

50 years of Doi-Peliti field theory: applications to critical phenomena, condensed matter physics and active matter

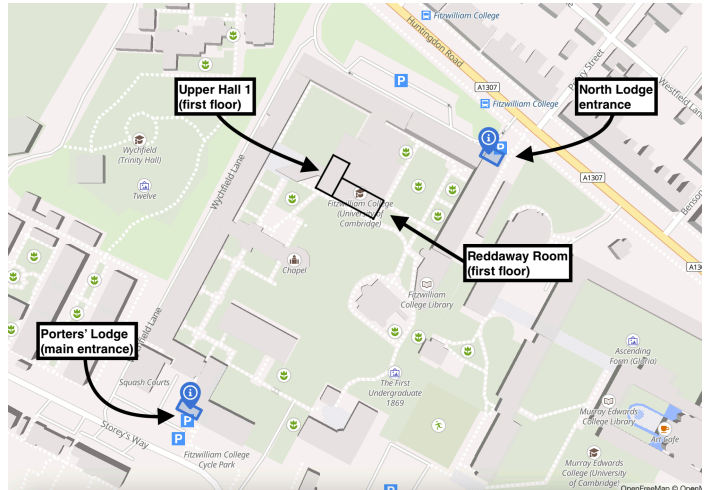
22 Sep 2026 - 25 Sep 2026

Fitzwilliam College,
Storey's Way,
Cambridge CB3 0DG, UK

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Rooms: Reddaway Room and
Upper Hall 1

Conference website



Programme

	Tue 22 Sep	Wed 23 Sep	Thu 24 Sep	Fri 25 Sep
9:00 - 9:30	Coffee & refreshments	Coffee & refreshments	Coffee & refreshments	Coffee & refreshments
9:30 - 10:30	Chair: R Garcia-Millan Welcome L Peliti	Chair: M Cates P Sollich	Chair: G Pruessner History panel discussion	Chair: M te Vrugt M Szymanska
10:30 - 11:00	Coffee & refreshments	Coffee & refreshments	Coffee & refreshments	Coffee & refreshments
11:00 - 12:30	Chair: P Sollich G Pisegna C Britton B Morling	Chair: L Peliti A Baule E Tjhung	Chair: G Pruessner History panel discussion	Chair: G Pisegna B Vollmayr-Lee E Rozas Garcia Closing remarks
12:30 - 13:30	Lunch	Lunch	Lunch	Lunch
13:30 - 15:00	Chair: M Doi E De Giuli Flash talks and poster session	Chair: B Vollmayr-Lee A Sorinca T Sparmann J Öftring F De Luca	Chair: E De Giuli U Täuber J Peltier SH Huang	
15:00 - 15:30	Coffee & refreshments	Coffee & refreshments	Coffee & refreshments	
15:30 - 17:00	Chair: U Täuber I Adjaout E Sezik S Sahu	Cultural visit	Chair: M Szymanska M Del Razo L Chen A Squarcini	
17:00 - 18:00				
18:00			Conference dinner (buffet)	

Organisers

Rosalba Garcia-Millan, King's College London
Gunnar Pruessner, Imperial College London
Peter Spichtinger, Johannes Gutenberg-Universität Mainz
Michael te Vrugt, Johannes Gutenberg-Universität Mainz

Tuesday 22 September 2026

9:00 Coffee & refreshments

Chair: R Garcia-Millan

9:30 Welcome

9:40 Luca Peliti, Santa Marinella Research Institute

Using Cell Lineage Statistics for the Evaluation of Fitness

A prime example of birth-death process is population dynamics. In this process different individuals harbor different traits, which affect their reproduction effectiveness, and might be inherited by their progeny. One of the most relevant questions in this setting is how to evaluate the effect of a trait on reproduction effectiveness—a quantity known as **fitness**. It is possible to estimate the fitness of a trait in a population in which complete genealogies are available by comparing two sampling statistics: a chronological one (forward in time) and a retrospective one (backwards in time), by a method which is reminiscent of the way fluctuation relations are obtained in non-equilibrium statistical mechanics. The method can also be applied when some trees are incomplete, i.e., when lineages terminate. This procedure can be applied, e.g., to evaluate the effect of antibiotics on a bacterial population.

10:30 Coffee & refreshments

Chair: P Sollich

11:00 Giulia Pisegna, Max-Planck-Institut für Dynamik Und Selbstorganisation

Emergent dynamical order from non-reciprocal interactions

Self-organization in living and non-equilibrium systems originates from microscopic interactions constrained by the symmetries and properties of their individual constituents. Yet collective organization can generate effective degrees of freedom, and even macroscopic symmetries, that are absent at the microscopic level. Non-reciprocal active matter provides a striking example: asymmetric interactions between otherwise nonpolar components can spontaneously produce polarity and collective motion.

In this talk, I will present a micro-to-macro approach to non-reciprocal systems. Starting from a microscopic model of phoretically interacting particle mixtures in a dry environment, I will motivate a mesoscopic field theory, the non-reciprocal Cahn-Hilliard model, in which two conserved scalar fields are coupled through non-reciprocal interactions. Despite the absence of microscopic alignment, these couplings generate an emergent polar degree of freedom and a transition to collectively moving states. I will discuss how the resulting polar order remains robust against fluctuations, with its long-wavelength dynamics governed by the Kardar-Parisi-Zhang universality class.

