. We then showed that the long-term evolution of the cancer was affected by durations of on- and off-treatment periods.

Session 9: Cardiac and Wave Dynamics

Electromechanical Vortex Filaments During Cardiac Fibrillation

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Self-organized dynamics of vortex-like rotating waves or scroll waves underlie complex spatial-temporal pattern formation in many excitable chemical and biological systems. In the heart, filament-like phase singularities associated with three-dimensional scroll waves are considered to be the organizing centers of life-threatening cardiac arrhythmias. The mechanisms underlying the onset, perpetuation, and control of electromechanical turbulence in the heart are inherently three-dimensional phenomena. However, the visualization of three-dimensional spatial-temporal dynamics of scroll waves inside cardiac tissue has thus far evaded experimental realization. We show that three-dimensional mechanical scroll waves and filament-like phase singularities can be observed deep inside contracting cardiac tissue using high-resolution 4D ultrasound-based strain imaging. We found that mechanical phase singularities co-exist with electrical phase singularities during cardiac fibrillation. We investigated the dynamics of electrical and mechanical phase singularities using a novel, simultaneous tri-modal measurement of membrane potential, intracellular calcium, and mechanical contraction of the heart. Our results demonstrate that cardiac fibrillation can be characterized through the three-dimensional spatial-temporal dynamics of mechanical phase singularities, which arise inside the fibrillating contracting ventricular wall. We demonstrate that electrical and mechanical phase singularities show complex interaction and we characterize their dynamics in terms of trajectories, topological charge, and lifetime. We anticipate that our findings provide novel perspectives for non-invasive diagnostic imaging and therapeutic applications.

Not all heartbreak is the same

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Much research has been devoted to investigating the initiation of cardiac arrhythmias by alternans, a period doubling bifurcation in the duration of cardiac action potentials which is strongly correlated with the onset of sudden cardiac death. Alternans results from a cellular level instability in the bidirectionally coupled voltage and calcium dynamics. Although the formation and maintenance of alternans has been studied extensively in animal models such as rabbit, rat, and zebrafish, surprisingly little attention has been given to the discrepancies observed across species. Even when the hearts of two species are anatomically similar, the electrophysiology can behave quite differently. In this talk I will present high spatiotemporal resolution experimental data from optically mapped fluorescent recordings of simultaneous transmembrane voltage and intracellular calcium transients from the surfaces of Langendorff-perfused whole hearts of a variety of species including rabbit, porcine, canine, cat, rat, zebrafish, alligator, and snake, and we will discuss the variety of alternans observed in these species and the different driving mechanisms behind them.

Quantification of spatiotemporal complexity during ventricular fibrillation

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During ventricular fibrillation, a life-threatening uncoordinated contraction of the heart muscle, the spatiotemporal dynamics on the heart undergo complexity fluctuations. Understanding these short-term fluctuations could play an important role for understanding the mechanisms behind this lethal arrhythmia and lead to advances in their treatment. Many previous approaches concentrate on the identification and tracking of phase singularities which characterize the spiral wave dynamics on the heart. In this contribution we concentrate on permutation entropies which provide a robust and efficient method for quantifying complexity of time series. We demonstrate how a spatio-temporal adaptation of PE can be used to characterize complexity fluctuations in simulated excitable media and in data from optical mapping experiments. Furthermore, it is shown that spatiotemporal order patterns can be used to quantify complexity information at different spatial scales. By comparing this method to phase singularity analysis we highlight that spatiotemporal PE has a low susceptibility to noise and a high computational efficiency while providing a useful quantification of the underlying spatiotemporal patterns.

Modeling reentry formation due to diffuse fibrosis in cardiac tissue: Effects of topological quantities

