TT 36: Brownian Motion (jointly with DY)

Time: Tuesday 10:00–13:00 Location: ZEU 147

TT 36.1 Tue 10:00 ZEU 147

Convex Hulls of Random Walks in High Dimensions: A Large-Deviation Study — •Hendrik Schawe[1], Alexander K. Hartmann[1], and Satya N. Majumdar[2] — [1]Institut für Physik, Carl von Ossietzky Universität Oldenburg — [2]Laboratoire de Physique Théorique et Modèles Statistiques, Université de Paris-Sud

We study the convex hulls of random walks in high dimensions, i.e., the smallest convex polytope enclosing the trajectory of a random walk with T steps. While the convex hulls of two-dimensional random walks are decently studied [1, 2], very little is known about the convex hulls of random walks in $d \geq 3$. Using Markov chain Monte Carlo sampling-techniques, we can study a large part of the support of the distributions of the volume V of the convex hulls or its surface ∂V. This enables us to reach probability densities below $P(A) = 10^{-800}$ and scrutinize large-deviation properties. Similar to two-dimensional random walks, the probability densities show a universal scaling behavior dependent on the exponent $\nu = 0.5$ and the *effective* dimension of the observable, i.e., $d_{\mathrm{eff}} = d$ for V and $d_{\mathrm{eff}} = d-1$ for ∂V. Further, we determined the rate function $\Phi(\cdot) = -\frac{1}{T}\log P(\cdot)$ which shows convergence to a limit shape for $T \to \infty$, which seems to be a power law with an exponent only dependent on d_{eff} and ν.

[1] G. Claussen, A. K. Hartmann, and S. N. Majumdar, Phys. Rev. E **91**, 052104 (2015); [2] T. Dewenter, G. Claussen, A. K. Hartmann, and S. N. Majumdar, Phys. Rev. E **94**, 052120 (2016)

TT 36.2 Tue 10:15 ZEU 147

The transient subdiffusive behavior of particles in mucus — •Thomas John[1], Matthias Ernst[2], Marco Günther[2], Ulrich Schäfer[3], Christian Wagner[1], and Claus-Michael Lehr[4] — [1]Experimental Physics, University of Saarland — [2]Faculty of Engineering, University of Applied Sciences, Saarbrücken — [3]Helmholtz Institute for Pharmaceutical Research Saarland — [4]Biopharmaceutics and Pharmaceutical Technology, University of Saarland

Biological barriers are crucial in protecting our body from environmental influences. Well-known outer barriers are intestinal, pulmonary, nasal, buccal, cervico-vaginal and dermal barriers. Except for the dermal barrier, all these are covered by a mucus layer, providing an additional barrier to the epithelial cell layer.

We have applied a model to explain the reported subdiffusion of particles in mucus, based on the measured mean squared displacements (MSD). The model considers Brownian diffusion of particles in a confined geometry, made from permeable membranes. The applied model predicts a normal diffusive behavior at very short and long time lags, as observed in several experiments. In between these time scales, we find that the "subdiffusive" regime is only a transient effect, $MSD \propto \tau^{\alpha}$, $\alpha < 1$. The only parameters in the model are the diffusion-coefficients at the limits of very short and long times, and the distance between the permeable membranes L. Our numerical results are in agreement with published experimental data for realistic assumptions of these parameters.

This work was submitted and accepted in the Biophysical Journal.

TT 36.3 Tue 10:30 ZEU 147

Non-Gaussian Statistics of Tracer Positions in Fluids Stirred by Microswimmers — •Thomas John[1], Levke Ortlieb[1], Philippe Peyla[2], Salima Rafaï[2], and Christian Wagner[1] — [1]Experimental physics University of Saarland — [2]Laboratoire Interdisciplinaire de Physique, Grenoble

We performed statistical analyses on the measured positions of μm-sized tracer particles in liquids stirred by the microswimmer *Chlamydomonas reinhardtii*. Various tracer diameters, swimmer concentrations and mean swimmer velocities were examined. The statistical characteristics are compared with predictions from various models. Our observed mean squared displacement of the tracer is linear over more than two order of magnitudes in time. The underlying probability density function ($pdf(\Delta t)$) of the displacements has a Gaussian core from the Brownian motion and non-Gaussian tails from the interactions with the flow field from the swimmers. The *pdf* shows a transient diffusive scaling behavior at short times. This scaling breaks down at times longer than few seconds. Our results are in very good agreement with the predictions of the microscopic model by Thiffeault, PRE **92** 023023(2015).