I will then extend this framework to wet environments by incorporating the surrounding fluid and show how hydrodynamic interactions reshape the stability and large-scale dynamics of the ordered states. Finally, I will illustrate how additional microscopic ingredients can be introduced within the same bottom-up framework. In particular, combining single-particle chirality with emergent non-reciprocal polarity produces chiral currents localized at boundaries.

Together, these results establish non-reciprocity as a versatile mechanism through which heterogeneous systems generate collective motion, polar order, and boundary transport.

11:50 Callum Britton, Imperial College London

Non-gaussian fluctuations and moment-based inference by Doi-Peliti Field Theory: the example of microRNA-based circuits

Biological systems are intrinsically noisy and live in noisy environments. Yet, living systems are able to survive and carry out all living functions despite the intrinsic stochasticity of nature. In the context of molecular networks, specific circuit topology has been selected by evolution and appear to be almost universally present across organisms. Understanding why still remains an open question. One prominent such circuit involves microRNAs, small non-coding RNA molecules which target messenger RNAs and degrade

them, thus acting as post-transcriptional regulators. Besides decreasing the number of proteins, microRNAs have been found to shape the final protein distributions, inducing even bimodal distributions in the regime of strong coupling although bistability is absent in the deterministic underlying systems. So far, most of the analytical work has been aimed at predicting the moments of the distributions in the low coupling regime (or high number of molecules regime). In this work, we propose an approach using Doi-Peliti field theory in order to compute with high precision the first two moments of the target distributions in the high coupling regime and low number of molecules regime. We show how our approach is able to capture the onset of non-gaussian fluctuations and it is sufficient to robustly infer kinetic parameters in synthetic and in vitro data.

12:10 Benjamin Morling, University of Guelph

Polymer dynamical self-consistent field theory in the grand canonical ensemble

The non-equilibrium dynamics of inhomogeneous polymer systems undergoing processes that change the number of polymers is an essential component of many biological systems, such as solvent exchange with an external reservoir or the binding of small molecules to a polymer backbone. Our previous theories were formulated in the canonical ensemble, fixing the number of polymers and limiting our ability to describe grand canonical systems (with variable polymer number) without ad hoc modifications to the dynamical equations. To overcome this limitation, we construct a manifestly grand-canonical theory in the Fock space formalism of quantum field theory. We introduce polymer creation and annihilation operators that act to create or destroy polymer chains in a given configuration, obeying bosonic commutation relations. The microscopic dynamics of interacting polymer systems are reformulated as an operator theory capable of naturally describing processes that change polymer number. We introduce bosonic coherent states to convert the operator theory to a field theoretic representation in terms of a complex single chain propagator. In the saddle-point approximation, we obtain a Smoluchowski equation describing the mean-field dynamics of the propagator. The power of this formalism is that chemical reactions between polymer species can be easily constructed in the operator theory, and we can systematically derive the corresponding terms in the mean-field Smoluchowski equation, which is the central equation of the theory. We demonstrate the formalism by showing that a pair of spatially localized reactions that create and destroy chains on the system boundary can be used to model the exchange of chains with an external reservoir, leading to boundary conditions that we had previously imposed ad hoc in our canonical theory. The power and flexibility of this theory to describe the dynamics of interacting grand canonical polymer systems makes this a promising approach for quantitative modeling of biological systems.

12:30 Lunch

Chair: M Doi

13:30 E De Giuli, Toronto Metropolitan University

Noise-control duality

Stochastic systems have a control-theoretic interpretation in which noise plays the role of control. I will argue that the ‘response’ (or ‘momentum’) field π in the Doi-Peliti formalism is a control variable. Although π evolves backward in time, it has a clear physical role as the control that steers the system along rare trajectories. This allows us to consider that nature is constantly sampling control strategies. I will illustrate the mapping on multistable chemical reaction networks, and specifically on stochastic resonance and Brownian ratchets. The noise-control mapping justifies goal-directed descriptions of these phenomena, and builds intuition for otherwise puzzling phenomena of stochastic systems, such as why biological mechanisms can work better in the presence of noise.

14:00 Flash talks and poster session

15:00 Coffee & refreshments

15:30 Idriss Adjaout, Institut Pascal

Beyond Feynman-Kac: Doi-Peliti Path Integrals for Monte Carlo Solutions of Nonlinear Drift-Diffusion Problems

Probabilistic representations such as the Feynman-Kac formula provide a natural basis for mesh-free Monte Carlo methods for solving linear partial differential equations, particularly in high-dimensional, multiphysics, or geometrically complex problems. Extending this approach to nonlinear drift-diffusion equations is more difficult: nonlinearities naturally generate branching stochastic processes, and naive branching estimators may suffer from large variance, instability, or divergence.

We explore the Doi-Peliti formalism as a systematic framework for representing observables of interest through probabilistic path integrals and diagrammatic expansions. The free, non-interacting part is shown to correspond either to the classical backward Feynman-Kac representation or to a forward stochastic representation, depending on the chosen treatment of time. Interaction vertices then encode the reaction events associated with the nonlinear terms.

Using the corresponding Kolmogorov equations, these diagrams can be related to stochastic paths and sampled using Monte Carlo methods. The resulting framework provides a basis for constructing probabilistic estimators for nonlinear reaction-drift-diffusion problems with boundary conditions, motivated in particular by charge-carrier transport in semiconductor devices.