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Ischemia and fibrosis are known to promote the formation of many types of cardiac arrhythmia. The formation of ectopic beat in the heart may vary substantially, however it is frequently co-located to near border-zone of infarct areas, regions of micro-fibrosis or heterogeneous tissues, around the pulmonary vein. The propagation of the electrical stimulus changes from the sustained broad wave which regularly propagates to a more breakable noisy propagation, where the electrical wave follows the zig-zag dynamics in the maze of non-conducting fibrotic tissue. We consider a discrete model of cardiac tissue where disconnections a randomly included among cells to model the growing of fibrotic tissue in case of local diffuse fibrosis. Then, Monte Carlo simulations are performed to identify for which levels of fibrosis and ischemia the infarct region has high probabilities to behave as an ectopic focus. We observe that ectopic beats are generated for a range of the percentage of fibrosis that is near a topological metric known as percolation threshold [1]. We employ the discrete heterogeneous model to study separately spatio-temporal chaos formation in atria and in ventricle. First we consider the results of a simple model of atria tissue to compare experimentally observed complex fractional atrial electrograms (CFAE) in this tissue with the electrocardiograms obtained from the numerical simulation. The good agreement between both electrocardiaograms indicates that reentry and ectopic activity are triggered by micro-fibrotic regions [2]. Second, we consider patient-specific geometrical models of the heart as well as of the infarct and peri-infarct zone regions were obtained from MRI images from a patient. Electrophysiology is modeled with a well established cardiac myocyte model of human ventricle [3]. The minimal size of the three-dimensional slabs which can sustain reentries, is evaluated under different conditions and initial perturbation protocols [4]. In both cases the the discrete topology of the tissue and the proximity of the fraction of fibrosis seems to be a crucial quantity to induce the formation of reentries in the tissue and the appearance of different types of arrhythmias.

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Traveling fronts and stationary patterns in complex bistable networks: Theory and applications to chemical reactions

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Self-organization processes in complex networks is an interdisciplinary research field with great theoretical interest and many potential applications in chemistry and biology. Stationary localized patterns constitute a classical example of self-organization; they can spontaneously be generated by the Turing mechanism, as it was reported in both continuous and networked media. However, an alternative mechanism for the emergence of stationary patterns in networks has been recently discovered [1, 2, 3]. We have experimentally demonstrated and theoretically anlyzed that bistable networks can support a rich variety of stationary patterns determined both by the network architecture and initial conditions [1, 2, 3]. Although our experimental system is actually more complex than the simplifying assumptions under which the theory was constructed, the results show a surprisingly good agreement. This indicates that the found pattern formation mechanism is robust and generic. In this talk I will present theoretical and experimental studies with chemical bistable reactions coupled in such a way thus forming tree [1, 2] or star [3] networks. Negative feedback control of such patterns will also be discussed [4]. Our results are also relevant for large random networks. At the end of the talk, I will discuss experiments with linear chains of sequentially sized bistable elements. It was found that this simplified experimental setup reproduces exactly the same dynamic behavior observed in the more complex structures of tree or star networks.

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Hemodynamics guided microparticles for drug delivery in atherosclerosis lesions

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Intravascular drug delivery at target lesions is a commitment of precision medicine. The biochemical approaches have not found yet a convincing response for atherosclerosis. Sites for atherosclerotic lesions and intravascular deposition of particles seem to be dependent on the blood flow wall shear stress. Inadequate bloodstream flow due to lesions or the presence of flow-distorting particles is at the origin of vascular disease. New strategies based on flow characteristics of blood flow-guided drug carriers are demanded to overcome these problems. A smart design is required for tiny drug carriers to favor clinging to the plaque and clearing the path for bigger blood cells to flow easier, so reducing inflammation in the vicinity and improving the effectiveness without increasing the toxicity. Particle size, shape, core-shell structure and stiffness play important roles in influencing particle behavior in blood flow in terms of cell-particle, vessel-particleinteractions, transport and lateral margination. Deeper understanding of these effects on designing new particles for drug delivery on intravascular targetable lesions is the main objective of this talk. Numerical experiments using CFD models and experiments in microfluidic platforms covered by endothelial cells mimicking vessel's spatial conformation have been performed to validate the predicted behavior of particles.

Session 11: Brain and Neuronal Dynamics

From cerebral cortex complexity to consciousness

María Sánchez-Vives

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It has been proposed that the distributed neural process underlying conscious experience must be functionally integrated and at the same time highly differentiated . And indeed, the evaluation of cortical complexity reveals that during wakefulness and REM sleep, the brain engages in complex patterns of activity, whereas during NREM sleep and anesthesia, situations in which consciousness is lost, the brain activity breaks down in causally independent modules, generating low complexity patterns of activity. Different metrics have been devised to gauge brain complexity based on the analysis of spontaneous activity in terms of entropy and mutual information, causal density, or through the integration of neuroimaging data in graph theoretical models. Recently, these metrics have been complemented by a measure of brain complexity in humans that is based on direct cortical perturbations, such as the perturbational complexity index. Most of these measures have been explored in human brains, however, in order to bridge with a mechanistic understanding of cortical dynamics, we need to adapt this measures to simple, more accessible brain models. In this presentation we will discuss experimental findings that link cortical dynamics in different brain states with measures of complexity, some of its mechanistics underpinnings and potential modulation.

