**Higgs Centre Workshop: New Vistas in Stochastic Resetting**

**(17-19 June 2024)**

**Speaker Abstracts**

Resetting expedites quantum hitting times
**Eli Barkai** (Bar Ilan University)

Classical random walks with resetting are important stochastic processes with many applications. We study monitored quantum walks with resetting to expedite search pro- cesses on quantum computers. The resetting is shown to maintain the quantum supremacy of fast search due to constructive interference while eliminating the well known problem of quantum dark states. Quantum oscillations impact the resetting problem, leading to multiple minima of the mean hitting time versus the resetting time. A restart uncertainty relation for monitored quantum walks is derived and tested on a quantum computer. The effects of resetting, are particularly pronounced close to quantum resonances of the mean hitting time, even if it is by far smaller than the reset time. This effect is related to a topological transition, where the mean hitting time divided by the sampling time, in the absence of resetting, jumps discontinuously from one integer value to another, while re- setting smoothens and widens the transition, leading to fluctuations in time, and a restart time-energy like relation.

References
[1] R. Yin, E. Barkai Restart expedites quantum walk hitting times Phys. Rev. Lett. 130, 050802 (2023).
[2] R. Yin, Q. Wang, S. Tornow, and E. Barkai, Restart uncertainty relation for monitored quantum dynamics submitted arXiv:2401.01307 [cond-mat.stat-mech].

Brownian motion with stochastic diffusion coefficient under stochastic resetting
**Urna Basu** (S. N. Bose National Centre for Basic Sciences, Kolkata)

We study the effect of stochastic resetting on Brownian motion with stochastic diffusion coefficient. We first study the Brownian motion with stochastic diffusivity in arbitrary dimensions and find the scaling form and the corresponding scaling function of the position distribution. We then introduce the resetting dynamics where, at a constant rate, both the position and the diffusion coefficient are reset to zero. This eventually leads to a nonequilibrium stationary state, which we study in arbitrary dimensions. In stark contrast to ordinary Brownian motion under resetting, the stationary position distribution in one dimension has a logarithmic divergence at the origin. For higher dimensions, however, the divergence disappears and the distribution attains a dimension-dependent constant value at the origin, which we compute exactly. The distribution has a generic stretched exponential tail in all dimensions.

Distributed resetting
**Denis Boyer** (Universidad Nacional Autónoma de México)

We study the problem of a target search by a Brownian particle subject to stochastic resetting to a distribution of sites. Starting with the simple case of a pair of sites, we find that the mean search time is minimised by an optimal resetting rate r^\* which does not vary smoothly, in contrast with the well-known single site case. Rather, r^\* exhibits a discontinuous transition between two finite non-zero values as the position of the further resetting site is varied. This jump exists provided that the relative weight m of the further site exceeds a critical value mc = 6.6008…, while the discontinuity vanishes at a “liquid-gas” critical point. If the initial position of the particle is fixed, a critical point also exists in parameter space if m is comprised in the interval [2.9028...,8.5603...]. This setup can be mapped onto an intermittent search problem with switching diffusion coefficients, and can be relevant for applications in ecology, among others. We then consider other resetting distributions having a finite support, such as truncated Gaussians or truncated exponentials. We show that the discontinuous/critical behaviour of the optimal rate is a robust phenomenon, although in the latter examples the mechanism of the transition differs from the two-site case.

Applications of optimal protocols to resetting and erasure
**Sergio Ciliberto** (CNRS and Ecole Normale Superiéure de Lyon)

In statistical physics optimal protocols are useful techniques which allow us to reduce either the time or the energy needed to perform physical processes. In this talk we will present several experiments in which such techniques have been applied. We will start by describing the Engineered Swift Equilibration (ESE) which is a method to switch a system from one state to another much faster than its natural equilibration time. The initial and final states can be either in equilibrium or out of equilibrium. For example, one can perform the compression of a single Brownian particle trapped in an harmonic potential by increasing its stiffness. We will discuss the parameters which can be tuned in order to reach the desired dynamics and the stability of the protocol to external perturbations. We will then present the application of ESE to the problem of first passage time. The resetting to the origin is one of the efficient theoretical strategies that allow a Brownian particle to reach a target in an optimal time. However we will show how in realistic situation the original assumptions used in these theoretical strategies must be modified in order to optimize the searching time. ESE is actually very useful to speed up the resetting. Finally we will present another technique that optimizes the amount of energy needed to perform a very fast ERASURE protocol in a 1 bit memory. We will show that thank to this technique the energy needed for fast erasure is only about twice that imposed by Landauer’s bound which can be reached only in quasi static erasure protocols.