15:50 Emir Sezik, Imperial College London

Non-Equilibrium Steady States using Doi-Peliti Field Theory

Collective behaviour in active matter gives rise to striking phenomena with no equilibrium counterpart. Through the breaking of detailed balance, such systems do not relax to a thermal steady state, allowing them to sustain non-trivial phases. Moreover, being far from equilibrium renders their characterisation difficult: unlike equilibrium systems, one typically lacks analytical control over their stationary distributions. Motivated by this gap, we introduce a general method to access non-equilibrium steady states of interacting active matter systems. By isolating the active terms in the microscopic description, we derive a systematic perturbative expression linking the non-equilibrium steady state to the equilibrium stationary distribution in the limit of vanishing activity. We further show that this expression can be evaluated diagrammatically through the Doi-Peliti field theory framework. Finally, we implement the method on a minimal model and characterise its non-equilibrium steady state.

16:10 Sankarshan Sahu, LPTMC, Sorbonne Université

Supersymmetry, Time Reversal, and Static-Dynamic Decoupling in Model A

In the path integral formulation of Langevin dynamics or Model A, supersymmetry is often identified with time-reversal invariance. We show that these are distinct properties: time reversal requires, in addition to supersymmetry, a reality condition in superspace. Supersymmetric actions can therefore contain time-reversal-odd operators. Nevertheless, supersymmetry and causality protect a closed zero-frequency static sector of the dynamical effective action. Its (functional) renormalization-group flow coincides with that of the equilibrium effective action and determines all equal-time correlation functions. Thus, supersymmetry can preserve equilibrium statics while allowing non-time-reversal-invariant dynamics. As a result, we also show that the probability distribution of the total magnetization in the Ising model can be recovered within the Model A framework.

Wednesday 23 September 2026

9:00 Coffee & refreshments

Chair: *M Cates*

9:30 Peter Sollich, University of Goettingen

Doi-Peliti theory for transient dynamics in nonlinear reaction networks

Predicting the dynamics of chemical reaction networks remains an outstanding challenge, particularly when molecule numbers are low, i.e. when intrinsic stochasticity is high. Solutions to this "forward problem" are also the first step towards the inverse problem of estimating system parameters from observed stochastic trajectories via e.g. likelihood-based inference. Here, we demonstrate how to derive a robust analytical approximation scheme based on a Doi-Peliti path integral description, by combining the Plefka expansion as originally developed for spin glasses with an approximate resummation. We demonstrate the application of the resulting generalized self-consistent bubble resummation (gSBR) method on problems of stochastic gene regulation dynamics, enzyme kinetics and infection dynamics. In each of the cases, we discuss new phenomenology that arises in the regime dominated by intrinsic noise and in comparison with standard approximation methods, and show how our method, on account of its accuracy, is able to successfully capture these effects.

10:30 Coffee & refreshments

Chair: *L Peliti*

11:00 Adrian Baule, Queen Mary University of London

Field-theoretic approach to the passive tracer problem in active matter

The diffusion process followed by a passive tracer in prototypical active media such as suspensions of active colloids or swimming microorganisms differs significantly from Brownian motion, manifest, e.g., in a greatly enhanced diffusion coefficient and non-Gaussian tails of the displacement statistics. While such characteristic features have been extensively observed in experiments, their theoretical derivation from a first-principles treatment of the tracer-swimmer interactions in various density regimes has been a long-standing open problem. Focusing on dilute active suspensions, I discuss how the effective tracer process can be coarse-grained using a field-theoretic approach based on the MSRJD action functional. The result is a universal Poisson representation of the tracer process valid for general interaction forces and a large class of swimmer dynamics [1]. Mathematically, the tracer is shown to be described by a generalized occupation time problem, for which exact solutions are available in specific regimes. The theory captures in particular peculiar non-Gaussian features that appear in the tracer's displacement statistics such as a Lévy flight regime with non-monotonic crossover between two different power-law exponents [2]. Apart from providing a comprehensive framework for the effective tracer dynamics, the theory provides the first validation of the celebrated Lévy flight model from a physical microscopic dynamics.

[1] A. Baule; PNAS 120, e2308226120 (2023)

[2] K. Kanazawa, T. Sano, A. Cairoli, A. Baule; Nature 579, 364 (2020)

11:50 Elsen Tjhung, The Open University

Exact results in stochastic processes with division, death, and diffusion

We consider a generic class of stochastic particle-based models whose state at an instant in time is described by a set of continuous degrees of freedom (e.g., positions), and the length of this set changes stochastically in time due to birth-death processes. Using a master equation formalism, we write the dynamics of the corresponding (infinite) set of probability distributions: this takes the form of coupled Fokker-Planck equations with model-dependent source and sink terms. By systematically integrating out excess degrees of freedom, we obtain the marginal probability distribution, enabling exact calculations of key statistical properties such as average density and correlation functions. We validate our analytical results through numerical Langevin simulations, finding excellent agreement

between theory and simulation. Our method thus provides a powerful tool for tackling previously unsolved problems in stochastic birth-death dynamics.

12:30 Lunch

Chair: B Vollmayr-Lee

13:30 Alexandra Sorinca, King's College London

Field Theory of Coupled Discrete-Continuous Systems

We employ a novel combination of the Doi-Peliti (DP) and Martin-Siggia-Rose (MSR) [1,2] field-theoretic frameworks to study coupled discrete-continuous processes characterized by Poissonian and Gaussian fluctuations respectively. We calculate observables such as particle averages and two-point correlators performing perturbative expansion. Analytical results are validated numerically using Monte Carlo simulations. Linear terms in the perturbative expansion accurately capture numerical results about weak coupling for all parameter regimes. Resummation techniques systematically extend the theory's validity beyond weak coupling within limited parameter regimes. Overall, our combined field-theoretical approach successfully captures nontrivial dynamics arising from nonlinear couplings, with potential applications to cloud dynamics [3] and neurodegenerative diseases [4].