Dynamics of a Brain: Oscillations and Synchronization in a Cultured Neuronal Network

Elisha Moses

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Hippocampal neurons grown on a dish are sufficiently complex to perform rudimentary computations, yet remain simple enough that we can completely unravel their behavior in terms of a statistical physics approach. We present a unified picture in which individual oscillator neurons link up to form a complex oscillatory neuronal network whose timescales can be understood in terms of ionic leakage currents. Connecting several separate networks that are comprised of different types of neurons such as excitatory, inhibitory, central nervous our peripheral sensory neurons allows for internal communication to develop within the network, and leads to the observation of novel dynamical states.

Connectivity and Dynamics in Neuronal Cultures: Experiments, Simulations, and Medical Applications

Jordi Soriano

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Neuronal cultures offer a unique platform to study collective phenomena in neuronal networks. The ability of experimentalists to modify the connectivity among neurons and their dynamics offer a unique scenario to investigate key open questions in neuroscience, including the emergence of spontaneous activity patterns, the importance of spatial embedding, network connectivity, and the resilience of the networks to damage. Here I will present different experiments and theoretic-numerical resources to shed light on these questions. In particular, I will pinpoint the potential of effective connectivity inference to characterize the behavior of neuronal networks affected by Sanfilippo, Alzheimer's and other diseases.

What does the complexity of the cerebral cortex network tell us about brain states?

Alessandra Camassa[1], *Miguel Dasilva*[2], *Lorena Pérez-Méndez*[3] *and Maria V Sánchez-Vives*[4]

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Brain's complexity is high during awake conscious behavior while it collapses during deep sleep in the unconscious bistable dynamical regime of slow oscillation (SO) [1]. Sos emerge from the cortical network both in vivo and in vitro and they have been suggested to represent the default mode of operation of the cerebral cortex [2]. The sleep-like bistable dynamic state of Sos (<1Hz) that propagate across the network as slow waves can be also recorded in vivo in anesthetized animals (Ruiz-Mejias et al., Journal of neurophysiology, 2011) and it is possible to vary the brain state by varying the anesthesia level. In this study we varied the anesthesia levels without getting out of the bistable regime, such that the emergent oscillatory activity varied from low (0.12 Hz) to high (1.15 Hz) frequency for higher to lower anesthesia levels respectively. Our questions was: does the complexity of the network, and thus the operating mode of the network, vary in a detectable way for different anesthesia levels? To evaluate the complexity of the cortical network, we used a superficial 32-channels electrodes array placed on the surface of the brain of eight mice anesthetized at three different levels. We recorded both the unperturbed, spontaneous activity and the evoked response, by means of electrical stimulation. The evaluation of the complexity of spontaneous activity was carried out by analyzing the slow waves propagation patterns that are related to the underlying spatiotemporal organization of the cortex [3]. Propagating slow waves in each state were reconstructed from the population firing rate of each recording channel. A principal component analysis (PCA) was performed and used to discriminate different propagation modes and to calculate the entropy accounting for their regularity/complexity [4]. The perturbational complexity was calculated by means of an adapted version of the Perturbational Complexity Index (PCI) introduced by Casali et. Al., Science Translational Medicine, 2013. The PCI here was calculated based on the population firing rate obtained after perturbing the cortex with electrical stimuli, as a measure of the compressibility of the evoked response in space and time by means of a Lempel Ziv algorithm. We found that the complexity of both the spontaneous and perturbed activity varies inversely with the anesthesia levels: it is highest for the lowest anesthesia levels and viceversa. A statistical comparison revealed that the PCI was able to differentiate significantly the lightest anesthesia level from the other two, while the entropy differentiated significantly all the three levels. In the cortical network bistable regime, these are two complementary complexity measurements, one accounting for causal interactions and the other for spontaneous activity, that are able to capture subtle variations of brain states and they can be used to further characterize the cortical activity patterns of physiological and pathological models.

