39th Marian Smoluchowski
Symposium on Statistical Physics

FRONTIERS IN COMPLEXITY THEORY AND FRACTIONAL DYNAMICS

BOOK OF ABSTRACTS

23-25 IX 2026
Rome, Italy

PAN Polish Academy of Sciences | Rome Scientific Center

Uniwersytet Jagielloński w Krakowie
Wydział Fizyki, Astronomii i Informatyki Stosowanej

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39th Marian Smoluchowski Symposium on Statistical Physics

FRONTIERS IN COMPLEXITY THEORY AND FRACTIONAL DYNAMICS

23 - 25 IX 2026 | Rome, Italy

Wednesday, 23/09

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FRONTIERS IN COMPLEXITY THEORY AND FRACTIONAL DYNAMICS

23 - 25 IX 2026 | Rome, Italy

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4	Mohammad Salar Ghasemi Nasab	Curvature-Driven Phase Behavior in a Vertex Model of Epithelial Tissues
5	Goutham R	Probabilities of Rare Events in Product Kernel Aggregation: An Exact Formula and Phase Diagram
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7	Pablo Vidal Franco	Behavior of Hidden Nodes in Artificial Neural Networks Under Increasing Cognitive Load
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9	Enrique Puga Cital	Strong Violation of the Thermodynamic Uncertainty Relation in a Minimal Autonomous Heat Engine
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39th Marian Smoluchowski Symposium on Statistical Physics

FRONTIERS IN COMPLEXITY THEORY AND FRACTIONAL DYNAMICS

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IT Invited Talk (25 min. + 5 min. Q&A)

Symposium’s Venue

Accademia Polacca Delle Scienze, Vicolo Doria 2, Rome

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Accademia Polacca in Rome and Marian Smoluchowski Symposium

The Scientific Centre of the Polish Academy of Sciences in Rome, traditionally known in Italy as **the Accademia Polacca**, is one of the oldest Polish research institutions abroad. Formally established in 1927, it grew from the nineteenth-century tradition of Polish historical research in the Vatican Archives. The first *Expeditio Romana*, led by the medievalist Stanisław Smolka, arrived in Rome in 1886. An important foundation for the future Centre was the scholarly library donated to the Polish Academy of Arts and Sciences by the historian and bibliophile Józef Michałowski. In 1938, the institution moved to Palazzo Doria near Piazza Venezia. During the Second World War, its collections were protected in the Vatican Library, and in 1952 the Centre became part of the newly established Polish Academy of Sciences. Today, it provides an interdisciplinary forum for Polish–Italian scientific, academic and cultural cooperation.

Since **1 March 2026**, the Centre has been directed by **Dr Magdalena Wrana**, appointed for a four-year term. A scholar of Italian studies associated for many years with the Jagiellonian University, she completed an award-winning doctoral dissertation on Angelo Maria Durini, the eighteenth-century Apostolic Nuncio to Poland. Her professional experience combines academic research, conference interpreting, cultural diplomacy and cooperation with Italian institutions. In 2025, she was appointed an Officer of the Order of the Star of Italy for her contribution to Polish–Italian relations.

The Marian Smoluchowski Symposium on Statistical Physics was founded on the initiative of **Professor Andrzej Fuliński**, with Professor Jan Popielawski among its early collaborators. The first meeting, initially called *the Symposium on Statistical Physics*, took place in Zakopane in September 1988. The first conference proceedings appeared in *Acta Physica Polonica B* in 1992, while the name *Marian Smoluchowski Symposium on Statistical Physics* was formally adopted in 1997.

Professor Fuliński was the founder and long-time head of the Department of Statistical Physics at the Jagiellonian University, as well as a former Dean of the Faculty of Mathematics, Physics and Chemistry and Director of the Institute of Physics. His research included the theory of master equations, stochastic resonance, anomalous transport and the kinetics of molecular ion channels. Through the Symposium, he created a durable international community centred on stochastic processes, fluctuations and nonequilibrium statistical physics. In 2006, the Jagiellonian University awarded him its Medal of Honour for his scientific achievements and for continuing and disseminating the tradition initiated by Marian Smoluchowski.

The 39th Marian Smoluchowski Symposium, held in Rome on **23–25 September 2026** under the theme *Frontiers in Complexity Theory and Fractional Dynamics*, brings this long-standing scientific tradition to the Accademia Polacca. Its programme – covering anomalous diffusion, fractional dynamics, rare events, complex networks, information theory and biological systems—demonstrates the continuing vitality of Smoluchowski's legacy and symbolically connects two important traditions of Polish science: the Kraków school of statistical physics and the nearly century-long Polish academic presence in Rome.

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POSTERS

Wednesday 23 September 2026 · *09:30 – 10:00*

IT Fast Rare Events in Exit-Time Statistics of Jump Processes

Raffaella Burioni[1]

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Rare events in first-passage and exit-time statistics of jump processes can play a decisive role in triggering anomalous reactions and extreme responses in a wide range of systems. This is particularly relevant when jump lengths or waiting times follow broad, heavy-tailed distributions, for which rare events are not exponentially suppressed and can significantly affect macroscopic observables. Quantifying the contribution of such fast, atypical events to exit probabilities therefore poses a fundamental challenge. In the presence of heavy-tailed distributions, large fluctuations follow the Big Jump Principle, a counterintuitive mechanism according to which rare events arise not from the accumulation of many small deviations, but from a single, dominant fluctuation.

In this talk, we present a general framework for estimating the contribution of fast rare events to exit probabilities in jump processes with fat-tailed distributions. We apply this approach to three paradigmatic models-discrete-time random walks, Lévy walks, and the Lévy – Lorentz gas - which are widely used to describe transport in biological systems, disordered media, ecology, and finance. We derive the exact scaling form of the probability distribution associated with fast exit events, in which the process leaves a finite interval over distances much larger than the typical scale and on timescales orders of magnitude shorter than the characteristic timescale of the dynamics.

Our results show that these fast rare events can provide a non-negligible, and in some cases dominant, contribution to the total exit probability, despite being far outside the typical regime of the process. We also discuss extensions to systems of N independent walkers, where collective effects can further enhance the contribution of fast rare events to exit statistics.