[1] Uwe C Täuber. Critical dynamics: a field theory approach to equilibrium and non-equilibrium scaling behavior. Cambridge University Press, 2014.

[2] Benjamin Walter, Gunnar Pruessner, and Guillaume Salbreux. Field theory of survival probabilities, extreme values, first-passage times, and mean span of non-Markovian stochastic processes. *Physical Review Research*, 4(4):043197, 2022.

[3] Hugh Morrison, Marcus van Lier-Walqui, Ann M Fridlind, Wojciech W Grabowski, Jerry Y Harrington, Corinna Hoose, Alexei Korolev, Matthew R Kumjian, Jason A Milbrandt, Hanna Pawlowska, et al. Confronting the challenge of modeling cloud and precipitation microphysics. *Journal of advances in modeling earth systems*, 12(8):e2019MS001689, 2020.

[4] Thomas PJ Knowles, Michele Vendruscolo, and Christopher M Dobson. The amyloid state and its association with protein misfolding diseases. *Nature reviews Molecular cell biology*, 15(6):384–396, 2014.

13:50 Tobias Sparmann, Johannes Gutenberg-Universität Mainz

Stochastic behavior of coupled Poissonian and Gaussian fluctuations

Natural phenomena often consist of both discrete and continuous quantities. In thunderstorms, for example, the formation of raindrop cascades originates from very few droplet collisions, the probability of which is distinctly influenced by quantities such as temperature and humidity [1]. In this work, we analyze the interplay between a coupled Poissonian (discrete) and Gaussian (continuous) quantity. We investigate the effects of the coupling on distribution shapes and show that continuous density approaches cannot sufficiently capture the coupled system's behavior, which can deviate strongly from the initial Poissonian and Gaussian shape, depending on the coupling strength. Finally, we show that we can capture the numeric behavior of the system using a field-theoretic approach.

[1] K. D. Beheng, The Evolution of Raindrop Spectra: A Review of Microphysical Essentials, in *Rainfall: State of the Science*. American Geophysical Union (AGU), 2010, pp. 29–48.

14:10 Jonas Öftring, Johannes Gutenberg-Universität Mainz

Toward a Field-Theoretic Description of Amyloid Aggregation Dynamics

Amyloid formation is a paradigmatic non-equilibrium process in which soluble protein monomers undergo a transition into highly ordered fibrillar states. At the microscopic level, this transition involves a large, in principle infinite, number of interacting aggregate states distinguished by their length. While existing kinetic frameworks [1, 2] derived from deterministic analyses of rate equations successfully capture averaged experiment observables, they do not explicitly account for fluctuations, correlations, and rare events inherent to stochastic aggregation dynamics. We outline a field-theoretic approach to amyloid aggregation based on the Doi-Peliti formalism, which may provide a systematic route beyond deterministic kinetics.

Starting from a discrete master equation that resolves individual filament lengths, one can formulate a second-quantized description that incorporates elongation, fragmentation, and nucleation processes. This construction naturally leads to a Doi-Peliti action involving an infinite set of fields, one for each aggregate size. Within this framework, classical kinetic equations are expected to emerge as saddle-point equations of the action, providing a controlled connection to existing models. Beyond this limit, the field-theoretic formulation could allow for the systematic computation of fluctuation corrections, correlation functions, and rare-event statistics.

Overall, this approach aims to establish a transparent mapping between microscopic stochastic aggregation mechanisms and macroscopic kinetic laws, while offering a flexible theoretical framework to explore regimes of amyloid self-assembly that are not accessible within standard rate-equation models.

[1] T. C. T. Michaels et al., Amyloid formation as a protein phase transition, *Nat. Rev. Phys.* 5, 379–397 (2023)

[2] T. P. J. Knowles et al., An analytical solution to the kinetics of breakable filament assembly, *Science* 326, 1533–1537 (2009)

14:30 Filippo De Luca, University of Cambridge

Non-local stationary measure in conserved active systems

The stationary measure of equilibrium systems with detailed balance follows a Boltzmann distribution, so that for short-ranged interactions the measure is local, meaning that distant spatial domains are statistically independent. In contrast, active systems break detailed balance, and can have nonlocal stationary measure even for fully local dynamics. Here, by expanding in nonlinearity about a Gaussian-model limit, we construct the measure perturbatively deep in the disordered phase for a class of models that includes Active Model A, Active Model B+, Model AB, the Nonreciprocal Cahn-Hilliard model, and the Toner-Tu model. In this regime, nonlocality is linked to a dynamical conservation law. Our results generically preclude construction of a Landau-Ginzburg expansion of the stationary measure (as opposed to the dynamical equations) for conserved active field theories.

15:00 Coffee & refreshments

15:30 Cultural visit

Thursday 24 September 2026

9:00 Coffee & refreshments

Chair: G Pruessner

9:30 History panel discussion

10:30 Coffee & refreshments

Chair: G Pruessner

11:30 History panel discussion

12:30 Lunch

Chair: E De Giuli

13:30 Uwe C. Täuber, Virginia Tech

Doi-Peliti Field Theory Analysis of Hierarchical and Cyclic Predator-Prey Models

Doi-Peliti field theory tools are applied to analytically study fluctuation and correlation effects in spatially extended stochastic predator-prey systems. In the mean-field rate equation approximation, the classic Lotka-Volterra (LV) model for predator-prey competition is characterized by undamped oscillations for both populations. Based on the path integral representation of the master equation for the corresponding stochastic spatially extended system, a perturbative expansion is devised in the two-species coexistence phase to demonstrate that intrinsic noise induces damping and instabilities toward structure formation, and to compute the fluctuation corrections for the oscillation frequency and diffusion coefficient. The resulting drastic downward renormalization of the frequency and the enhanced diffusivity are in qualitative agreement with Monte Carlo simulations [1].