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Complexity in Brain Structure and Functions

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Many intricate aspects of nature are now well understood from the mathematical perspective of the theory of non-equilibrium phase transitions and critical phenomena. It does not therefore came as a surprise that recent studies try to deep on the structure and high-level functions of the brain -where experiments have revealed that complexity may be a main ingredient-by using analogies according to those strategy and ideas and perhaps also involving the concept of chaos. This talk will illustrate and ground this situation [1, 2, 3].

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Session 12: Science of Cities and Human Mobility

Scaling in cities

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Scaling has been proposed as a powerful tool to analyze the properties of complex systems, and in particular for cities where it describes how various properties change with population. The empirical study of scaling on a wide range of urban datasets displays apparent nonlinear behaviors whose statistical validity were recently the focus of many debates that I will present here. I will also discuss a more recent aspect which is the implication of such scaling forms on individual cities and how they can be used for predicting the behavior of a city when its population changes. I will illustrate this on the case of delay due to traffic congestion in US cities. I will show that the congestion induced delay in a given city does not depend on its population only, but also on its previous history. This strong path-dependency prohibits the existence of a simple scaling form valid for all cities and shows that we cannot always agglomerate the data for many different systems. More generally, these results also challenge the use of transversal data for understanding longitudinal series for cities.

Synchronization in populations of moving oscillators

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Here we will show results obtained in our group concerning synchronization of populations of moving oscillators. On the one hand, populations of identical Kuramoto oscillators that move randomly on a plane, without considering excluded volume effects, enables to obtain analytical results for the time needed to synchronize [1]; later on, we hace extended this framework to locally interacting self-propelled particles for which synchronization generically proceeds through coarsening verifying the dynamic scaling hypothesis, with the same scaling laws as the the 2d XY model following a quench [2]. Our results shed light into the generic nature of synchronization in time- dependent networks, providing an efficient way to understand more specific situations involving interacting mobile agents. Alternatively, we have also investigated synchronization in populations of integrate and fire oscillators, showing that under restrictive conditions of connectivity, the time needed for the population to synchronize is not a monotonous function of velocity [3, 4].

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Quantifying the Inherent Chaos of Human Movement Variability

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Movement variability is defined as the variations that occur in motor performance across multiple repetitions of a task and such behaviour is an inherent feature within and between each persons' movement [1]. In the previous three decades, research on measurement and understanding of movement variability with methodologies of nonlinear dynamics has been well established in areas such as biomechanics, sport science, psychology, cognitive science, neuroscience and robotics [2, 3]. To quantify movement variability, we therefore consider a methodology from nonlinear dynamics called uniform reconstructed state space where essentially dynamics of an unknown system can be reconstructed using one dimensional time series. As pointed out by Bradley et al. [4] uniform reconstructed state space, if done right, can guarantee to be topologically identical to the true dynamics and determine dynamics invariants such as fractal dimension, Kolmogorov-Sinai entropy or Lyaponov exponents. These algorithms, however, require time series measured with costly sensors that provide well sampled data with little noise. Such requirement is generally a common problem when doing precise characterisation of time series using dynamic invariants, to which Bradley et al. [4] proposed additional tools of nonlinear time series analysis for practitioners such as surrogate data, permutation entropy, recurrence plots and network characteristics for time series. For this study, we are interested in the use of uniform reconstructed state space and the analysis of recurrence plots so as to understand the quantification of movement variability. Particularly, we are interested in the analysis of data collected through cheap wearable inertial sensors and its effects on the reconstructed state space and the recurrence plots for different lengths and preprocessing techniques of the time series. So, here we show the characterisation of human movement variability in the context of human-humanoid imitation activities. Specifically, we explore the reconstruction of state spaces and its recurrence plots for 20 participants performing repetitions of simple vertical and horizontal arm movements in normal and faster velocity. We also explore the differences between wearable inertial sensors attached to the person and to the humanoid robot and between different axes of inertial sensors. With that in mind, our contribution to knowledge is in regard to the reliability of data from cheap wearable inertial sensors to analyse human movement variability in the context of human-humanoid imitation activities using methodologies of nonlinear dynamics. Such understanding and measurement of movement variability using cheap wearable inertial sensors lead us to have a more intuitive selection of parameters to reconstruct the state spaces and to create meaningful interpretations of the recurrence plots. Additionally, having a better understanding of nonlinear dynamics tools with the use of cheap inertial sensors can enhance the development of better diagnostic tools for various pathologies which can be applied in areas of rehabilitation, entertainment or sport science [1].