Wednesday 23 September 2026 · *10:00 – 10:30*

IT Anomalous Diffusion, Non-Gaussianity and Long-Range Dependent Motion

Ralf Metzler[1]

[1] *University of Potsdam*

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Deviations from the standard laws of Brownian motion, the linear time dependence of the mean squared displacement and the Gaussian probability density function, are quite commonly observed in an abundance of systems. The physical mechanisms for these anomalies are non-universal, prompting the need for different stochastic models along with their identification from measured time series of dynamic motion. The model classification and parameter regression of anomalous diffusion can be successfully achieved by machine-learning tools such as Bayesian Deep Learning [1], which will be introduced along with a brief summary of the two recent AnDi (Anomalous Diffusion) Challenges [2].

The talk will mainly focus on long-range dependent stochastic motion, identified in a large range of systems. In particular, it will be discussed how to generalise such models to situations, in which the observed probability density function is non-Gaussian and/or when the processes display scaling exponents varying in time or space. Diffusion models with stochastically [3] and deterministically [4] varying diffusion coefficients and scaling exponents will be introduced. Applications to experimental data will be discussed.

References:

[1] H. Seckler and R. Metzler, Bayesian deep learning for error estimation in the analysis of anomalous diffusion, Nature Commun. 13, 6717 (2022).

[2] G. Munoz-Gil et al, Objective comparison of methods to decode anomalous diffusion, Nature Commun. 12, 6253 (2021); G. Munoz-Gil et al, Quantitative evaluation of methods to analyze motion changes in single-particle experiments, Nature Commun. 16, 6749 (2025).

[3] M. Balcerek, S. Thapa, K. Burnecki, H. Kantz, R. Metzler, A. Wylmanska, and A. Chechkin, Multifractional Brownian motion with telegraphic, stochastically varying exponent, Phys. Rev. Lett. 134, 197101 (2025).

[4] W. Wang, M. Balcerek, K. Burnecki, A. V. Chechkin, S. Janusonis, J. Slezak, T. Vojta, A. Wylmanska, and R. Metzler, Memory-multi-fractional Brownian motion with continuous correlations, Phys. Rev. Res. 5, L032025 (2023).

Wednesday 23 September 2026 · 10:30 – 11:00

IT Boltzmann equations: From random exchange models for the distribution of wealth to the Lorentz gas

Enrico Scalas[1]

[1] *Department of Statistical Sciences, Sapienza University of Rome*

Corresponding author: enrico.scalas@uniroma1.it

In recent times, several rigorous results on simple random exchange models were proved. In this talk, after a short review of the literature, I focus on a subset of results in a recent paper in which we discuss various limits of a simple random exchange model that can be used for the distribution of wealth. We start from a discrete state space - discrete time version of this model and, under suitable scaling, we show its functional convergence to a continuous space - discrete time model. Then, we show a thermodynamic limit of the empirical distribution to the solution of a kinetic equation of Boltzmann type.

Lorentz processes are presented in two different settings. Both cases are characterized by infinite expectation of the free-flight times, contrary to what happens in the classical Gallavotti – Spohn models. Under a suitable Boltzmann – Grad type scaling limit, they converge to non – Markovian random-flight processes with superdiffusive behavior. A further scaling limit yields another non Markovian process, i.e., a superdiffusion obtained by a suitable time-change of Brownian motion. Using a technique based on mixtures of Feller semigroups, the governing equations for the random flights and anomalous diffusion are obtained, which represent a non-local counterpart for the linear-Boltzmann and diffusion equations arising in the classical theory.

Wednesday 23 September 2026 · *11:30 – 12:00*

IT Different types of random motion and generalized Fokker-Planck equations

Luca Angelani[1,2]

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By analyzing physically meaningful solutions of a generalized one-dimensional Fokker-Planck equation, I show that a broad class of random motions can be described within a unified framework. The approach recovers a variety of stochastic processes, ranging from Brownian diffusion to active motion, and including anomalous transport, stochastic resetting, and trapping mechanisms.

Wednesday 23 September 2026 · *12:00 – 12:30*

IT Multimodality of stationary states in single-well potentials

Bartłomiej Dybiec[1]

[1] *Faculty of Physics, Astronomy and Applied Computer Science, Jagiellonian University*

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Noise-driven dynamics in single-well potentials can produce bimodal, or more generally multimodal, stationary states. The emergence of multimodality depends sensitively on the properties of the driving noise. Such behavior is typically associated with systems subject to strong fluctuations, for example those driven by Lévy noise, or with systems driven by temporally correlated noise, such as Ornstein–Uhlenbeck noise or fractional Brownian noise.

Multimodality may also arise from the combined action of several stochastic mechanisms. In particular, dichotomous noise may randomly alter the potential landscape, while an additional driving noise spreads trajectories within the currently realized potential. As a result, the stationary probability density can develop multiple maxima even when the underlying deterministic potential has only a single well. A closely related mechanism may occur in systems with stochastic resetting. In such systems, resetting can concentrate probability mass near the reinjection points, thereby facilitating the formation of additional maxima in the stationary distribution.

In this work, we examine the formation of multimodal stationary states in various types of noise-driven systems. We focus on how the statistical properties of the noise, including its intensity, temporal correlations, and mode of coupling to the dynamics, determine whether the stationary state remains unimodal or becomes bimodal or multimodal.

[1] B. Dybiec and L. Schimansky-Geier, Emergence of bimodality in noisy systems with single-well potential, Eur. Phys. J. B **57**, 313 (2007).

[2] K. Capała and B. Dybiec, Multimodal stationary states in symmetric single-well potentials driven by Cauchy noise, J. Stat. Mech. 033206 (2019).

[3] P. Pogorzelec and B. Dybiec, Resetting induced multimodality, Chaos **33**, 063105 (2023).

[4] B. Dybiec, Multimodality in systems driven by Ornstein–Uhlenbeck noise, Chaos **34**, 113105 (2024).

[5] M. Mandrysz and B. Dybiec, Dynamical multimodality in systems driven by Ornstein–Uhlenbeck noise, Entropy **27**, 263 (2025).