We next apply a similar analysis to the stochastic spatial Rock-Paper-Scissors (RPS) and May-Leonard (ML) models, in which three species compete cyclically. We find that the qualitative features of the ML model are insensitive to reaction noise. In contrast, the RPS model acquires significant fluctuation-induced renormalizations. We also provide an explanation for the absence of spatial patterns in the RPS system, whereas the spontaneous emergence of spatio-temporal structures features prominently in the LV and the ML models [2]. For the latter, we derive the complex Ginzburg-Landau equation as the effective representation near its Hopf bifurcation and delineate parameter constraints that allow time scale separation and thus a reduction to just two slow degrees of freedom [3].

[1] U. C. Täuber, J. Phys. A: Math. Theor. 45, 405002 - 1-34 (2012); arXiv:1206.2303

[2] L. H. Yao, M. Swailem, U. Dobramysl, and U. C. Täuber, J. Phys. A: Math Theor. 56, 225001 - 1-42 (2023); arXiv:2303.08713

[3] S. R. Serrao and U. C. Täuber, J. Phys. A: Math. Theor. 50, 404005 - 1-16 (2017); arXiv:1706.00309

14:20 Jane Peltier, King's College London

Chirality switching Active Brownian Particles with a continuous switching mechanism

A chiral active Brownian particle is a self-propelled particle whose motion combines straight-line swimming with rotation, so that its trajectory traces out loops in two dimensional space. Some of these particles can spontaneously reverse their rotational direction. They are known as chirality switching Active Brownian Particles (switching cABPs). In existing models the switch is treated as instantaneous, but recent experiments on synthetic chiral swimmers show that the reconfiguration takes a finite time [1].

We develop a new model that captures this delay by introducing a continuous internal degree of freedom whose relaxation timescale sets the duration of the switch. Using a Doi-Peliti field-theoretic approach, we compute statistics of the trajectory and identify clear signatures of the delay. Most notably, we find a skewness in the velocity distribution that is absent when the switch is instantaneous. We also characterise the dynamics around a switching event through two-time correlation functions. These results provide quantitative predictions that we test against experiments.

[1] Alvarez, L., Fernandez-Rodriguez, M. A., Alegria, A., Arrese-Igor, S., Zhao, K., Kröger, M., & Isa, L. (2021). Reconfigurable artificial microswimmers with internal feedback. *Nature Communications*, 12(1), 4762.

14:40 Shih-Huan Huang, University of Cambridge

Exact instantons in a 1D active lattice gas

Rare events are fundamental to understanding phase transitions in interacting particle systems. In particular, the nucleation problem remains of profound interest. In the equilibrium scenario, two nice properties hold: (i) the most probable transition path, or the instanton, from a metastable state (homogeneous) to a transition state (a critical nucleus) is equal to the time-reversal of the relaxation path from the transition state; (ii) the action of the instanton equals the free energy difference between the transition state and the initial state. Those two properties do not hold in the nonequilibrium context. Recent developments in macroscopic fluctuation theory [1] and the minimum action method (MAM) [2] enable us to solve for the exact instanton and characterise the transition state, without prior knowledge of a global free energy landscape. Here, we investigate a 1D active lattice gas (ALG) model, which exhibits mobility-induced phase separation (MIPS) in the hydrodynamic limit. We use MFT and MAM to obtain instantons between a metastable state (homogeneous) and a stable state (droplet). We show that 1D ALG nucleation is similar to equilibrium nucleation. For the evaporation path, we find non-trivial dynamics: non-uniform spatial density bumps arise during the evaporation, yet the transition state is still a single critical nucleus and coincides with that of the nucleation path. Our approach remains valid across the entire metastable region, overcoming the conventional limitations of Classical Nucleation Theory. Our method can be applied to other nonequilibrium systems.

[1] T. Agranov, S. Ro, Y. Kafri, and V. Lecomte, *SciPost Phys.* 14, 045 (2023)

[2] R. Zakine and E. Vanden-Eijnden, *Phys. Rev. X* 13, 041044 (2023)

15:00 Coffee & refreshments

Chair: M Szymanska

15:30 Mauricio Del Razo, Zuse Institute Berlin

Field theories and quantum methods for multiscale complex systems

Many real-world complex systems —from biochemical networks and ecological dynamics to epidemics and socioeconomic models— share a common mathematical structure: agents or particles that move, interact, and change in number. Stochastic reaction-diffusion processes provide a natural and unifying framework to model this broad class of systems, yet their standard probabilistic formulations become unwieldy due to combinatorial complexity arising from nonlinear interactions and varying particle numbers. In this talk, I will show how quantum-inspired methods —second quantization, Fock space, creation and annihilation operators, and path integrals— offer an elegant and powerful alternative. Originally developed for quantum field theory, these tools can be brought into the classical domain of stochastic systems, where they handle combinatorial bookkeeping automatically and enable systematic derivations of emergent behavior at multiple scales. I will present a unifying field theory representation that encompasses previous formulations (Doi, Doi-Peliti, RDME) as special cases, and demonstrate how it yields consistent multiscale numerical schemes and parameter relations across scales. Crucially, while the framework is grounded in reaction-diffusion systems, its structure is sufficiently general to extend to a wide range of complex systems — including population dynamics, neuroscience, social systems and problems in higher dimensions — wherever agents interact and change in number, opening new avenues for multiscale modeling across disciplines.