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Modeling language competition: social networks and Turing structures

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Self-organization is a ubiquitous phenomenon in Nature and it is the expression of the intrinsic complexity of its internal dynamics. Examples range from the skin of some animals or simple bacteria till the more sophisticated dynamics of ecosystems. Among these, maybe the human relationships are one of the most intriguing cases to consider. Several authors have devoted interest to mathematically understand some aspects. In particular, linguistics has benefited from that research and some models have been proposed describing the interrelationships between competing languages. Within this context we present our contribution. We aim to include concepts such as Turing structures and the effect of networks into consideration. Our analysis demonstrate that the coexistence of two competing languages can be enhanced by means of the network in opposition to the general believe. The relevant parameters of the model will be analyzed and some application to a real experimental case will be presented. Our results might be general beyond language drift phenomena and apply to the dynamics of arbitrary competing options in a social network. [1, 2]

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Epidemic detriment driven by recurrent human mobility patterns

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During the last decade, the globalisation of different autoctonus diseases such as Ebola or Zika have encouraged the scientific community to study the spread of epidemic using metapopulations. A metapopulation is a network whose nodes are places where agents live and diffuse according to the network connections. Although there are several models [1, 2, 3] which make use of metapopulations, they usually rely on strong assumptions, such as the statistical equivalence of all the patches with the same degree, which limit their validity with respect to numerical simulations and also their application to real systems. To improve the former models, here we propose a novel framework, the MIR model[4]. First, we make use of the MMCA approach [5] adapted to the case of metapopulation to leave the statistical equivalence of the agents. Besides, each agent has a residence and each time step involves three different stages: movement to one of her residence neighbours driven by the metapopulation links, update of her dynamical state after interacting with all the agents inside her new temporal node according to SIS model inside there and return to her residence.In this talk, we will analyse the spread of SIS diseases over a real metapopulation like the city of Cali. We will show the excellent agreement between the MIR model predictions and results from numerical simulations and, interestingly, we will reveal a counter-intuitive result: the mobility has a detrimental effect on the spread of the diseases. To support this statement with our equations, we will deduce analytically an expression for the epidemic threshold which is able to capture very precisely the previous behaviour. Finally, to get more insight on this detriment, we will extend a perturbation theory [6] to the case of metapopulations, unveiling the existence of three regimes: epidemic enhancement, epidemic detriment or a mixture between them with the mobility. To explain all of them, we address the simple case of a star-like network where the emergence of the three different regimes will be justified heuristically from the demography of the metapopulations as well as their topology.

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Session 13: Geophysics

Tropical teleconnections and model biases in the Community Earth System Model using network tools

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Global climate change represents one of the greatest challenges facing society and ecosystems today. It impacts key aspects of everyday life and disrupts ecosystem integrity and function. The exponential growth of climate data combined with Knowledge-Discovery through Data-mining promises an unparalleled level of understanding of how the climate system responds to anthropogenic forcing. The focus of this talk is on a particular method, δ-MAPS, stemming from complex network analysis. This is a recent developed methodology for climate fields analysis capable of inferring the high-level abstract linkages across components of the climate system and quantifying differences across datasets. It provides a reduced form model that can be continuously informed from data updates and that can aid in investigating and addressing climate model biases. δ-MAPS identifies the spatially contiguous components of the climate system that contribute in a homogenous way to its dynamics, and then infers their connections accounting for autocorrelations. Once the domains are identified, δ-MAPS further infers a functional network between them by examining the statistical significance of each lagged cross-correlation between any two domains, calculating a range of potential lag values for each edge, and assigning a weight. While a temporally ordered correlation does not imply causation, it provides information on the plausible directionality of interactions. Finally, a 'strength' is assigned to each domain, quantifying the domain influence on the climate system. Here δ-MAPS is applied to unveil the network structure of sea surface temperature and ice cloud fraction in reanalyses products and in 30 members of the Community Earth System Model (CESM) Large Ensemble. The analysis spans 35 years, from 1980 to 2015, during which we have satellite data. The "observed" climate network is then used to evaluate 30 members of the Community Earth System Model (CESM) Large Ensemble over the same time period. Three metrics, one recently developed by the authors, and two adopted from the network analysis literature, aid the comparison, allowing to quantify similarities and differences across all SST networks and the internal variability of the CESM ensemble. The focus is on connections between domains in the tropics, where the major climate mode of interannual variability, ENSO (the El Nino Southern Oscillation) takes place, and on the relation between ENSO and the South Tropical Atlantic, a key region in the development of hurricanes.