Does first-passage duality hold in run-and-tumble processes?
**Rosemary Harris** (University College London)

I will discuss recent work on the validity of the so-called first-passage duality [1] for run-and-tumble motion (and other renewal-type processes) in both discrete and continuous settings. This symmetry relates the distributions of first-passage times to absorbing boundaries in the directions of and against a bias. It can generally be derived for entropy-like quantities [2] but does not necessarily hold for currents of active run-and-tumble particles; indeed for finite systems the violation can have a non-trivial dependence on the tumbling rate. By considering the current in each renewal interval, I will present conditions for the symmetry to be restored asymptotically (in the limit of large distances to the absorbing boundaries) and interpret these conditions in terms of underlying trajectory properties, exploring connections to the Gallavotti-Cohen fluctuation relation [3,4] and the classical method of images. In addition, I will discuss finite-size corrections to the asymptotic behaviour with the aid of simple models amenable to exact calculations and/or perturbation analysis for small tumbling rate.  [Based on joint work with Samvit Mahapatra, Edgar Roldán, Yonathan Sarmiento, and Benjamin Walter]

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[2] Neri, I., Roldán, E. & Jülicher, F. Statistics of infima and stopping times of entropy production and applications to active molecular processes. Phys. Rev. X 7, 011019 (2017).
[3] Lebowitz, J. L. & Spohn, H. A Gallavotti-Cohen-type symmetry in the large deviation functional for stochastic dynamics. J. Stat. Phys. 95, 333–365 (1999).
[4] Gingrich, T. R. & Horowitz, J. M. Fundamental bounds on first passage time fluctuations for currents. Phys. Rev. Lett. 119, 170601 (2017).

Stochastic Resetting for Enhanced Sampling of Molecular Dynamics
**Barak Hirshberg** (Tel Aviv University)

We present a new approach for enhanced sampling of Molecular Dynamics (MD) simulations using stochastic resetting (SR) [1]. MD simulations are a powerful tool used to study physical and chemical systems at the microscopic level. However, their atomic resolution limits them to processes shorter than a few microseconds. Longer processes, such as protein folding or crystal nucleation and growth, cannot be sampled by standard MD simulations. SR is well known to expedite different kinds of random processes, ranging from queuing systems to the diffusion of colloidal particles. Here, we employ it to enhance MD simulations for the first time, leading to speedups up to an order of magnitude. This combination of SR with molecular simulations also raises an important question - can we infer the unbiased kinetics of the underlying stochastic process from simulations with resetting? We present an inference procedure to obtain the mean first-passage time without resetting from the Laplace transform of the first-passage time distribution obtained from simulations with resetting.
Next, we demonstrate that combining SR with state-of-the-art enhanced sampling methods, such as Metadynamics (MetaD), may lead to higher speedups than either approach independently [2]. Moreover, restarting MetaD simulations with sub-optimal collective variables (CVs) gives comparable accelerations to using optimal ones, suggesting resetting can be an alternative to improving CVs. We demonstrate the power of the combined approach in simulations of protein folding in explicit water and in improving the tradeoff between speedup and accuracy in kinetics inference [2-3].