16:15 Letian Chen, University of Edinburgh

Controlling reentrance in a non-equilibrium Hamiltonian flocking model

The clustering of self-motile and repulsive particles, so-called motility-induced phase separation (MIPS), is one of the clearest signatures of active physics. Typically, increasing the amplitude of self-motility increases the degree of clustering, however for high enough self-motility the homogeneous phase is reentered. Being able to control such reentrance would let active matter not only display distinct exotic phases but also switch between

them on demand. Yet the microscopic origin of this phenomenon remains unclear. Here, we report that such reentrance naturally emerges in a non-equilibrium Hamiltonian flocking model (N-HFM), and is controlled by a single spin-velocity coupling intrinsic to the Hamiltonian. We demonstrate the reentrance of the homogeneous phase and identify the underlying mechanism as a competition between the amplitude of a spin-velocity-coupled drive and kinetic frustration. We reveal, both numerically and analytically, that strong spin-velocity coupling suppresses the transverse and rotational degrees of freedom, which causes a dimensional reduction for the particle dynamics, thereby leading the system into an arrest that closes the window for phase separation. Overall, our work offers a Hamiltonian bridge between reentrant physics across equilibrium and non-equilibrium materials, and turns kinetic frustration into a control strategy for self-assembly.

16:40 Alessio Squarcini, University of Luxembourg

Transport and pair reactions on comb-like graphs: a Doi-Peliti approach

We construct a coherent-state Doi-Peliti theory for unbiased Markovian walkers initially on an infinite one-dimensional backbone with identical side graphs attached through single vertices. Excursions into these graphs suspend longitudinal motion, generating memory from an underlying Markovian dynamics. Exact elimination of the side fields determines the waiting-time distribution between successive backbone jumps through $R(t)$, the probability of occupying the attachment vertex at time t when starting there on the isolated side graph. If $R(t) \sim Ct^{-\beta}$, with $0 < \beta < 1$, the waiting-time density has a tail proportional to $t^{-1-\alpha}$, and the longitudinal scaling limit obeys fractional diffusion of order $\alpha = 1 - \beta$. This recovers familiar transport laws: infinite linear teeth yield a mean-square displacement proportional to $t^{1/2}$, with a non-Gaussian scaling distribution, while planar side lattices yield logarithmic growth. Finite side graphs restore normal diffusion with an exact effective diffusion coefficient. The same construction gives displacement and backbone-jump statistics. Our main results concern pair annihilation, $2A \rightarrow \emptyset$, restricted to the backbone. This interaction preserves the exact elimination of the side fields and leaves the reaction vertices local. Resumming the two-particle contact diagrams gives an exact expression for the Laplace transform of pair survival at arbitrary positive finite reaction rate. For two particles initially at the same backbone site, infinite linear teeth leave a nonzero probability of never reacting, whereas finite teeth ensure eventual annihilation. For long reflecting teeth with N sites, at fixed microscopic hopping and reaction rates, we identify two parametrically separated timescales: longitudinal diffusion becomes normal on a scale proportional to N^2 , while pair survival remains near a plateau whose decay occurs on the longer scale proportional to N^3 . The talk concludes with a brief outlook on a common longitudinal biasing force and spectral properties (in preparation).

18:00 Conference dinner (buffet)
Fitzwilliam College

Friday 25 September 2026

9:00 Coffee & refreshments

Chair: M te Vrugt

9:30 Marzena Szymanska, University College London

From Keldysh to KPZ: Emergent Stochastic Dynamics from Quantum to Living Matter

Over the past fifty years, Doi-Peliti field theory has demonstrated how microscopic stochastic dynamics can give rise to universal collective behaviour far from equilibrium. A related question arises in open quantum systems: how does microscopic driven-dissipative quantum dynamics reduce, at long wavelengths, to an effective classical stochastic description? I will explore this question starting from our early work on exciton-polariton condensates using the Keldysh formalism. Driven polariton condensates can display both equilibrium-like Berezinskii-Kosterlitz-Thouless (BKT) physics and genuinely non-equilibrium Kardar-Parisi-Zhang (KPZ) scaling, with topological defects playing a central role. I will then turn to recent work on two-dimensional photon condensates, whose low-energy dynamics can be described by the noisy Kuramoto-Sivashinsky equation. Here, conventional interactions are essentially absent, with the nonlinearity arising instead from dissipation. Remarkably, the system can nevertheless undergo a BKT transition and, in a different regime, may display KPZ scaling despite substantial density fluctuations.

Finally, I will consider biological pattern formation in populations of the amoeba *Dictyostelium*, where defects in cAMP signalling emerge as cells begin to communicate. Their dynamics exhibits scaling behaviour with features suggestive of compact KPZ dynamics. Moreover, as cell density is increased across the transition from non-communicating to communicating phases, the resulting defect density and signalling-wave patterns point to a Kibble-Zurek mechanism. Together, these examples show how coarse graining can uncover common stochastic dynamics across seemingly disparate systems, from driven quantum condensates to living matter.