Complex networks and climate dynamics: from regional to global teleconnections

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In this talk, it will be shown how the theory of complex networks can be used as an efficient tool for data analysis in climate dynamics. Specifically, complex networks will be applied to analyze the spatial structure of co-variability between climatic observables at potentially remote locations. Possible choices of variables include temperature, pressure, wind, or rainfall. After an introduction to the mathematical preliminaries, I first review some of the most successful applications of such climate networks. Thereafter, I will focus on synchronization patterns of extreme rainfall. At regional scales, it will be shown how network approaches can be used for analyzing and classifying atmpospheric dynamics relevent to extreme event occurences, and how the performance of climate models can be evaluated along these lines. Furthermore, it will be shown how directed and weighted networks can be employed for statstical prediction of extreme rainfall events and associated flash floods. I will then demonstrate how global-scale teleconnections of extreme events in the climate system can be inferred on the basis of networks. These teleconnections, which are associated with planetary-scale atmospheric Rossby waves, can be clearly identified from a scale-break in the distance distribution of significant network links. In particular in the global context, it becomes apparent that the phenomenon of multiple comparisons generally imposes serious problems for data-driven interdependency analyses in the climate sciences. Possible biases caused be the resulting, spurious relationships are finally discussed, and techniques to correct for them will be proposed.

Information dynamics of the paleoclimate

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The Earth's climate system is a nonstationary complex system with intricate spatiotemporal dynamics and complicated external forcing. One promising way to explore the dynamics of this system is to study the detailed histories that are laid down in ice cores. From the water isotope records in these cores, for instance, it is possible to reconstruct climatological factors like temperature and accumulation rates dating back to the last glacial period, and beyond. For our initial study we used the two highest-resolution records available, one from Northern Greenland and one from West Antarctica (WAIS). The NGRIP core, drilled in 1999-2003, covers 128,000 years at 5cm resolution. The WAIS core, completed in the past few years, covers a shorter timespan (68,000 years), but at 0.5cm sampling. From these data, we would like to answer questions like: Do these records contain any information about the climate system? If so, what information can we reliably extract? Are there different regimes in these data? Do extreme events like super volcanic eruptions or abrupt temperature transitions (e.g., Dansgaard-Oerschger events), have detectable signatures? As a first pass at answering these questions, we used weighted permutation entropy (WPE) to calculate the Shannon entropy rate in a sliding window across these records. WPE is a measure of the average rate at which new information—unrelated to anything in the past—is produced by the system from which a time series is sampled. Our preliminary results suggest that analytical techniques, as well as thermodynamic, climactic, and glaciological effects, impact the information production of the climate system. For instance, WPE can detect differences in hydrogen and oxygen isotope records that are likely related to interesting geoscientific effects: kinetic fractionation in the hydrologic cycle, including evaporation of source waters, diffusion in the firn column, and solid diffusion during geothermal heating. The second-order thermodynamic differences between these isotopes are known in theory, but detecting these effects in data has been elusive until now.