Wednesday 23 September 2026 · *12:30 – 13:00*

IT Continuous-time random walks with resetting: scaling limits and anomalous diffusions

Luisa Beghin[1], Fausto Colantoni[2], Gianni Pagnini[3]

[1] *Sapienza University of Rome*

[2] *Ulm University*

[3] *Basque Center for Applied Mathematics, Bilbao*

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Continuous-time random walks (CTRWs) with stochastic resetting provide a natural framework for modelling anomalous transport under intermittent restart mechanisms. In this seminar, we present recent asymptotic results for CTRWs with resetting under suitable space–time scaling limits. For heavy-tailed waiting times and jumps in the domain of attraction of stable laws, we show convergence to an α-stable process time-changed by the inverse of a β-stable subordinator, combined with a resetting structure inherited from the original dynamics. We also discuss functional convergence in the Skorokhod J_1 topology, based on a pathwise construction via concatenation of independent excursions. Finally, we examine the effect of scaling the resetting mechanism itself, showing that different asymptotic regimes lead either to an equilibrium random limit or to a nontrivial time-rescaled CTRW with resetting.

Wednesday 23 September 2026 · *14:00 – 14:30*

IT Janus Percolation in Anisotropic Limited-Degree Networks

Lucilla de Arcangelis[1]

[1] *Department of Mathematics and Physics, University of Campania "Luigi Vanvitelli", Viale Lincoln 5, Caserta, 81100, Italy*

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Many real-world infrastructures, from sensor and road networks to power grids, are spatially embedded and anisotropic, with constraints on the maximum number of links each node can establish. Such systems can be represented as anisotropic limited-degree networks, in which each node forms at most q outgoing links preferentially oriented along a fixed direction. By increasing the node density σ at fixed q, we uncover a reentrant percolation transition: a giant strongly connected component emerges, but unexpectedly disintegrates again at high densities. This counterintuitive behavior implies that adding nodes, normally expected to enhance robustness, can instead reduce mutual accessibility and weaken global connectivity. The critical behavior displays two coexisting "faces": random-percolation scaling along the preferred direction and directed-percolation scaling transversely, therefore we name this phenomenon Janus percolation, in analogy with the dual-faced Roman god. These findings demonstrate that anisotropy and degree limitation can jointly induce a novel reentrant connectivity with mixed universality that bridges the universality classes of random and directed percolation, providing fresh insight into how structural constraints shape connectivity and resilience in spatial networks.

Garofalo et al, to appear on Phys. Rev. Lett.

Wednesday 23 September 2026 · *14:30 – 15:00*

IT The Cost of Ignorance: Sparse Corruption and BBP-Type Transitions in Low-Rank Matrix Inference

Pierpaolo Vivo[1]

[1] *King's College London*

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Low-rank matrix inference is a central problem in high-dimensional statistics, machine learning, and statistical physics. In the classical spiked random matrix setting, a rank-one signal is corrupted by dense random noise, and the celebrated BBP transition marks the point at which the signal becomes detectable by principal component analysis. In many applications, however, the corrupting noise is not dense but sparse, structured, and graph-like. What is the cost of ignoring this sparsity and applying 'vanilla' PCA to recover the signal buried under a sparse noise?

In this talk, I will discuss a rank-one spiked matrix model in which the noise is the weighted adjacency matrix of a sparse random graph with finite average connectivity. Using the replica method, we compute the typical top eigenvalue, the distribution of the top eigenvector components, and the overlap between the top eigenvector and the planted signal. The solution is expressed through recursive distributional equations (integral equations for auxiliary probability density functions) that can be solved efficiently by a population dynamics algorithm.

The resulting phase diagram reveals a sparse analogue of the BBP transition, whose threshold depends explicitly on the graph degree distribution and average connectivity. In our setting, the detachment of a signal-related eigenvalue from the spectral bulk does not necessarily coincide with successful recovery by the leading eigenvector. A structural outlier generated by the sparse noise can dominate the spectrum, creating an intermediate regime in which the signal is spectrally visible but not recoverable by the top principal component. In the large-connectivity limit, the standard dense-noise BBP results are recovered.

These results illustrate how tools from disordered systems and random graphs can sharpen our understanding of spectral inference beyond the classical dense-noise paradigm.

Wednesday 23 September 2026 • *15:00 – 15:30*

IT Preferential attachment graphs: random initial degrees

Federico Polito[1]

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First, we consider the so-called preferential attachment random graphs, which appear extensively in the mathematics, physics, and computer science literature. We then present some variants in which the attachment mechanism is not of pure preferential type, or in which the initial degrees with which the nodes appears in the graph are random. In particular, regarding the latter case, we address the open problem concerning the possible lack of concentration of the degree distribution when distribution of the initial degrees is characterized by extremely heavy tails of power-law type. We show that the addition of such a large number of edges causes a significant upset of the degree distribution, leading to its non-concentration. Furthermore, we show that the smallest value of the exponent for which the degree distribution exhibits concentration is 2.

Wednesday 23 September 2026 · *15:30 – 16:00*

IT Information engine fueled by first-passage times

Alberto Imparato[1]

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Corresponding author: alberto.imparato@units.it

I will consider the thermodynamic properties of an information engine that uses feedback control to extract work from a manipulated stochastic system. I will discuss the fluctuation theorems that involve the information associated with the feedback-controlled stochastic trajectories. Such an information turns out to be based on the first-passage-time distribution. I will then discuss the experimental verification of the above results with a setup consisting of a cantilever submitted to an electrostatic feedback force. I will finally show that the fluctuation theorems extend beyond the specific application to such an experiment.

Reference:

A. Archambault, C. Crauste-Thibierge, A. Imparato, C. Jarzynski, S. Ciliberto, L . Bellon, Information Engine Fueled by First-Passage Times, Phys. Rev. Lett 135, 147101 (2025)

Thursday 24 September 2026 · *09:00 – 09:30*

IT The real butterfly effect: from the pop culture to mathematics and physics

Angelo Vulpiani[1]

[1] *Dip. di Fisica, Univ. Sapienza, Roma*

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The butterfly effect, introduced about half century ago by E. Lorenz, is now part of the folklore of chaos and of the pop culture. We show how for the understanding of a realistic scenario in fully developed turbulence, one must to go beyond the pure mathematical study of infinitesimal perturbations of the Lyapunov exponent.

