DY 57: Poster: Statistical Physics; Critical Phenomena; Stochastic Thermodynamics; Extreme Events; Data Analytics

Time: Thursday 15:00–18:00 Location: P1C

DY 57.1 Thu 15:00 P1C

Collecting and Analysing Formulas for Non-Linear Response — •Tristan Holsten and Matthias Krüger — Georg-August-Universität, Göttingen, Germany

We study, based on a path integral approach, the non-linear responses of interacting systems perturbed by an external stimulus. To reach a better understanding of such systems, we split the perturbative part of the system's action into its time-symmetric and time-antisymmetric, entropic component. Starting from equilibrium or more general from a steady state, relations and knowledge about the interchangeability of these two components are gathered, by evaluating correlation functions. To obtain these correlation functions, we employ series expansions in the strength of perturbation as well as a time transient approach.

DY 57.2 Thu 15:00 P1C

Haldane Insulator in the 1D Nearest-Neighbor Extended Bose-Hubbard Model with a Cavity-Mediated Long-Range Interaction — •Johannes Sicks and Heiko Rieger — Theoretical Physics, Saarland University, Campus E2.6, 66123 Saarbrücken, Germany

In the one-dimensional Bose-Hubbard model with on-site and nearest-neighbor interactions, a gapped phase characterized by an exotic non-local order parameter emerges, the Haldane insulator. Bose-Hubbard models with cavity-mediated global range interactions display phase diagrams, which are very similar to those with nearest neighbor repulsive interactions, but the Haldane phase remains elusive there. Here we study the one-dimensional Bose-Hubbard model with nearest-neighbor and cavity-mediated global-range interactions and scrutinize the existence of a Haldane Insulator phase. With the help of extensive quantum Monte-Carlo simulations, we find that in the Bose-Hubbard model with only cavity-mediated global-range interactions no Haldane phase exists. For a combination of both interactions, the Haldane Insulator phase shrinks rapidly with increasing strength of the cavity-mediated global-range interactions. Thus, in spite of the otherwise very similar behavior, the mean-field like cavity-mediated interactions strongly suppress the non-local order favored by nearest neighbor repulsion in some regions of the phase diagram.

DY 57.3 Thu 15:00 P1C

Large deviations of far-from-equilibrium RNA hairpin work processes — •Peter Werner and Alexander K. Hartmann — Institut für Physik, Carl von Ossietzky Universität Oldenburg

We investigate numerically [1] the work distribution $P(W)$ of a driven unfolding and folding process of secondary structures for simple RNA hairpins [2] of varying sizes. For the simulation of the RNA dynamics, we use a standard Monte Carlo (MC) method with creation and removal of pairs in the secondary structure. We control these MC simulations by a large deviation technique [3] to reach rare realizations of work values, similar to a previous publication [4] on the work distribution of the Ising model. This allows us to reach very small probabilities as small as 10^{-100} and to apply the Jarzynski relation and to confirm the validity of Crooks' theorem for processes far from thermal equilibrium. Furthermore, by directly sampling RNA secondary structures in equilibrium, we calculate the overlap between the equilibrium structures and non-equilibrium ones which allows us to further characterize the rare events.

[1] A.K. Hartmann, *Big Practical Guide to Computer Simulations* (World Scientific, 2015).
[2] D. Collin, F. Ritort, C. Jarzynski, S.B. Smith, I. Tinoco and C. Bustamante, Nature, vol. 437, 231-234, 2005.
[3] A.K. Hartmann, Phys. Rev. E **65**, 056102 (2002).
[4] A.K. Hartmann, Phys. Rev. E **89**, 052103 (2014).

DY 57.4 Thu 15:00 P1C

Many-body Invariants for One-Dimensional Gapped Fermions with Anti-Unitary Symmetry — •Lorenz Mayer and Martin R. Zirnbauer — Universität zu Köln, Institut für theoretische Physik

Following a proposal by S. Ryu, an invariant of ground states of topological insulators and superconductors will be defined and subsequently calculated for fermionic matrix product states (fMPS). This invariant is expressed in terms of the many-body wave-function.