TT 36.4 Tue 10:45 ZEU 147

Dynamically Crowded Solutions of Brownian Needles — •Sebastian Leitmann[1], Felix Höfling[2], and Thomas Franosch[1] — [1]Institut für Theoretische Physik, Universität Innsbruck, Technikerstraße 21A, A-6020 Innsbruck, Austria — [2]Fachbereich Mathematik und Informatik, Freie Universität Berlin, Arnimallee 6, 14195 Berlin, Germany

We perform Brownian dynamics simulations of solutions of infinitely thin needles up to densities n deep in the semidilute regime. With increasing density, the motion of a needle becomes increasingly restricted to a sliding back-and-forth movement in a tube composed of the surrounding needles. From the density-dependent behavior of the rotation and the translation we extract the corresponding longtime transport coefficients and corroborate the scaling behavior of $\sim n^{-2}$. The characteristic algebraic decay of $\sim t^{-1/2}$ in the intermediate scattering function and a plateau over many decades in time in the non-Gaussian parameter represent a fingerprint of the sliding motion of the needle within the tube. We show that on coarse-grained time and length scales, the dynamics of a needle in solution is captured by a single needle (phantom needle) with the extracted transport coefficients as input parameters [1] as anticipated from the tube theory of Doi and Edwards [2]. We also compare the dynamics to needle Lorentz systems where a single tracer needle explores a quenched array of other needles.

[1] S. Leitmann, F. Höfling, and T. Franosch, Phys. Rev. Lett. 117, 097801 (2016). [2] M. Doi and S. F. Edwards, J. Chem. Soc., Faraday Trans. 2 74, 560 (1978).

TT 36.5 Tue 11:00 ZEU 147

Electronic and photonic counting statistics as probes of non-equilibrium quantum dynamics — •Björn Kubala[1], Joachim Ankerhold[1], and Andrew D. Armour[2] — [1]Institute for Complex Quantum Systems and IQST, Ulm University, Ulm, Germany — [2]School of Physics and Astronomy, University of Nottingham, Nottingham, UK

The emission of radiation generated by the flow of charges through a mesoscopic conductor depends not just on the properties of the conductor itself, but also on those of its electromagnetic environment. Coupling a conductor to a high-quality electromagnetic cavity generates strong mutual feedback which can lead to novel far-from-equilibrium regimes where the charge current and the photon flux leaking out of the cavity are both determined by the nonlinear behavior of the combined system. Using a voltage-biased Josephson junction as an example, we investigate how the photonic and charge current statistics are related to each other and to the underlying coupled dynamics in the non-equilibrium regime. We demonstrate that there is a simple connection between the full counting statistics of the charges and the photons in the long time limit. We also show that measurements of photon statistics would signal the crossover from linear to nonlinear dynamics in the conductor-cavity hybrid through the emergence of highly coherent charge transport.

[1] B. Kubala, J. Ankerhold, and A. D. Armour, arXiv:1606.02200

15 min. break

TT 36.6 Tue 11:30 ZEU 147

Anomalous statistics and ergodicity breaking in a semi-classical electron transfer dynamics — •Igor Goychuk — Institute for Physics and Astronomy, University of Potsdam, Karl-Liebknecht-Str. 24/25, 14476 Potsdam-Golm, Germany

Can statistical properties of single-electron transfer events be correctly predicted within a common equilibrium ensemble description? This fundamental in nanoworld question of ergodic behavior is scrutinized within a very basic semi-classical model of electron transfer. It is shown that in the limit of non-adiabatic electron transfer (weak tunneling) well-described by the Marcus-Levich-Dogonadze (MLD) rate the answer is yes. However, in the limit of the so-called solvent-controlled adiabatic electron transfer, a profound breaking of ergodicity occurs. Namely, for sufficiently large activation barriers, the ensemble survival probability in a state remains always nearly exponential with the inverse rate given by the sum of the adiabatic curve crossing (Kramers) time and the inverse MLD rate. In contrast, near to adiabatic regime, the single-electron survival probability is clearly non-exponential, even though it possesses an exponential tail which agrees well with the ensemble description. Initially, it is well described by a Mittag-Leffler distribution with a fractional rate. Paradoxically, the mean transfer time in this classical on the ensemble level regime is well described by the inverse of nonadiabatic quantum tunneling rate on a single particle level. An analytical theory is developed which perfectly agrees with stochastic simulations and explains our findings.

TT 36.7 Tue 11:45 ZEU 147

Strong coupling, non-Markovian transport: Transient deviations from fluctuation-dissipation theorems — •Javier Cerrillo, Maximilian Buser, and Tobias Brandes — Institut für Theoretische Physik, Technische Universität Berlin, Hardenbergstraße 36, 10623 Berlin

Transient dynamics of transport settings in the strong coupling and non-Markovian regimes are expected to exhibit deviations from steady state fluctuation-dissipation theorems. We show that these may be exactly quantified in terms of equilibration dynamics under alternative measurement schemes. This relation holds far from equilibrium and extends to high-order transport cumulants. In order to explore the strong-coupling, non-Markovian regime where these deviations are expected to be strongest, a new simulation method based in a hierarchy of equations of motion has been developed for the computation of arbitrary cumulants in transport settings. We instantiate our proposal with the study of deviations of high-order cumulants of energetic transport between two baths connected via a few level system.