In particular it is necessary to take into account:

a) the pre-asymptotic behavior of an infinitesimal perturbation;

b) the growth of finite perturbations via the Finite Size Lyapunov Exponents;

c) the role of noise at small scale.

Once one accepts that the evolution equation of the atmosphere can be approximate with a set of (many) ordinary differential equations the metaphor of the butterfly is just a poetic version of the sensitive dependence on the initial conditions.

Of course the butterfly, typically, after two weeks will not provoke a tornado, but just for sure will be able to change (usually in a non dramatic way) the state of the atmosphere.

Thursday 24 September 2026 · *10:00 – 10:30*

IT Observers, fluctuations and fluctuation theorems

Francesco Caravelli[1]

[1] *Theoretical Division, Los Alamos National Laboratory, Los Alamos 87545, NM, USA*

Corresponding author: caravelli@lanl.gov

We formulate coarse-grained dynamics and irreversibility from an observer-centered perspective within nonequilibrium statistical mechanics. Here, an observer is specified by a resolved subspace of observables, which determines the associated relevant ensemble, unresolved degrees of freedom, noise, and memory. We analyze how different choices of observer modify the reduced dynamics and compare nested observers through an entropy hierarchy, and discuss fluctuation theorems within this approach.

Thursday 24 September 2026 · *10:30 – 11:00*

IT Formal Fluctuation-Response Relations for Non-Stationary Systems

Igor Sokolov[1]

[1] *Humbold University at Berlin*

Corresponding author: igor.sokolov@physik.hu-berlin.de

Fluctuation-responce relations (FRRs), or fluctuation-dissipation theorems (FDTs), are an important tool for understanding and predicting the response of physical systems to external perturbations. They come in different kinds and flavors. Thus, in equilibrium, the linear FDT of the first kind connects the linear response of a system to an external perturbation with properties of spontaneous fluctuations of the variable conjugated to this perturbation in the unperturbed system. The aim of the present discussion is to investigate, how far the standard discussion can be extended into a non-equilibrium domain, even beyond stationarity. We provide a simple derivation of FRRs for non-stationary dynamics following an almost standard way based on introducing a variable conjugated to perturbation ("dynamic conjugate"). The structure of this variable is however unusual: it is a two-time one, and reduces to a single-time one (customary "static conjugate") in stationary situations, including equilibrium. We discuss the domain of applicability of the results, and show that the general mathematical structure obtained (the "formal" FRR) underlays several known, some of them quite recent, results. We, moreover, discuss the explicit forms of dynamic conjugates for some simple examples.

Thursday 24 September 2026 · *11:30 – 12:00*

IT **Heavy distribution tails and explosive moments in a doubly-stochastic model of cell proliferation**

Marek Kimmel[1], Nathaniel Kroeger[1]

[1] *Rice University*

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This presentation generalizes and expands the theory for a particular branching process (see Kimmel and Axelrod (2015) Branching processes in biology) used to model cancerous tumors. The process was first introduced by us in Ernst et al. (2018) Adv Appl Prob 50A: 99-114. The motivation were data from Perez-Garcia et al. Nat Phys (2020) 16: 1232 who found super-exponential growth examples among published cancer data. Ernst et al. (2018) introduced a branching process model with randomly mutating reproduction rates of this phenomenon, and found that it exhibited heavy tails and first moment explosions in finite time with implications for statistical analysis. In this presentation we expand this study by allowing to include cell death and/or the use of an arbitrary non-negative distribution of mutated reproduction rates (originally exponential only was allowed). We found conditions to exclude first-moment explosions. Moreover, for a well-defined class of "light-tailed" distributions, the same is true, with no restriction on death or mutation rates. One interesting observation is that under the first-moment explosion regime, the canonical classification of the branching processes into sub-critical, critical, and supercritical has to be modified. Since transitions of the parameters of the cell cycle distributions are quite common, and not only in cancer cells, the process we are developing may be of interest to biologists.

Thursday 24 September 2026 · *12:00 – 12:30*

IT Statistical fluctuations of large-scale mind states

Dante Chialvo[1]

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Corresponding author: dchialvo@conicet.gov.ar

It is well established that the brain spontaneously fluctuates through a very large number of states. Nevertheless, despite its relevance to understanding brain function, still is often ignored that its origin formally correspond to critical phenomena. We discuss the most recent results at large and small scale that are consistent with the view that such ubiquitous fluctuations are critical.

Thursday 24 September 2026 · *12:30 – 13:00*

IT Fractal and multifractal organisation of neuroimaging signals

Jeremi Ochab[1], Dante Chialvo[2], Ewa Gudowska-Nowak[1], Ignacio Cifre[3], Jacek Grela[1], Jakub Janarek[1], Maciej A. Nowak[1], Marcin Wątorek[4,1,5], Marta Lotka[6], Paweł Oświęcimka[5,1], Wojciech Tomczyk[1,5], Zbigniew Drogosz[1]

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The brain is a complex system whose multiscale organization supports cognitive functioning. In neurodegeneration in particular, alterations in brain structure are accompanied by a broad cognitive decline, motivating the question of whether changes to that in multiscale brain organization track these impairments. Multifractal measures provide a promising description of brain organization that captures its cross-scale heterogeneity.

Presently, we report fractal and multifractal analyses of both temporal and spatial structure of EEG, MRI and functional MRI data. We cover cognitive experiments, as well as neurodegeneration studies of multiple sclerosis and dementia (the latter based on open databases). The techniques presented include multifractal detrended fluctuation analysis (MFDFA) and detrended cross-correlation analysis and how we have adapted them to particular use cases. For instance, DFA methods have been reserved for 1D series, whereas neuroimaging – including MRI and fMRI – produces multidimensional spatially grounded data. Hence, we focus on our recent development of MFDFA to structural brain scans transformed via space-filling curves (SFC).

We selected SFCs that reliably preserve the multi-scale spatial correlations and showed that in theoretically-driven models it allows recovery of linear correlations and nonlinear features, as quantified by the multifractal spectrum. Applied to a cross-sectional MRI dementia dataset, the proposed method reveals a systematic shift from multifractality toward monofractality with increasing age and disease progression. Further statistical and machine-learning analyses identified the brain regions most strongly affected by these processes, highlighting both shared and distinct spatial patterns associated with ageing and dementia.