As the calculation rests only on very coarse features of the formalism, this thus is suitable to tighten classification results obtained within the formalism of fMPS, which are of a more algebraic nature.

DY 57.5 Thu 15:00 P1C

Segregation Phenomena of driven Model Colloids in two-dimensional confined Geometries — •Marc Isele, Kay Hofmann, Tobias Vater, Ullrich Siems, and Peter Nielaba — Universität, Konstanz, Deutschland

Brownian dynamics simulations were employed to investigate the segregation phenomena of driven model colloids in two-dimensional confined geometries. The interactions between the colloids were calculated with a repulsive screened Coulomb potential. In the first part, two sorts of spherical particles of different sizes were driven in the same direction. This setting was created since the corresponding experimental setups are supposedly easier to prepare than oppositely driven particles. A segregation occurred that is similar to the lane formation of oppositely driven colloids. In a second setup, a closer look was taken at oppositely driven particles in circular channels. Here, not only lane formation was observed but also a previously unknown effect of bands forming perpendicularly to the channel walls.

DY 57.6 Thu 15:00 P1C

Capturing large fluctuations in the dynamics of biochemical reaction networks — •Maximilian Kurjahn[1], Ander Movilla[2], and Peter Sollich[1,2] — [1]University of Göttingen, Institute for Theoretical Physics, 37077 Göttingen, Germany — [2]Department of Mathematics, King's College London, Strand, London WC2R 2LS, UK

Biological systems such as gene expression and metabolism can often be described by chemical reaction networks. Their dynamics is governed by a chemical master equation that cannot be solved analytically, so approximations are necessary. Standard approaches such as the linear noise approximation predict Gaussian fluctuations into the unphysical regime of negative concentrations, particularly when small mean molecule numbers lead to large fluctuations.

We present an alternative approach that works with Poisson fluctuations and is based on a Doi-Peliti coherent state path integral representation of the dynamics. To this we apply the Plefka expansion, a systematic approximation technique from the physics of glasses.

Up to first order the standard mass action kinetics are recovered that describe the dynamics for large molecule numbers. An accurate description in the large fluctuation regime of low copy numbers is obtained by a second order Plefka expansion. The method can be taken further by constraining as order parameters not just first moments but also second moments, i.e. time correlations.

We demonstrate the approach on simple but paradigmatic reaction networks from systems biology, comparing with the results of mass action kinetics and full stochastic simulations.

DY 57.7 Thu 15:00 P1C

Machine Learning the Anderson Transition — Djénabou Bayo[1], •Andreas Honecker[1], and Rudolf Römer[1,2] — [1]Université de Cergy-Pontoise, LPTM (UMR8089 of CNRS) , F-95302 Cergy-Pontoise, France — [2]University of Warwick, Coventry, CV4 7AL, United Kingdom

The Anderson metal-insulator transition (MIT) is characterized by a transition from a delocalized to a localized state in presence of high disorder. This phenomenon has been investigated for many years and numerical studies have given valuable insight through the determination of the critical properties of the localization length, for example. Machine Learning (ML) and Deep Learning (DL) techniques are still relatively new methods when applied to physics. Recent work shows that ML/DL techniques allow to detect quantum phase transitions directly from images of computed quantum states. The 3D Anderson model is a good candidate for this kind of analysis because of relatively easy access to its quantum states close to the MIT. Here, we implement ML/DL techniques to identify the MIT and to characterize its universal properties. We employ a standard image classification

strategy with a multi-layered convolutional neural network. Common ML/DL libraries such as Keras, TensorFlow and FastAI are used in our implementation. We find that a classification by disorder and a reconstructing of the phase diagram appear possible.