10:30 Coffee & refreshments

Chair: G Pisegna

11:00 Ben Vollmayr-Lee, Bucknell University

Nonequilibrium Work Relations in Chemical Reaction Networks from Doi-Peliti Field Theory

We investigate the dynamics of classical particles undergoing diffusion and chemical reactions while coupled to a thermal reservoir and to local chemostats. These particles are driven from equilibrium by local, time-varying potentials. We impose detailed balance on the hopping rates and map the system dynamics to the Doi representation, from which the Jarzynski and Crooks nonequilibrium work relations naturally emerge. We further formulate the Doi-Peliti field theory for these spatially-extended chemical reaction networks in the continuum limit and demonstrate that time-reversal symmetry in this field theory manifests as a gauge-like transformation that leaves the action invariant up to a generated work term. We exploit this symmetry to derive a far-from-equilibrium generalization of the fluctuation-dissipation relation (GFDR). Finally, we present numerical tests of the GFDR to validate these theoretical results.

11:50 Enrique Rozas Garcia, University of Gothenburg

Nucleation in ferromagnetic superfluids

We study thermal nucleation in a one-dimensional ferromagnetic superfluid, a controllable quantum-gas setting for false-vacuum decay. We compute the nucleation rate, which is controlled by the energy cost of a critical droplet (the smallest domain which is more likely to grow than dissipate) and by fluctuations around this configuration. When the stable and metastable phases are nearly degenerate in energy, we obtain analytical results for this critical droplet and use them to develop an effective description of nucleation and subsequent domain growth as a Kramers escape problem. This framework separates the

time scales of nucleation and domain expansion and identifies experimentally accessible signatures of the nucleation rate. Our results provide quantitative predictions for comparison with current experiments on metastable ferromagnetic superfluids.

12:20 Closing remarks

12:30 Lunch

Posters

Thomas Alfonsi, Laboratoire Charles Coulomb

Equilibrium cluster statistics of (anti)cooperative binding on finite one-dimensional rings

Adsorption processes on a finite substrate are widespread among biological machines, such as the Bacterial Flagellar Motor (BFM). The BFM recruits torque-generating units (stators) that bind to the rotor of the bacteria to produce the rotative motion of the flagella [1]. These recruitment dynamics can be modeled using a lattice gas model in contact with a particle reservoir and with short-range interactions between bound particles [2].

To characterize the spatial organization of bound units within the framework of the BFM, exact results at equilibrium were obtained using two different formalisms: an analytical site-based approach employing transfer-matrix and correlation-function methods, yielding closed expressions at finite size, and a cluster-based enumerative combinatorial approach in which configurations are classified by cluster counts and sizes, effectively reducing the state space while still reproducing the cluster statistics exactly. These equilibrium statistics encompass the mean occupancy, the mean number of domain walls, the mean number of clusters, and, for cluster-size observables, the mean cluster size, the mean number of clusters of size k , and the associated cluster-size distributions.

These results allow us, by combining measurements of the mean occupancy with a cluster observable, to constrain the nearest-neighbor coupling more tightly than occupancy-only statistics, complementing approaches that infer (anti)cooperativity strength from occupancy fluctuations alone [2], which can be applied to a wide array of biological systems where short-range interactions seem to play a key role [3][4].

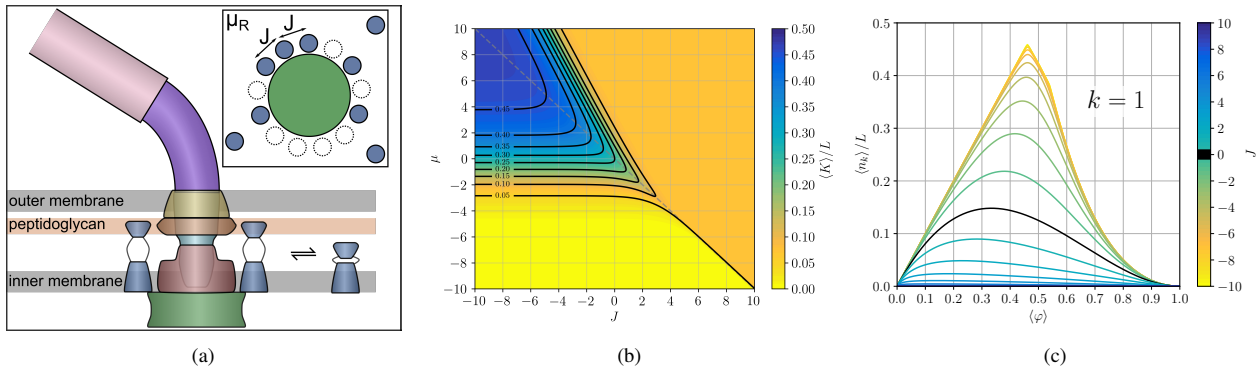


Figure 1: (a) Flagellar motor structure and schematic model. (b) Contour plot and heat map of the normalized mean number of clusters at equilibrium, $\langle K \rangle / L$, as a function of the dimensionless interaction potential J and chemical potential μ . (c) Parametric plot of the normalized mean number of clusters of size $k = 1$ at equilibrium, $\langle n_k \rangle / L$, as a function of the mean relative occupancy $\langle \phi \rangle$.

- [1] A. Baker and G. O'Toole. "Bacteria, Rev Your Engines: Stator Dynamics Regulate Flagellar Motility". In: *Journal of Bacteriology* 199 (2017).
- [2] María-José Franco-Oñate et al. "Signature of cooperativity in the stochastic fluctuations of small systems with application to the bacterial flagellar motor". In: *Scientific Reports* 15.1 (2025).
- [3] Ashley L Nord et al. "Catch bond drives stator mechanosensitivity in the bacterial flagellar motor". In: *Proceedings of the National Academy of Sciences* 114.49 (2017), pp. 12952–12957.
- [4] Weicheng Li et al. "Thermodynamic coupling between neighboring binding sites in homo-oligomeric ligand sensing proteins from mass resolved ligand-dependent population distributions". In: *Protein Science* 31.10 (2022), e4424.