Thursday 24 September 2026 · *14:00 – 14:30*

IT Non-local dynamic boundary conditions for sticky Brownian motions on smooth domains

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Sticky diffusion processes on bounded domains can spend finite time (and finite mean time) on the lower-dimensional space given by the boundary. Once the process hits the boundary, then it starts again after a random amount of time. While on the boundary it can stay or move according to dynamics that are different from those in the interior. Such processes may be characterized by a time-derivative appearing in the boundary condition for the governing problem. We use suitable time changes in order to describe fractional sticky conditions and the associated boundary behaviours. We obtain that fractional boundary value problems (involving fractional dynamic boundary conditions) lead to sticky diffusions, strong Markov on the interior, spending an infinite mean time (and finite time) on the boundary. Such a behaviour can be associated with a trap effect from the macroscopic point of view. We provide an example on fractals.

Thursday 24 September 2026 · *14:30 – 15:00*

IT Superdiffusion in a system with a thin membrane

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Superdiffusion is a process in which diffusing molecules can make anomalously long jumps with relatively high probability. This process occurs, among others, in turbulent media and various biological processes related to cell migration. Superdiffusion is often described by the equation with the fractional Riesz derivative with respect to a spatial variable. This derivative is a differential-integral operator with respect to the spatial variable, which makes the equation non-local in space. For this reason, non-local boundary conditions have been used in solving the fractional superdiffusion equation. As far as we know, this equation has not been used to describe superdiffusion in a system thin membranes. A superdiffusion model will be shown, based on an equation with the time-fractional Caputo derivative with respect to another function g (the g-superdiffusion equation). This equation is local in space and can therefore be used to model diffusion processes in a thin-membrane system. By appropriately defining the function g, the g-subdiffusion equation describes superdiffusion in such a way that its solutions (Green's functions) converge to solutions of the fractional superdiffusion equation with a Riesz derivative in the long time limit. Solutions for various boundary conditions assumed at thin membranes will be discussed.

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Thursday 24 September 2026 · *15:00 – 15:30*

IT Analysis of fractional Cauchy problems with some probabilistic applications

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In this talk we give an explicit solution to Dzherbashyan-Caputo-fractional Cauchy problems related to equations with derivatives of order ν_k, for k non-negative integer and $\nu > 0$. The solution is obtained by connecting the differential equation with the roots of the characteristic polynomial and it is expressed in terms of Mittag-Leffler-type functions. Under some additional hypothesis, the solution can be expressed as a linear combination of Mittag-Leffler functions with common fractional order ν. We establish a probabilistic relationship, involving the inverse of stable subordinator, between the solutions of differential problems with order α_ν and ν, for $\alpha \in (0, 1)$.

Finally, we use the described method to solve fractional differential equations arising in the fractionalization of partial differential equations related to the probability law of planar random motions with finite velocities.

Friday 25 September 2026 · *09:30 – 10:00*

IT Large deviations for linear regression

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Linear regression is one of the simplest and most widely used tools to learn patterns from data: it fits a set of coefficients so that a linear combination of predictors best matches observed responses. The quality of the fit is measured by the residual sum of squares, the total squared mismatch between predictions and data, whose minimum defines the training loss. For Gaussian data, the residual sum of squares is a random variable whose statistics is considered for large number P of predictors and N of observations, keeping their ratio $r = P/N$ fixed. Although the typical training loss and the interpolation transition at $r = 1$ are well known, much less is known about rare sample-to-sample fluctuations of the optimal loss. Using the zero-temperature replica method, we compute analytically the full distribution (including large deviation tails) of the minimal regularized training loss for arbitrary penalty function, including Ridge and Lasso. Extensive numerical simulations are in excellent agreement with our theory and clearly show a pronounced deviation from the Gaussian regime of typical fluctuations in the tails.

Friday 25 September 2026 · 10:00 – 10:30

IT Heterogeneous Diffusion and Its Connection to the Noisy Voter Model

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The noisy voter model is a widely used framework for stochastic opinion dynamics in finite populations, where changes in individual opinions are driven by two competing mechanisms: spontaneous opinion changes and social imitation. Although the model is originally formulated in terms of discrete states and transition rates, its continuum approximation can be related to Fokker-Planck-type transport equations with state-dependent drift and diffusion terms. In this talk, I discuss how the noisy voter model can be formally connected to heterogeneous diffusion with a position-dependent diffusion coefficient. The main focus is on the limitations of the standard Fokker-Planck description. Since this equation is parabolic, it implies infinite propagation speed, which would correspond, in the voter-model interpretation, to a nonzero probability of instantaneous opinion changes over arbitrarily large distances in the state space. To address this limitation, I present a heterogeneous Cattaneo–Vernotte-type formulation, in which memory is introduced into the probability flux through a finite time lag. This leads to a physically motivated continuum model with finite propagation speed.

Reference:

K. Górska, A. Horzela, D. Jankov Maširević, T. Pietrzak, T. K. Pogány, T. Sandev Heterogeneous Cattaneo-Vernotte equation connection to the noisy voter model, Chaos 36, 043108 (2026)

Friday 25 September 2026 · *10:30 – 11:00*

IT Random walks with stochastic resetting: a discrete time approach

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We consider a discrete-time random walk with resets on a connected undirected network. The resets, in which the walker is relocated to randomly chosen nodes, are governed by an independent discrete-time renewal process (we consider both light- and fat-tailed inter-reset distributions). Some nodes of the network are target nodes, and we focus on the statistics of first hitting of these nodes. We derive the propagator matrix in terms of discrete backward recurrence time PDFs and in the light-tailed case we show the existence of a non-equilibrium steady state. In the non-Markov scenario, we derive a defective propagator matrix which describes an auxiliary walk characterized by killing the walker as soon as it hits target nodes. This propagator provides the information on the mean first passage statistics to the target nodes. We apply all these results to study the mean first passage times for Markovian and non-Markovian (Sibuya) renewal resetting protocols in realizations of Watts-Strogatz and Barabási–Albert random graphs. We show non trivial behavior of the dependence of the mean first passage time on the proportions of the relocation nodes, target nodes and of the resetting rates.
The talk is based on joint works with Thomas M. Michelitsch, Federico Polito and Alejandro P. Riascos.