DY 57.8 Thu 15:00 P1C

Subharmonic oscillations in stochastic systems under periodic driving — •Lukas Oberreiter[1], Andre Cardoso Barato[2], and Udo Seifert[1] — [1]II. Institut für Theoretische Physik, Universität Stuttgart, 70550 Stuttgart, Germany — [2]Department of Physics, University of Houston, Houston, Texas 77204, USA

Subharmonic response is a well-known phenomenon in, e.g., deterministic nonlinear dynamical systems. We investigate the conditions under which such subharmonic oscillations can persist for a long time in open systems with stochastic dynamics due to thermal fluctuations. In contrast to stochastic autonomous systems in a stationary state, for which the number of coherent oscillations is fundamentally bounded by the number of states in the underlying network [1], we demonstrate that in periodically driven systems, subharmonic oscillations can in principle remain coherent forever, even in networks with a small number of states [2]. We also show that, *inter alia*, the thermodynamic cost rises only logarithmically with the number of coherent oscillations in a model calculation. By interpreting our finite state model as a single subharmonically oscillating spin, we can construct an interacting spin system, which above a critical coupling strength subharmonically oscillates in synchrony.

[1] A. C. Barato and U. Seifert *Phys. Rev. E* **95**, 062409, (2017)
[2] L. Oberreiter, U. Seifert, and A. C. Barato *Phys. Rev. E* **100**, 012135, (2019)

DY 57.9 Thu 15:00 P1C

Long-range correlated bonds for the two-dimensional Ising spin glass: is there an ordered phase? — •Lambert Muenster, Christoph Norrenbrock, and Alexander K. Hartmann — Institut für Physik, Carl-von-Ossietzky Universität Oldenburg, Oldenburg (Germany)

The standard short-range two-dimensional Ising spin glass does not exhibit an ordered low-temperature phase [1]. Motivated by work that was done on the random field Ising magnet [2] we investigate the two-dimensional Ising spin glass model with long-range spatially correlated bonds. The bonds are drawn from a a standard normal distribution with a two point correlation for bond-distance r that decays as $1/(r+1)^a$, $a > 0$. Whether there exists an ordered low-temperature phase is investigated via the scaling of domain wall exitations from the ground state that are induced to the system by applying different boundary conditions. By utilizing the Kasteleyn city approach [3] to numerically calculate the ground states and corresponding excited states, systems sizes up to $N = 724^2$ spins were studied.

Our results indicate that the correlation do not inflict a global ordered spin-glass phase at finite temperature.

[1] A.K. Hartmann and A.P. Young, Phys. Rev. B. **64**, 180404 (2001).
[2] B. Ahrens and A.K. Hartmann, Phys. Rev. B. **84** 144202 (2011).
[3] Creighton K. Thomas and A. Alan Middleton, Phys. Rev. B. **76**, 220406(R) (2007).

DY 57.10 Thu 15:00 P1C

Theoretical study the heat rectification via a superconducting artificial atom — •Meng Xu, Juergen Stockburger, and Joachim Ankerhold — Institute for Complex Quantum Systems and IQST, University of Ulm, 89069 Ulm, Germany

Rectification of heat transfer at nanoscales have received increasing attention in theoretical and experimental fields. Here, We theoretically studied the heat rectification via a superconducting artificial atom where a superconducting transmon qubit coupled to two strongly unequal resonators terminated by mesoscopic heat baths. In the simulations, we have combined Hierarchical equations of motion (HEOM) and tensor network (TN) methods to efficiently study this complex system dynamics.

DY 57.11 Thu 15:00 P1C

Escape from Metastable States Driven by Asymmetric Non-Gaussian Noise — •Daniel Pflüger[1], Adrian Baule[2], and Peter Sollich[1] — [1]Institut für Theoretische Physik, Georg-August-Universität Göttingen, Deutschland — [2]School of Mathematical Sciences, Queen Mary University of London, United Kingdom

The escape of Brownian particles trapped in a metastable state was originally investigated by Kramers and finds numerous applications, e.g. in the Arrhenius rate formula for chemical reactions. The underlying assumption is that the escape process is driven by Gaussian white noise. For particles in granular gases or solutions of bacterial swimmers this is no longer appropriate. We therefore consider the problem of escape from a metastable state driven by the most general kind of noise process that is stationary and uncorrelated in time. Such a noise process is a combination of Gaussian white noise and Poissonian shot noise with an arbitrary amplitude distribution. We show that an analogue of Kramers' low-temperature limit can be constructed, and use this to investigate the effect of the noise statistics on the transition rates; these can be exponentially larger than in the Gaussian case. We focus in particular on the effects of asymmetry in the noise amplitude distribution, generalizing earlier work on one-side exponential noise. We also investigate applications to systems with multiple reaction coordinates, where the selection of the most likely transition path can become dependent on the noise statistics.