References:
[1] O. Blumer, S. Reuveni and B. Hirshberg, [J. Phys. Chem. Lett. 13 (2022) 11230−11236](https://eur02.safelinks.protection.outlook.com/?url=https%3A%2F%2Fdoi.org%2F10.1021%2Facs.jpclett.2c03055&data=05%7C02%7C%7C4556f12061864c23d8df08dc6d1d2e83%7C2e9f06b016694589878910a06934dc61%7C0%7C0%7C638505219305284240%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzIiLCJBTiI6Ik1haWwiLCJXVCI6Mn0%3D%7C0%7C%7C%7C&sdata=u6etZQaBxNc0kQ7REk9UcjlI%2FSXp70IlzgZpMsbomC8%3D&reserved=0).
[2] O. Blumer, S. Reuveni and B. Hirshberg, [Nat. Commun. 15 (2024) 240](https://eur02.safelinks.protection.outlook.com/?url=https%3A%2F%2Fdoi.org%2F10.1038%2Fs41467-023-44528-w&data=05%7C02%7C%7C4556f12061864c23d8df08dc6d1d2e83%7C2e9f06b016694589878910a06934dc61%7C0%7C0%7C638505219305294896%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzIiLCJBTiI6Ik1haWwiLCJXVCI6Mn0%3D%7C0%7C%7C%7C&sdata=C%2F0QG36VYdx9OYI%2BjDOrV8Arx1FUWb63IQdI63LHATA%3D&reserved=0).
[3] O. Blumer, S. Reuveni and B. Hirshberg, accepted, [J. Chem. Theory Comput. (2024)](https://eur02.safelinks.protection.outlook.com/?url=https%3A%2F%2Fdoi.org%2F10.1021%2Facs.jctc.4c00170&data=05%7C02%7C%7C4556f12061864c23d8df08dc6d1d2e83%7C2e9f06b016694589878910a06934dc61%7C0%7C0%7C638505219305301575%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzIiLCJBTiI6Ik1haWwiLCJXVCI6Mn0%3D%7C0%7C%7C%7C&sdata=t5LG3QoUMrizQczQxatMledvC4AHhy1EHLqBpSeOR8c%3D&reserved=0)

Thermodynamic costs for resetting processes
**Supriya Krishnamurthy** (Stockholm University)

What is the thermodynamic cost for implementing a resetting process in the lab? This has been of interest recently. In this talk I will present some of our recent results on the thermodynamic costs that a resetting entails for some variations of the resetting process which have been implemented experimentally. I will also discuss the connection with Landauer's bound for information erasure.

Entanglement and First detection probability via Quantum Resetting
**Manas Kulkarni** (ICTS-TIFR, Bangalore)

We will first consider a closed quantum system subjected to stochastic Poissonian resetting. Resetting drives the system to a nonequilibrium stationary state (NESS) with a mixed density matrix which has both classical and quantum correlations [1]. We provide a general framework to study these NESS correlations for a closed quantum system with a general Hamiltonian. We then apply this framework to a simple model of a pair of ferromagnetically coupled spins. One of our main conclusions is that a nonzero resetting rate and a nonzero interaction strength generate quantum entanglement in the NESS (quantified by a nonzero concurrence) and moreover this concurrence can be maximized by appropriately choosing the two parameters. Our results show that quantum resetting provides a simple and effective mechanism to enhance entanglement between two parts of an interacting quantum system. We will then provide a general framework to compute the probability distribution of the first detection time of a 'state of interest' in a generic quantum system subjected to random projective measurements [2]. In our 'quantum resetting' protocol, resetting of a state is not implemented by an additional classical stochastic move, but rather by the random projective measurement. We then apply this general framework to Poissoinian measurement protocol with a constant rate and demonstrate that exact results for first detection probability can be obtained for a generic two level system.

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[2] M. Kulkarni, S. N. Majumdar, J. Phys. A: Math. Theor. 56, 385003 (2023)

Stochastic resetting with stochastic returns
**Anupam Kundu** (International Centre for Theoretical Sciences – TIFR)

Stochastic resetting has recently become a subject of immense interest. Most of the theoretical studies so far focused on instantaneous resetting which can be a major impediment to practical realisation or experimental verification in the field. This is because in the real world, taking a particle from one place to another requires finite time. In this talk I will discuss possible generalization of the existing theory to incorporate non-instantaneous resetting. I will demonstrate how different features of a brownian particle, such as non-equilibrium stationary state, relaxation to it and search efficiency get affected by non-instantaneous resetting.

Optimal control with resetting in animal navigation
**Francesco Mori** (University of Oxford)

While resetting is recognized as an effective strategy in a variety of settings, quantifying its effectiveness and optimality remains an open challenge. In this talk, I will combine ideas from optimal control and stochastic resetting to address this question. The emerging analytical framework allows not only to measure the performance of a given restarting strategy, but also to obtain the optimal policy for a wide class of dynamical systems. This framework can be directly applied to derive optimal strategies in the context animal navigation, where resetting events correspond to directional reorientations.