Friday 25 September 2026 · *11:30 – 12:00*

IT Monte-Carlo search for nematic liquid crystals of non-standard symmetries

Michał Cieśla[1], Lech Longa[1], Piotr Kubala[1]

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Liquid crystals (LCs) are a mesophase that combines the properties of liquids and solids. They are commonly found in nature and are a basis of liquid-crystal display (LCD) technology. The two most recent generations LC observed in the 21^{st} century, including phases such as twist-bend (N_{TB}), splay (N_S), and ferroelectric (N_F) nematics, are the subject of ongoing scientific debate. While new classes of molecules forming them are synthesized by the experimentalists, the theorists discuss the molecular factors that stabilize them. For example, it has been shown that purely entropic interactions are enough to promote twist-bend modulation in bent-core systems, which was further confirmed by different computational studies. On the other hand, the origin of N_S and N_F is still being discussed. The two most important factors appear to be a conical shape and a large dipole moment of a molecule. Here, using hard-core- particle Monte Carlo simulations, we assess the possibility of obtaining N_S and N_F phases without the help of dipolar interactions by studying various shapes of molecules. Moreover, we show several phases of non-standard symmetries, which have not been observed before.

Friday 25 September 2026 · *12:00 – 12:30*

IT A new exact fractal mean-field analysis in phase transition

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Moving beyond simple associations, researchers need tools to quantify how variables influence each other in space and time. Correlation functions provide a mathematical framework for characterizing these essential dependencies, revealing insights into causality, structure, and hidden patterns within complex systems. In physical systems with many degrees of freedom, such as gases, liquids, and solids, a statistical analysis of these correlations is essential. For a field $\Psi(\vec{x}, t)$ that depends on spatial position $\vec{x}$ and time t, it is often necessary to understand the correlation with itself at another position and time $\Psi(\vec{x}_0, t_0)$. This specific function is called the autocorrelation function. In this context, the autocorrelation function for order–parameter fluctuations, introduced by Fisher[1], provides an important mathematical framework for understanding the second-order phase transition at equilibrium. However, his analysis is restricted to a Euclidean space of dimension d, and an exponent η is introduced to correct the spatial behavior of the correlation function at $T = T_c$. In recent work, Lima et al[2] demonstrated that at T_c a fractal analysis is necessary for a complete description of the correlation function. In this study, we investigate the fundamental physics and mathematics underlying phase transitions, emphasizing the deep interplay between scaling behavior, critical exponents, and fractal geometry. {In particular, we show that the application of modern fractional differentials allows us to write down an equation for the correlation function that recovers the correct exponents below the upper critical dimension.} We obtain the exact expression for the Fisher exponent η. Furthermore, we examine the Rushbrooke scaling relation, which has been questioned in certain magnetic systems, and, drawing on results from the Ising model, we confirm that both our relations and the Rushbrooke scaling law hold even when d is not an integer[3].

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Friday 25 September 2026 · *12:30 – 13:00*

IT Estimation of Methylation Entropy Distribution in Genomics

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DNA methylation is an epigenetic modification that adds a methyl group to cytosine within CpG dinucleotides. CpG-rich regions often occur in gene promoters and regulatory elements. Methylation at these sites is a relatively stable, heritable mark that modulates transcription, chromatin state and genome stability [1]. Dysregulation is linked to several diseases including cancer [2]. Each CpG on a single DNA molecule is either methylated or unmethylated. While mean methylation levels capture the overall tendency of a locus to be methylated, they fail to differentiate between fundamentally different underlying stochastic configurations.

We use Shannon entropy to quantify randomness and develop a simulation framework to explore the entropy landscape [3]. We sample probability vectors from a symmetric Dirichlet prior on the simplex and condition them to a specified mean methylation. Accepted distributions are used to compute entropy and site-level summaries. Simulating ~10 million reads per setting and comparing to whole-genome nanopore calls from human blood, we found that entropy is low at extreme means and peaks near 0.5. Increasing CpG count expands the space of possible methylation patterns and so increases entropy, while the Dirichlet concentration controls dispersion.

Shannon entropy is thus a sensitive metric of epigenetic heterogeneity, while simple Dirichlet-based models are able to reproduce the characteristics of distributions seen in empirical data.

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POSTER Unusual transport in odd-diffusive systems

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Odd systems, characterised by broken time-reversal or parity symmetry, exhibit striking transport phenomena due to transverse responses. In this talk, I will introduce the concept of odd diffusion, a generalisation of diffusion in two-dimensional systems that incorporates antisymmetric tensor components. Focusing on systems of interacting particles, I present analytical results on effective transport coefficients and show how oddness in interacting systems gives rise to unusual transport. I present effects like enhanced self-diffusion, reversed Hall drift, and even absolute negative mobility that solely originate in odd diffusion. These results reveal how microscopic symmetry-breaking, encoded in unusual autocorrelation functions, gives rise to emergent equilibrium and non-equilibrium transport with implications for soft matter, chiral active systems, and topological materials.

POSTER Conflict between ensembles in a system with random disorder on a complete graph

Nir Schreiber[1], Reuven Cohen[1]

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We study two variants of the Blume-Emery-Grifith model with long range mean-field-like interaction and random disorder, described by different Hamiltonians. In one variant the system is uniformly populated by N spins and the disorder is represented by *i.i.d* random variables chosen with probability p. In the other one, we consider $N_s \sim Bin(N,p)$ *strong* spins, i.e., spins that interact with a uniform field, while the other $N - N_s$ spins are inert with respect to the field.

Indeed, it is found that the free energy within the two scenarios is unique. The expected energy due to the two Hamiltonians is preserved, leading to an exclusive entropy.

Conflict in the critical behavior between the canonical and the microcanonical ensembles is evident. For example, tricritical points, observed for any amount of disorder in the microcanonical ensemble, emerge only at high disorder, in the canonical ensemble. Constants of motion specifying the microcanonical ensemble, or gaps that open up in the magnetization landscape of the entropy, are other manifestations of disagreement between the two ensembles.