Influence of non-uniform rotation on turbulent spectra

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The combination of rotation and spherical geometry, which is typical of large-scale geophysical processes, is inherent to a spherical Couette flow, representing the flow of a viscous incompressible fluid driven by the rotation of concentric spherical boundaries about their common axis. It was previously established [1] that the laminar–turbulent flow transition caused by periodic modulation of the velocity of rotation of a boundary of a spherical layer can result in both two-dimension and three-dimensional (3D) turbulence. Conclusions concerning the kind of turbulence [1] were based on both the slope of the velocity spectrum and the sign of the third-order velocity structure function. Nevertheless, there still remains an open question concerning the susceptibility of developed turbulence, formed in SCF at constant velocities of boundary rotation, to the action of velocity modulation. The present work is devoted to an experimental investigation of the influence of modulation of the velocity of inner-sphere rotation on the properties of turbulent flows in a rotating spherical layer. First, the initial turbulent flow was formed between counter-rotating spheres. Then, modulation frequency was set and the modulation amplitude was increased from zero. Measurements of flow velocity were carried out by laser Doppler anemometer in single point at mean latitude near outer sphere. In the absence of modulation, the slopes of velocity spectra were found to be close to -11/5. Modulation amplitude enhancing can lead to the formation of velocity spectra typical to 3D turbulence with slope -5/3. At subsequent amplitude enhancing it is possible formation of typical for 2D turbulence spectra, with slopes -5/3 at low frequencies and -3 at high frequencies. It was shown, that at small amplitudes, modulation of rotation velocity can lead to a decrease in the level of turbulent velocity pulsations. The transition from 3D to 2D turbulence under the action of modulation occurs in the case of high level of synchronization between inner sphere rotation velocity and flow velocity.

This work was supported by Russian Foundation of Basic Research, projects 16-05-00004 and 18-08-00074.

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ECC15 GENERAL INFORMATION

Reaching Madrid

The Adolfo Suárez Madrid-Barajas Airport is 12 kilometers northeast of the city. For more information on the airport please visit the website

http://www.aena-aeropuertos.es/csee/Satellite/Aeropuerto-Madrid-Barajas/en/Home.html.

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- Underground. Metro line 8 runs from all the airport terminals to *Nuevos Ministerios* station in central Madrid, where you can connect with other lines. A map of Madrid Metro can be downloaded from: http://www.metromadrid.es/en. See the Section **Public transportation fares** for more information.
- Taxi. All airport terminals have clearly signed taxi ranks outside the arrivals area. Official taxis are white with a red stripe and the coat-of-arms of Madrid City Council on the doors. The trip from the airport to the city center has a fixed price of 30 euros. There is no supplement for luggage.
- City bus. Several bus lines run from the airport to central Madrid. City bus route 200 runs from Madrid-Barajas airport terminals T1, T2, T3 and T4 to the *Avenida de América* Transport Hub, where there are connections to several city and intercity bus routes and the Madrid Metro system.

Reaching the Conference Venue

The ECC15 Madrid 2018 will be held at the facilities that the Rey Juan Carlos University has in the Madrid Campus located in the Madrid district of Vicálvaro. The address is:

Universidad Rey Juan Carlos - Campus Madrid
Paseo de los Artilleros St.
28032 Vicálvaro (Madrid)

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How to reach us:

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- By bus: There are four locations around the campus where the following bus lines stop:
  - Daroca Street stop: lines 4, 100, 106, N7 (night bus)
  - Camino Viejo stop: lines 4, 100, 106, 130
  - Calahorra Street stop: lines 4, 106, 130, N7 (night bus)
  - San Cipriano Street stop: line E3

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Preparing your contribution

Talks

The programme is organized in thematic sessions (2 h aprox) consisting of invited and contributed talks. Talks given by Invited Speakers are 30 min long while contributed talks are 20 min, discussion included.

The lecture rooms will be equipped with a projector with standard VGA input and a Windows computer with Powerpoint software, although it is strongly recommended to bring the presentation converted to pdf to avoid font and formatting problems. Please, **upload your presentation to the computer 30 minutes before the session begins**. For those wishing to use their own machine, testing should also be done prior to the session.

There will be a **Best Contributed Talk Award** funded by **Hindawi Publisher**. The election of the awarded short talk will be decided by the members of the Local Scientific Committee. The award will be given during the closing ceremony (Thursday 7th, see Social Programme).