References:
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Homing as a resetting paradigm
**Arnab Pal** (The Institute of Mathematical Sciences, Chennai)

A fundamental aspect crucial for the survival of various animal species is their ability to successfully return home, whether it involves migration, foraging for food, or locating a breeding site. This innate behavior, known as Homing, is surprisingly ubiquitous, allowing animals to navigate back from seemingly unfamiliar locations over considerable distances. In this talk, I will try to shed some light on this phenomena from the perspective of stochastic resetting.

Monitored quantum dynamics from resets to dissipation and measurements
**Gabriele Perfetto** (Eberhard Karls Universitat Tuebingen)

In this talk, we discuss different instances of monitored quantum dynamics. Monitoring can take place in different forms such as measurements, resets and/or interaction with an external environment.

In the first part of the talk, we consider the effect of resets on both closed and open quantum systems. In the former case, the unitary many-body time evolution is interrupted by measurements and subsequent resets at randomly selected times. In the latter case, instead, stochastic resetting is superimposed to a Markovian open quantum dynamics. We provide a unified understanding of the two cases by showing that the averaging of the
microscopic unitary dynamics over all the possible reset realizations leads to an effective non-Markovian open dynamics, which generalizes the Lindblad form. For open quantum systems, we further exactly compute the large-deviation statistics of quantum-jumps. This approach allows to classify quantum trajectories of dissipative systems in the same way thermodynamics deals with ensembles of configurations and it shows that stochastic resetting may be exploited as a tool to tailor the dynamical phases of open quantum systems.

In the second part of the talk, we eventually consider a related problem, where unitary many-body quantum dynamics is interspersed with projective measurements of the many-body wavefunction. We show that the first detection return probability of a certain quantum state can be mapped into the equilibrium partition function of classical noninteracting magnetic domains. This mapping allows to classify different long-time universal decays of the first detection probability in terms of different thermodynamic phases of the associated classical spin model. This analysis thereby provides an overarching connection between non-equilibrium measurement-induced quantum fluctuations and equilibrium thermodynamic phases.

**References:**

[1] G. Perfetto, F. Carollo, M. Magoni, I. Lesanovsky, Phys. Rev. B **104**, L180303 (2021).
[2] G. Perfetto, F. Carollo, I. Lesanovsky, Scipost Phys. **13**, 079 (2022)
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Boosting Search Efficiency: Exploring Reset Protocols in Stochastic Systems
**Yael Roichman** (Tel Aviv University)

The seemingly counterintuitive notion that resetting a process can accelerate search, even in the presence of a slow drift towards the target, has fueled extensive research on stochastic resetting. Understanding how the specific resetting protocol—the procedure used to restart the process—impacts this phenomenon is crucial from a practical perspective. In this talk, I will focus on the effect of resetting protocols on the temporal and energetic cost of search under stochastic resetting. Starting from the known results for a single Brownian particle, I will delve deeper, investigating the ramifications of these protocols when applied to resetting a many-body system where multiple particles are involved in the search. I will also discuss the effect of complex return strategies.

Noninteracting particles in a harmonic trap with a stochastically driven center
**Sanjib Sabhapandit** (Raman Research Institute)

We study a system of N noninteracting particles on a line in the presence of a harmonic trap, where the trap center undergoes a bounded stochastic modulation. We show that this stochastic modulation drives the system into a nonequilibrium stationary state, where the joint distribution of the positions of the particles is not factorizable. This indicates strong correlations between the positions of the particles that are not inbuilt, but rather get generated by the dynamics itself. Moreover, we show that the stationary joint distribution can be fully characterized and has a special conditionally independent and identically distributed (CIID) structure. This special structure allows us to compute several observables analytically, even in such a strongly correlated system, for an arbitrary bounded drive. These observables include the average density profile, the correlations between particle positions, the order and gap statistics, as well as the full counting statistics. We then apply our general results to two specific examples where (i) the drive represents a dichotomous telegraphic noise, and (ii) the drive represents an Ornstein-Uhlenbeck process. Our analytical predictions are verified in numerical simulations, finding excellent agreement.