POSTER Reset-controlled thermodynamic transition in an inhomogeneous Brownian information engine

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We investigate a Brownian information engine driven by space-dependent diffusivity. The working protocol is described by overdamped Langevin dynamics within a harmonic confinement and is controlled via resetting. The geometry of the space-dependent diffusivity has a significant impact on the information processing. If the fluctuation increases, while moving away from the potential's center $D(x) \propto (1+x^2)$, a higher information-energy exchangeability is observed. This colossal information processing is hindered by a lower resetting cycle time. Interestingly, for a case of space-dependent fluctuations whose strength disappears going away from the potential center, $D(x) \propto (1-x^2)$ enables a reset-controlled thermodynamic phase behavior. In the slow-resetting limit $(r \to 0)$, the system exhibits an athermal engine-refrigerator transition governed by the ratio between the frequency of the confining potential and the strength of the space-dependent fluctuation $\alpha = \frac{k}{2D_0}$. The engine can convert the acquired information into a positive output work only if $\alpha > 1$, revealing a noise-induced thermodynamic transition. Moreover, a finite cycle time acts as a nonequilibrium control field, redistributing the probability by shifting the engine-refrigerator phase boundary. Our analytical predictions are supported by Langevin simulations and contrasted with the homogeneous diffusivity, highlighting the distinct role of multiplicative noise in enabling reset-controlled information use.

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POSTER Curvature-driven phase behavior in a vertex model of epithelial tissues

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Vertex models have been widely used to study mechanical phase transitions in confluent tissues. In the classical formulation, the normalized cell perimeter, or shape index, serves as a key geometric control parameter: increasing the shape index drives a transition from solid-like to fluid-like tissue behavior as cells become more elongated. Here, we extend the passive energy of the vertex model by introducing an average curvature-energy contribution for each cell.

The local curvature at each vertex is estimated by fitting a circle through the vertex and its two neighboring vertices, with curvature defined as the inverse radius of this circle. The resulting curvature is weighted by the area of the triangle formed by the three vertices, providing a local measure of cell-boundary bending.

Our simulations show that curvature energy strongly modifies tissue phase behavior. Increasing the curvature contribution fluidizes the tissue, as reflected by enhanced cell diffusion, and gives rise to a distinct dynamical regime beyond the conventional shape-index-controlled transition. This new regime is characterized by increased heterogeneity in cell morphology and the emergence of long-range bent structures across the tissue.

These results suggest that curvature is not merely a local geometric descriptor, but can act as an additional mechanical control parameter governing collective tissue organization and dynamics. Our work provides a generalized vertex-model framework in which curvature-mediated mechanics can drive emergent tissue-scale structures and alter the solid–fluid transition in epithelial tissues.

POSTER Probabilities of rare events in product kernel aggregation: An exact formula and phase diagram

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We present an exact method for calculating the large deviation function (LDF) describing rare fluctuations in the number of particles for product-kernel aggregation. Starting from the master equation, we derive an exact integral representation for the probability $P(M,N,t)$ of observing N particles at time t starting from M monomers for any finite M,N,t. From this, we obtain an exact expression for the exponential moment $\langle p^N \rangle$ for integer p. Employing a replica conjecture – numerically validated by finite-M scaling – we extend this result to real $p \geq 0$. The convex envelope of the large deviation function, obtained via a Legendre-Fenchel transform of the exponential moment, shows singular behavior. The singular structure allows us to construct the full phase diagram of product-kernel aggregation, which contains a tricritical point, separating continuous and discontinuous transitions. We also compute the asymptotic form of the LDF for small N/M. We obtain the full asymptotic structure of the distribution $P(M,N,t)$, including its non-convex regime. By casting the problem in a path integral framework, we solve the associated Euler – Lagrange equations and determine the instanton trajectories leading to rare events. Along these optimal paths, we compute exactly both the particle mass distribution and the gel fraction. Our results provide the exact LDF and the corresponding phase diagram derived from its singular structure, revealing features that go beyond previous analyses based on exponential moments.

POSTER Feller Diffusion in an Interval: Inhomogeneous Fluctuation-Induced Asymmetric Escapes

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We investigate the escape properties of a Feller diffusion process confined to a finite interval within an exactly solvable framework. The dynamics correspond to a particle in a shifted harmonic potential with state-dependent diffusivity, which lifts the symmetry of the escape events. By assigning the boundaries as extinction (near-zero, fluctuation-suppressed) and outbreak (enhanced-noise) states, we demonstrate that spatial heterogeneity in fluctuations alters both the mean escape rate and the splitting probabilities. Moreover, even from unbiased initial conditions, suppressed fluctuations near the extinction boundary bias trajectories toward the outbreak state. The mean exit time exhibits a non-monotonic dependence on the initial position and the location of the potential minimum, attaining a maximum when the particle is initialized toward the low-noise boundary. The condition of maximum exit time is then nicely corroborated with the least coefficient of variance (CV), which is the hallmark for a stochastic escape from an interval. Depending on the relative values of the drift-to-noise strength and the initial spatial bias, fluctuations in exit time may dominate over its mean or vice versa. Therefore, we further explored the effect of stochastic resetting on such escape asymmetry and revealed its role in shaping speed–accuracy trade-offs in stochastic first-passage processes.

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POSTER Behavior of hidden nodes in Artificial Neural Networks under increasing cognitive load

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Biological neural networks solve cognitive tasks with varying levels of complexity. However, it remains unclear how specific structural and functional features of these networks are related to increasing difficulty of the problems to be solved. How do network motifs change when the cognitive cost is increased? We address this question by evolving Artificial Neural Networks (ANNs) under the pressure of a functional goal of successfully playing the classic Atari game Pong with setups of increasing difficulty. These setups include deterministic modifications for varying degrees of ball velocities, different paddle sizes, and increasing levels of stochasticity in the system by varying angular velocity of the ball upon wall collisions. The resulting ensembles of ANNs contained an overrepresentation of the same motif: an excitatory and inhibitory edge of equal magnitude integrating the ball and paddle position into a single output node (hereafter M_1). This simple policy was successful for both deterministic and stochastic modifications. Further, stochastic modifications resulted also in different network motifs with M_1 embedded as part of the network, and, interestingly, with motifs that did not contain M_1. We focused our analysis on this latter, non-standard network motifs, that exhibited hidden nodes and complex policies for successfully playing the game. By re-evaluating the non-standard network solutions with graded levels of unpredictability of ball behavior, we identify the role of hidden nodes. Using this framework, we present a fingerprint of the hidden node behavior in the complex policies emerging in ANNs evolved under functional goals with increasing levels of stochasticity.