TT 36.8 Tue 12:00 ZEU 147

Full counting statistics in the non-Markovian, strong-coupling regime - a hierarchy of equations of motion approach — •Maximilian Buser, Javier Cerrillo, and Tobias Brandes — Institut für Theoretische Physik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany

Within the framework of open quantum systems, we present a new numerical approach to full-counting statistics (FCS) of environmental observables. It is based on the hierarchy of equations of motion (HEOM) technique, a well-established method for the simulation of general multilevel open systems. Thereby, our method directly inherits the key advantages from the HEOM. It faithfully represents non-Markovian effects of the environment and is non-perturbative in the open system-environment coupling strength. Additionally, arbitrary time dependencies of the system Hamiltonian are correctly treated. Here, we focus on usual two-point measurement statistics and show how the back-effect accompanying the initial measurement becomes especially relevant within the now accessible regime. We exemplify our method with a discussion of energetic fluxes trough open systems which are subject to environmental far from equilibrium constraints and study the effect of time-dependent control on the system.

TT 36.9 Tue 12:15 ZEU 147

Ratchet with tunable asymmetry based on φ Josephson junction: operation, loading & efficiency. — •Edward Goldobin[1], Rosina Menditto[1], Martin Weides[2], Hermann Kohlstedt[3], Dieter Koelle[1], and Reinhold Kleiner[1] — [1]Physikalische Institut, Universität Tübingen, Auf der Morgenstelle 14, 72076, Tübingen, Germany — [2]Physikalisches Institut, Karlsruher Institut für Technologie, 76128 Karlsruhe, Germany — [3]Nanoelektronik, Technische Fakultät, Christian-Albrechts-Universität zu Kiel, D-24143 Kiel, Germany

We demonstrate experimentally the operation of a deterministic Josephson ratchet with tunable asymmetry [1]. The ratchet is based on a φ Josephson junction with a ferromagnetic barrier [2] operating in the underdamped regime. The ratchet operation with a load, i.e. in the presence of the additional dc counter current trying to stop the ratchet, is also demonstrated. Under these conditions the ratchet produces a non-zero output power. We estimate the efficiency of the ratchet using a general model for Josephson ratchets with hysteresis [3].

[1] R. Menditto, et al. Phys. Rev. E **94**, 042202 (2016).
[2] H. Sickinger, et al. Phys. Rev. Lett. **109**, 107002 (2012).
[3] E. Goldobin, et al., Phys. Rev. E **94**, 032203 (2016).

TT 36.10 Tue 12:30 ZEU 147

Particle transport using rocking Brownian motors — •Christian Schwemmer[1], Stefan Fringes[1,2], Colin Rawlings[1], and Armin Knoll[1] — [1]IBM Research - Zurich, Switzerland — [2]Institute of Physical Chemistry, University of Zurich, Switzerland

Inspired by how intracellular transport is achieved in nature [1], artificial Brownian motors have been designed to allow for particle transport in fluids [2]. The two main requirements are a spatially asymmetric potential and an external driving force. For our implementation, we utilize a novel approach to transport 60 nm gold particles inside a nanofluidic slit. In detail, we use the electrostatic interaction between the gold particles and surfaces to define, similar to geometry induced trapping [4], a potential landscape. Therefore, one of the confining surfaces is patterned with a 3D ratchet topography by thermal scanning probe lithography [3] which then directly translates to a potential landscape. In contrast to most previous experiments which used flashing ratchets, we realized a rocking ratchet by applying a zero-mean AC electric field across the slit delivering high particle drift speeds of up to 100 μm/s. Experimentally, we could further show that the potential landscape and thus the transport properties strongly depend on the particle size and the gap distance of the slit. By exploiting this property, we plan to develop a fast and highly selective nanoparticle sorting device.

[1] Vale et al., Science, **288**, 88, (2000)
[2] Hänggi et al., Rev. Mod. Phys, **81**, 387, (2009)
[3] Pires et al., Science, **328**, 732, (2010)
[4] Krishnan et al., Nature, **467**, 692, (2010)

TT 36.11 Tue 12:45 ZEU 147

Brownian Carnot Engine — •Edgar Roldan[1], Ignacio A. Martinez[2,3], Luis Dinis[3], Juan MR Parrondo[3], Raul A. Rica[4,5], and Dmitry Petrov[4] — [1]Max Planck Institut fur Physik Komplexer Systeme — [2]Ecole Normale Superieure de Lyon — [3]Universidad Complutense de Madrid and GISC — [4]ICFO The Institute of Photonic Sciences — [5]Universidad de Granada

The Carnot cycle imposes a fundamental upper limit to the efficiency of a macroscopic motor operating between two thermal baths. However, this bound needs to be reinterpreted at microscopic scales, where molecular motors and some artificial micro-engines, operate. Energy transfers in microscopic systems are random and thermal fluctuations induce transient decreases of entropy, allowing for possible violations of the Carnot limit. Nearly two centuries after Carnot's work, we report an experimental realization of a Carnot engine with a single optically trapped Brownian particle as the working substance. We present an exhaustive study of the energetics of the engine and analyse the fluctuations of the finite-time efficiency, showing that the Carnot bound can be surpassed for a small number of non-equilibrium cycles. As its macroscopic counterpart, the energetics of our Carnot machine exhibits basic properties that one would expect to observe in any microscopic energy transducer operating with baths at different temperatures. Our results characterize the sources of irreversibility in the engine and the statistical properties of the efficiency, an insight that could inspire new strategies in the design of efficient nano-motors.