Stochastic Resetting Modelling to Optimise Therapy Change Protocols to Reduce Drug Resistance
**Daniel Sanchez** (Department of Visceral Surgery and Medicine, University of Bern)

Drug resistance occurs when pathogens develop mechanisms to become unaffected by the therapy. When this occurs, practitioners typically change the therapy the patient is receiving. Changes in therapy can also occur due to stochastic factors, such as the availability of a new cheaper drug or a drug with fewer side effects. Our work aims to study drug resistance development times by incorporating these stochastic influences.

We present a stochastic model in which drug resistance is studied as diffusion in a lattice representing the pathogen's phenotype, which varies stochastically due to random mutations. In this scenario, a therapy change is modelled as a stochastic resetting process, in which the pathogen must restart its evolution to develop resistance against the new therapy.

We found quantitative differences between diffusion in a continuous space and a discrete space with a limited number of states. We also determined how the simultaneous administration of multiple drugs impacts drug resistance development time. Finally, we identify optimal therapy change times that maximize the duration of drug effectiveness.

Our work shows the importance of stochastic resetting to understand drug resistance development and establishes a quantitative framework to study it, creating the basis for future research to inform clinical decisions to minimize drug resistance.

Heterogeneous processes under stochastic resetting
**Trifce Sandev** (Macedonian Academy of Sciences and Arts)

Various studies, including biological cells and porous media, have demonstrated that the underlying structure of the environment results in systematic variations of the local diffusion coefficient, and thus has a strong effect on the particle movement. These effects can be captured by heterogeneous diffusion models which describe the environment by using a position-dependent diffusion coefficient. Diffusion models with spatially varying diffusivity lead to anomalous diffusion and are used to describe transport processes on random fractals and in heterogeneous media. Such models can be further generalised if one considers diffusion processes with finite propagation speed in a non-homogeneous medium in terms of the heterogeneous telegrapher’s equation. Here I will present the effects of stochastic resetting on diffusion processes with (in)finite propagation speed in a non-homogeneous medium by analysis of the probability density functions, the non-equilibrium stationary states, and the mean squared displacements. The renewal equation approach and the integral decomposition method will be employed for analytical treatment of these equations. The analytical results will be confirmed by numerical simulations in terms of Langevin equations with multiplicative white and multiplicative dichotomic noise.

Extreme statistics and spacing distribution in a Brownian gas correlated by resetting
**Gregory Schehr** (CNRS-Sorbonne Université)

I will discuss a one-dimensional gas of N Brownian particles that diffuse independently, but are simultaneously reset to the origin at a constant rate r. The system approaches a non-equilibrium stationary state (NESS) with long-range interactions induced by the simultaneous resetting. Despite the presence of strong correlations, we show that several observables can be computed exactly, which include the global average density, the distribution of the position of the k-th rightmost particle and the spacing distribution between two successive particles. I will also discuss a possible realisation of this resetting gas in optical trap experiments.

Linear response and fluctuation-dissipation relations for Brownian motion under resetting
**Igor Sokolov** (Humboldt University Berlin)

We discuss a question of linear response of a stochastic system under resetting to a weak external perturbation affecting the evolution of the system between the resetting events, but not the timing of these events themselves. After discussing some general properties of different kinds of fluctuation-dissipation relations (FDRs), we consider a particular example of a Brownian motion under renewal resetting with arbitrary waiting time distribution between the resetting events. We show that if the distribution of waiting times of the resetting process possesses the second moment, the usual (generalized) FDR and the equivalent generalized Einstein’s relation (GER) apply for the response function of the coordinate. If the second moment of waiting times diverges but the first one stays finite,
the static susceptibility diverges, usual FDR breaks down, but the GER still applies. In any of these situations, the fluctuation dissipation relations define the effective temperature of the system which is twice as high as the temperature of the medium in which the Brownian motion takes place.
I.M. Sokolov Physical Review Letters 130 (6), 067101 (2023)

**Early Career Researcher Talk Titles**

(to be added)

**Poster Presenter Titles**

(to be added)