POSTER Phase diagram of Turing pattern formation

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Turing patterns are an example of thermodynamical systems out of equilibrium, exhibiting symmetry breaking and self-organization. Turing in 1952 showed theoretically that in reaction-diffusion under certain conditions a spatially homogeneous stable system can be destabilized by diffusion. Then, a large-scale spatially periodic static pattern emerges. In 1990, Cassettes et al., made the first experimental demonstration of Turing patterns in the chlorite–iodide–malonic acid (CIMA) reaction. Since then, Turing patterns have been proposed across a wide variety of chemical, physical, biological systems.

Just as phase diagrams characterize the different states of matter, Turing space classifies possible patterns. However, due to the nonlinear nature of Turing's conditions the exploration of Turing space is mostly numerical and on a case-by-case basis. Even with the recent implementation of neural networks these techniques are very computationally demanding. It is also often difficult to disentangle dependencies of the pattern on the specific model parameters and compare different models leading to the same pattern.

We propose a new approach to address these problems. First, using the dispersion relation we construct a general solution to Turing's conditions in the linear regime. Second, we show how to rewrite the parameters of any reaction model in terms of our general solution. These provide a common set of parameters for Turing space across models, making it easier to compare candidate models, and to identify universal features of Turing space independent of the model. Moreover, they drastically simplify the numerical exploration, since now it is possible to concentrate first on Turing space only, and on specific regions where a desired pattern is expected. We use CIMA and other models as examples of our formalism and provide numerical validation of our results.

POSTER Strong Violation of the Thermodynamic Uncertainty Relation in a Minimal Autonomous Heat Engine

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Thermodynamic uncertainty relations (TURs) bound the precision of thermodynamic currents in autonomous nonequilibrium steady states and constrain the trade-off between power, efficiency, and constancy in heat engines. We study a minimal autonomous heat engine composed of a discrete ratchet that performs work against a constant bias and an underdamped harmonic oscillator acting as an internal stochastic controller. The oscillator autonomously switches the ratchet between hot and cold phases without external periodic driving. In the regime of time-scale separation, the model becomes exactly solvable. We derive analytical expressions for the average current, its fluctuations, and the TUR ratio, showing that the effect of the continuous degree of freedom is fully captured by the Fano factor of oscillator zero crossings. As the internal control becomes more regular, current fluctuations are strongly suppressed and the TUR ratio can approach zero. We also identify regimes where the engine operates near maximal current and high efficiency while exhibiting pronounced TUR violations. These results show that strong TUR violations can arise already in a simple autonomous hybrid system with underdamped control.

POSTER Ferroelectric Twist-Bend Nematic Order from Competing Depolarization and Flexopolarization Energies

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The self-organization of recently discovered nematic phases is a central problem in contemporary soft-matter research [1, 2, 3, 4]. Several of these phases exhibit local or long-range ferroelectric order, in some cases accompanied by emergent structural chirality despite the chemical achirality of their constituent molecules. Prominent examples are the uniform ferroelectric nematic phase NF and the recently discovered heliconical ferroelectric nematic phase NTB,F. Closely related modulated phases, including the twist–bend nematic NTB and the splay–bend nematic NSB, provide a broader framework for understanding the spontaneous emergence of polar order and orientational modulation.

Here we investigate ferroelectric and modulated nematic phases within a generalized Landau–de Gennes framework in which the alignment tensor field **Q** is coupled to the polarization field **P** through bulk polar terms, a screened depolarization contribution, and the lowest-order flexopolarization coupling [5]. We expand both **Q** and **P** in helicity modes and perform global numerical minimization within a class of one-dimensional periodic structures. Within this variational class, the model stabilizes the experimentally observed uniform ferroelectric and heliconical ferroelectric nematic phases, together with additional polar and modulated structures not yet reported experimentally. The resulting phase diagrams map the stability regions of isotropic, uniform apolar, uniform ferroelectric, and spatially modulated nematic phases, and reveal how bulk polarity, depolarization,and flexopolarization jointly govern nematic self-organization. In particular, the NTB,F phase emerges from a balance between the screened depolarization energy associated with splay distortions of the polarization field and the energy gain arising from flexopolarization induced coupled deformations of **Q** and **P**.

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Notes

Wednesday, 23/09		Thursday, 24/09		Friday, 25/09	
09:00 – 09:30	**Opening Address**	09:00 – 09:30	Angelo Vulpiani		
09:30 – 10:00	Raffaella Burioni	09:30 – 10:00	Stefano Ruffo	09:30 – 10:00	Silvia Bartolucci
10:00 – 10:30	Ralf Metzler	10:00 – 10:30	Francesco Caravelli	10:00 – 10:30	Tobiasz Pietrzak
10:30 – 11:00	Enrico Scalas	10:30 – 11:00	Igor Sokolov	10:30 – 11:00	Giuseppe D'Onofrio
11:00 – 11:30	**Coffee Break**	**11:00 – 11:30**	**Coffee Break**	**11:00 – 11:30**	**Coffee Break**
11:30 – 12:00	Luca Angelani	11:30 – 12:00	Marek Kimmel	11:30 – 12:00	Michał Cieśla
12:00 – 12:30	Bartłomiej Dybiec	12:00 – 12:30	Dante Chialvo	12:00 – 12:30	Fernando de Oliveira
12:30 – 13:00	Luisa Beghin	12:30 – 13:00	Jeremi Ochab	12:30 – 13:00	Monika Kurpas
13:00 – 14:00	**Lunch Break**	**13:00 – 14:00**	**Lunch Break**	**13:00 – 14:00**	**Conference Closing & Lunch**
14:00 – 14:30	Lucilla de Arcangelis	14:00 – 14:30	Mirko D'Ovidio		
14:30 – 15:00	Pierpaolo Vivo	14:30 – 15:00	Tadeusz Kosztołowicz		
15:00 – 15:30	Federico Polito	15:00 – 15:30	Enzo Orsingher		
15:30 – 16:00	Alberto Imparato	**15:30 – 17:00**	**Poster Session**		
		20:00 – ...	**Conference Dinner**		