DY 57.12 Thu 15:00 P1C

Clarifying the Case of Zero - Temperature Coarsening — •Denis Gessert, Henrik Christiansen, and Wolfhard Janke — Institut für Theoretische Physik, Leipzig University, Germany

For coarsening to any temperature below the critical temperature of the non-conserved Ising model exponent 1/2. For the last 30 years, also including very recent work, it was not possible to clearly perform nonequilibrium simulations on GPUs with more than 1 billion spins, allowing us to finally in three spatial dimensions theory predicts a power-law growth of domains of like spins with observe this growth-law when the quench temperature was set to absolute zero. We here beyond question confirm the theory.

DY 57.13 Thu 15:00 P1C

Impurity-induced Wavefunction Scarring on curved surfaces — •Michael Kraus, Dominik Schulz, and Jamal Berakdar — Martin-Luther Universität Halle-Wittenberg, Halle (Saale), Germany

Quantum Scarring is a phenomenom where Eigenstates of a quantum chaotic system show enhanced probability along short periodic orbits. Recently, it has been shown that strong scarring occurs by perturbing quantum oscillator systems with localized impurities. [2] Among others, magnetic fields, impurity strength and their positioning can be used to control Scars. [3] Moreover, this effect is accompanied by very efficient wave-packet dynamics which opens the possibility for useful quantum-transport applications. In this work we address the influence of curvature (systems like cylinders and tori) by using the thin-layer approximation and additionally introduce Rashba-type spin-orbit coupling along the surface.

[1] E. Heller, Phys. Rev. Let. 53, (1984); [2] P. Luukko, et al., Sci. Rep. 6, 37656 (2016); [3] J. Keski-Rahkonen, et al., Phys. Rev. B 96, 094204 (2017);

DY 57.14 Thu 15:00 P1C

CFD simulation of the wind field over a terrain with sand fences: Critical spacing for the wind shear velocity — Izael Araújo Lima[1], •Eric Josef Ribeiro Parteli[2], Yaping Shao[2], José Soares Andrade Jr.[1], Hans Jürgen Herrmann[1,3], and Ascânio Dias Araújo[1] — [1]Departamento de Física, Universidade Federal do Ceará, Fortaleza, Brazil — [2]Department Geowissenschaften, Universität zu Köln, Cologne, Germany — [3]PMMH, ESPCI Paris, France

Sand fences are often erected to reduce wind speed and prevent aeolian soil erosion. However, the search for the most efficient array of fences by means of field experiments alone poses a challenging task. Here we apply Computational Fluid Dynamic simulations to investigate the three-dimensional structure of the turbulent wind field over an array of fences. We find that the area of soil associated with wind shear velocity values smaller than the minimal threshold for sand transport has two regimes, depending on the spacing L_x between the fences. When L_x is smaller than a critical value L_{xc}, the wake zones associated with each fence are inter-connected (regime A), while these wake zones appear separated from each other (regime B) when L_x exceeds this critical value of spacing. The system undergoes a second order phase transition at $L_x = L_{xc}$, with the cross-wind width of the protected zone scaling with $[1 - L_x/L_{xc}]^\beta$ in regime A, with $\beta \approx 0.32$. Our findings have implication for a better understanding of aeolian transport in the presence of sand fences, as well as to develop optimization strategies for anti-desertification measures.