Extended classical nucleation theory for active phase separation in the reversed Ostwald regime

Classical nucleation theory (CNT) is a model to describe how rare fluctuations lead to nucleation and thus describes the kinetics of phase transitions. In Ref. [1], CNT was extended to describe phase separation in Active Model B+ - a scalar field theory for active matter - for the case of positive active surface tension. Here, we further extend the theory to be applicable for negative active surface tensions. In this regime a stable fixed-point radius is expected to be found. Droplets smaller than this radius grow and droplets larger than this radius shrink, i.e. reverse Ostwald ripening. In Ref. [1], the theory was formulated by expanding the order parameter in powers of $1/R$, up to order $1/R$. Here, terms of order $1/R^2$ are included to describe nucleation for negative surface tension. In doing this the effective potential acquires an additional linear contribution. We calculate the prefactor of the linear contribution numerically to determine whether it suffices to capture the nucleation of droplets at negative surface tension that afterwards grow by reversed Ostwald processes.

[1] M. E. Cates and C. Nardini, Phys. Rev. Lett. 130, 098203 (2023)

Rosalba Garcia-Millan, King's College London

Effective attraction by repulsion

Numerical and experimental evidence shows that self-propelled particles that interact repulsively tend to form condensates, a phenomenon known as motility-induced phase separation (MIPS) that defies physical intuition. Active particles tend to accumulate where they move more slowly, and they tend to move slowly where they accumulate, giving rise to a positive feedback that reinforces the formation of dense and dilute regions [1, 2]. The microscopic details of this mechanism and the role of the activity, however, remain elusive.

In this poster, I will present a microscopic theory of soft run-and-tumble particles, that move at constant speed w , tumble with rate α and diffuse with constant D . Particles interact repulsively with strength ν and have a characteristic interaction length ξ . Our exact results establish the link between particle dynamics and the emergent effective attraction between them, as illustrated by the two-point correlation function shown in Fig. 1. I will present the key field theoretic aspects of this active system and the physical insights gained from a microscopic approach [3, 4].

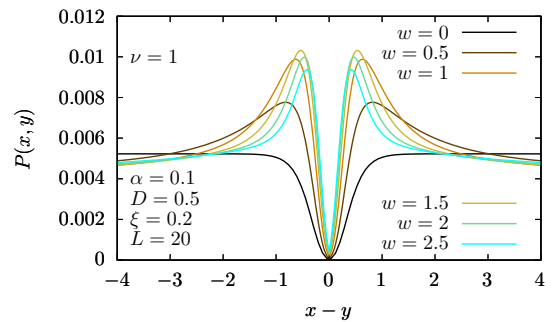


Figure 1: Two-point correlation function between interacting run-and-tumble particles for increasing self-propulsion speed.

[1] M. E. Cates, and J. Tailleur, Annu. Rev. Condens. Matter Phys. 6, 219–244 (2015)

[2] A. Slowman, M. Evans, and R. Blythe, Phys. Rev. Lett. 116, 218101 (2016).

[3] R. Garcia-Millan et al., arXiv:2605.01421 (2026).

[4] R. Garcia-Millan et al., arXiv:2605.01422 (2026).

Consistent hierarchies of (ice) cloud models

Ice clouds, as all clouds, are important components of the Earth-Atmosphere system, influencing Earth's energy budget and the hydrological cycle. For the representation of ice clouds in models on different scales, we have to design meaningful cloud schemes based on the relevant process (as, e.g., nucleation, growth/evaporation, or sedimentation). Since most of these processes are quite complex, we have to derive simple (or even much simpler) schemes, adapted adequately to the scales as resolved in the respective model. The derivation of bulk schemes from the underlying population balance equation is a typical example for such model reduction; this procedure typically results into a set of ordinary differential equations for averaged quantities. Even for such bulk models, simplification of these complex schemes is often necessary for the use in weather models. However, further reduction of the dynamical systems might alter their properties, i.e. the quality of solutions.

In this contribution, a consistent hierarchy of models for ice clouds at low temperatures ($T < 235\text{K}$) is developed. Using several consistent approximations and simplifications, complex (bulk) schemes can be reduced to simpler models, allowing a better understanding of the represented processes. These models are analyzed in terms of qualitative behavior of solutions which sometimes leads to non-linear oscillators [1]. Such models may also guide other model formulation procedures using stochastic approaches.

[1] Bergner, H. and P. Spichtinger, 2026: Ice clouds as nonlinear oscillators. *Chaos*, 36 (4), 043115. doi: 10.1063/5.0297531

Richard Weisbeck, Johannes Gutenberg-Universität Mainz

Multi-parameter nucleation theory for passive and active nematics.

We apply a non-classical nucleation approach to study the formation of a nematic phase from an isotropic phase. By projecting the stochastic continuum dynamics of the tensorial nematic order parameter onto macroscopic reaction coordinates, specifically the droplet radius and the focal distance between boojums, we derive effective Langevin equations governing the droplet geometry. For passive systems, we establish an analytical relationship between the effective tensorial surface tension and the mobility matrix. Extending this formalism to active nematics, we look to demonstrate that non-conservative active stresses manifest as effective non-conservative forces acting on the shape parameters, analogous to the dynamics of an active particle.