Posters

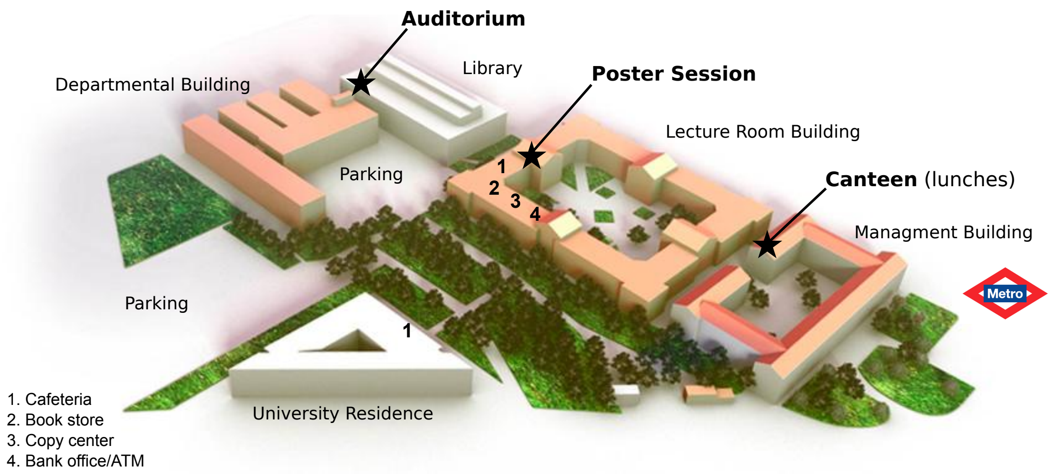
Will be on display throughout the entire event and can be affixed as early as Monday morning. Poster boards will be numbered. Please hang up your poster on the corresponding board with the number that matches the one assigned in the conference booklet. Tape will be provided at the Conference desk. Recommended poster size is **A0** (120 cm $\times$ 80 cm) with portrait orientation.

There will be **Best Poster Awards** funded by the **European Physical Society** and by the **Chaos, Solitons & Fractals Journal**. The election of the awarded posters will be made by a collaborative filtering method. Together with the conference material each participant will receive a sticker to vote for the Best Poster, which will be placed directly on the poster selected. The voting process will finish at the end of the poster session (Tuesday 5) and the awards will be given during the Gala Dinner (Wednesday 6, see Social Programme).

During the Conference

The relevant locations during the Conference are (see map):

- **The Conference Sessions** will be held at the Auditorium of the Campus Library.
- **The Registration** will take place at Hall of the Campus Library. Please be sure you are in line at the correct desk, especially if you chose to pay directly in cash. For your convenience **there will be a registration office at Novotel Madrid Center hotel on Sunday June 3**, from 18:00 to 20:00 h. A badge will be issued after payment.
- **Meetings Rooms** are at your disposal in the Library Building, please follow the indications.
- **Coffee breaks** will take place outdoors, in the space beside the Library.
- **Lunches** will take place at the campus Canteen, in the Management Building. Lunch tickets for each day of the Conference will be provided with your Conference material, please be sure to take with you the corresponding ticket to present it to the Canteen staff.
- **The Poster & Wine Session** will be held in the afternoon of Tuesday 5 at the second floor of the Lecture Rooms Building, please follow the indications. However, the posters will be displayed all along the Conference. Ask the Organizers for help to place your poster.



Connectivity

WiFi connectivity will be available in all the Conference areas. Please check for the user and password in the informative panels in the Auditorium. EDUROAM connection will be also available.

Social Programme

Three social events are programmed for the ECC15. All of them are free of charge for the registered ECC15 participants.

Welcome Reception & Registration

We will welcome you at the hotel Novotel Madrid Center the evening of **Sunday 3, from 18:00 to 20:00 h**. For your convenience, a Registration Stand will be at your disposal during the Welcome Reception.

Google Maps: https://goo.gl/maps/FGjdjQoG14U2

Metro stations: Goya (lines 2 and 4), Príncipe de Vergara (lines 2 and 9) and O'Donnell (line 6).

Guided walk to Madrid historical center

During the afternoon of **Wednesday 6** we will have a two-hours walk visit with a group of professional guides around the Imperial Center of Madrid. The guided tour will be in English for all the groups. The meeting point will be the **Plaza Mayor** (you will find us next to the statue of King Felipe III, in the center of the square) at **18:30** h:

Google Maps: https://goo.gl/maps/pa4YcBYz5rA2

Metro stations: Opera (lines 2 and 5), Sol (lines 1, 2 and 3).

Gala Dinner

It will take place at the hotel **Novotel Madrid Center** the evening of **Wednesday 6 at 21:30** h. Please contact the Organizers if you have any dietary restrictions that have not been communicated in your registration form.

Google Maps: https://goo.gl/maps/FGjdjQoG14U2

Metro stations: Goya (lines 2 and 4), Príncipe de Vergara (lines 2 and 9) and O'Donnell (line 6).