DY 57.15 Thu 15:00 P1C

Graph properties of metabolic networks reveals optimization for self-preservation — •Máté Józsa and Zsolt Iosif Lázár — Babeş-Bolyai University, Cluj-Napoca, Romania

Exploring the properties of living systems is a common topic for most fields of sciences, yet there is no comprehensive theory, that describes the most basic elements. In our search for the fundamental properties of life forms, we studied the topology of metabolic networks of thousands of organisms using carefully randomized counterparts as null model. In order to identify metabolism specific graph properties the same procedure was carried out also on other types of real networks. The discovered and quantified patterns may be the corner stones of any biochemical network of living systems: fast dynamics of the chemical processes, and optimal transport, that is, efficient distribution of chemical elements over the network. The stability of these properties, that is, resistance to network failures due to environmental effects also appears to be optimized in metabolic networks. The results suggest that modularity might arise as a consequence of these simultaneous optimizations.

DY 57.16 Thu 15:00 P1C

Immune Repertoire Dynamics across the Human Lifespan — •Mario Udo Gaimann[1,2], Jonathan Desponds[3], and Andreas Mayer[1] — [1]Lewis-Sigler Institute for Integrative Genomics, Princeton University — [2]Arnold Sommerfeld Center for Theoretical Physics and Center for NanoScience, LMU Munich — [3]NSF-Simons Center for Quantitative Biology, Northwestern University

Adaptive immunity relies on the dynamics of cells with specific receptors. The number of cells with the same receptor, the clone size, is known to be remarkably varied. However, the dynamical processes shaping this broad distribution remain poorly understood. Here, we develop a mathematical theory of T cell dynamics across the human lifespan compatible with statistical laws revealed by immune repertoire sequencing. We demonstrate that the frequency of large clones follows power-law scaling with a reproducible exponent across cohorts that is largely independent of age. We explain the early onset of scaling through a model for the establishment of the immune memory repertoire in infancy. We then derive predictions for how fast fluctuating selection allows later recruited clones to replace those founded early and compare them to experimental observations. We find a long-lived incumbency effect suggesting that ongoing selection only slowly reshapes the initial hierarchy of clone sizes. Together, our work provides a mechanism for how dynamical processes in infancy can have a large and long-lasting influence on the adaptive immune system with implications for pathogen defense and autoimmunity.

DY 57.17 Thu 15:00 P1C

Feedback in optical microcavity arrays — •Rebecca Cizek, Jakob Kreismann, and Martina Hentschel — TU Ilmenau, Ilmenau, Germany

Arrays of coupled optical microcavities are a rich and interesting model system with a big potential for applications [1]. Their functionality relies on the mutual coupling between the individual mircoresonators. Here, we study in detail how the coupling between two asymmetric optical microresonators depends on their geometric properties like distance, orientation, cavity size and resonance detuning based on numerical wave simulations using the FDTD package MEEP. In particular, we characterize the robustness of coupling and feedback in detuned cavities that is of special importance for applications where detuning can result from fabrication imperfections.

[1] J. Kreismann, J. Kim, M. Bosch, M. Hein, S. Sinzinger, and M. Hentschel, Superdirectional light emission and emission reversal from microcavity arrays, Phys. Rev. Research 1, 033171 (2019).

DY 57.18 Thu 15:00 P1C

Ray-wave correspondence in graphene billiards with sources — •Jule Katharina Schrepfer[1], Ming-Hao Liu[2], Klaus Richter[3], and Martina Hentschel[1] — [1]TU Ilmenau, Ilmenau, Germany — [2]National Cheng Kung University, Tainan, China — [3]Universität Regensburg, Regensburg, Germany

Graphene billiards are cavities for pseudo-relativistic electrons where trapping is modified by Klein tunneling. There are similarities to optical billiards that have proven to be an interesting model system for quantum chaos in open systems. However, the possibility to tune the effective refractive index of graphene billiards by means of gate voltages makes their study particularly interesting. In the presence of sources, properly tuned gate voltages lead a distinct lensing effect that collimates electrons in a narrow area near the graphene billiard. This lensing effect is seen both in wave simulations and ray modelling with a nice correspondence throughout the midfield of the graphene cavity. The position of the focal area can be controlled not only via the source position but also via gate voltages.