Workshop program

Out-of-equilibrium and collective dynamics of quantum many-body systems

Organizers: Nicolò Defenu, Gian Michele Graf, and Per Moosavi

ETH Zurich
June 27 – July 1, 2022

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Invited talks

Denis Bernard (CNRS & École Normale Supérieure)

The Quantum Symmetric Simple Exclusion Processes

Abstract: An alternative title could have been "How to characterise fluctuations in diffusive out-of-equilibrium many-body quantum systems?" In general, the difficulty to characterise non-equilibrium systems lies in the fact that there is no analog of the Boltzmann-distribution to describe thermodynamic variables and their fluctuations. Over the last 20 years, however, it was observed that there is a class of classical non-equilibrium systems with diffusive transport in which the statistics of particle density and particle current show universal properties that do not depend on the microscopic details of the model. The general framework to characterise these systems from a macroscopic point of view is today called the "Macroscopic Fluctuation Theory". A natural question is whether this framework can be extended to quantum mechanics to describe the statistics of purely quantum mechanical effects such as interference or entanglement in diffusive out-of-equilibrium systems. With this aim in mind, I will introduce the Quantum Symmetric Simple Exclusion Process (Q-SSEP), a microscopic model system, from which we hope to gain inside in possible universal features of fluctuations of those quantum mechanical effects.

Bruno Bertini (University of Nottingham)

Growth of Rényi Entropies in Interacting Integrable Models and the Breakdown of the Quasi-particle Picture

Abstract: Rényi entropies are conceptually valuable and experimentally relevant generalisations of the celebrated von Neumann entanglement entropy. After a quantum quench in a clean quantum many-body system they generically display a universal linear growth in time followed by saturation. While a finite subsystem is essentially at local equilibrium when the entanglement saturates, it is genuinely out-of-equilibrium in the growth phase. In particular, the slope of the growth carries vital information on the nature of the system's dynamics, and its characterisation is a key objective of current research. In the talk I will show that the slope of Rényi entropies can be determined by means of a spacetime duality transformation. I will argue that the slope coincides with the stationary density of entropy of the model obtained by exchanging the roles of space and time. Therefore, very surprisingly, the slope of the entanglement can be expressed as an equilibrium quantity. I will use this observation to find an explicit exact formula for the slope of Rényi entropies in all integrable models treatable by thermodynamic Bethe ansatz and evolving from integrable initial states. Interestingly, this formula can be understood in terms of a quasiparticle picture only in the von Neumann limit.

Pasquale Calabrese (SISSA)

Quantum Generalized Hydrodynamics

Abstract: Physical systems made of many interacting quantum particles can often be described by Euler hydrodynamic equations in the limit of long wavelengths and low frequencies. Recently such a classical hydrodynamic framework, dubbed Generalized Hydrodynamics (GHD), was found for quantum integrable models. Despite its great predictive power, GHD, like any Euler hydrodynamic equation, misses important quantum effects, such as quantum fluctuations leading to non-zero equal-time correlations. We reconstruct such quantum effects by quantizing linear fluctuations on top of GHD equations. The resulting theory of quantum GHD is a multi-component Luttinger liquid theory, with a small set of effective parameters that are fixed by the Thermodynamic Bethe Ansatz. It describes quantum fluctuations of truly nonequilibrium systems where conventional Luttinger liquid theory fails.

Adolfo del Campo (University of Luxembourg)

Dynamics of Phase Transitions: Beyond the Kibble-Zurek Mechanism

Abstract: Nonequilibrium phenomena occupy a central stage at the frontiers of physics. Among them, the dynamics across a phase transition has manifold applications, ranging from the preparation of novel phases of matter to adiabatic quantum computation. The Kibble-Zurek mechanism (KZM) is the main paradigm to describe critical dynamics and predicts the formation of topological defects when a phase transition is crossed in a finite time. Specifically, it predicts a universal power-law scaling for the average density of topological defects with the quench time. We identify strong signatures of universality in the number and spatial distribution of topological defects that lie beyond the scope of KZM and review recent progress exploring them.

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Olalla Castro Alvaredo (City, University of London)

Symmetry Resolved Entanglement in Integrable Quantum Field Theory

Abstract: In this talk I will review some recent results relating to a measure of entanglement known as symmetry resolved entropy (SRE). This is a measure that can be defined for theories that possess an internal symmetry and which quantifies the amount of entanglement that is contributed by each symmetry sector. In the context of integrable quantum field theory, the SRE can be computed using correlation functions of composite twist fields, extending the standard programme for entanglement measures. In my talk I will give a summary of some results I have contributed to in this direction, which deal with different models and/or states.

Benjamin Doyon (King's College London)

Ballistic Macroscopic Fluctuation Theory and Long-Range Correlations

Abstract: I will overview a new theory which gives access to fluctuations and correlations at large scales of space and time in many-body systems (quantum and classical) out of equilibrium. The theory is concerned with the ballistic scale, and is entirely based on the data from the Euler hydrodynamic equations of the many-body system. It is an adaptation of the well-known macroscopic fluctuation theory, that has been very successful for purely diffusive systems. The "ballistic macroscopic fluctuation theory" (BMFT) gives predictions for the large-deviation theory of fluctuations and for the Euler scaling limits of correlation functions. A surprising new result is that generically, long-range spatial correlations develop over time if the initial state of the many-body system is spatially inhomogeneous; therefore the "fluid cells" of Euler hydrodynamics are in fact generically correlated amongst each other. I will describe the basic principles underlying the BMFT - including rigorous results about ergodicity in quantum systems - and some of its main consequences, in particular in integrable systems. This is work in collaboration with G. Perfetto, T. Sasamoto and T. Yoshimura.

Thierry Giamarchi (University of Geneva)

Quantum Transport and Cold Atomic Gases

Abstract: Quantum transport of a system which is between two reservoirs, at e.g. different chemical potentials, is one of the most common but also most important ways to put a quantum system out of equilibrium. Such a situation is relevant not only for charge transport but also for other transport properties such as spin transport or Hall transport for systems which are put under a magnetic field. I will discuss in this talk how one can use the Keldysh technique to deal with various such transport situations such as the transport between two superconducting reservoirs, with and without loss of particles in the system. I will also discuss other ways to put the system out of equilibrium, in particular by coupling it to a time dependent noise acting either on the density or the hopping between sites. These situations can be directly relevant for experimental situations encountered in cold atomic gases and I will discuss the contact with experimental realizations.

Michael Kastner (Stellenbosch University & Hanse-Wissenschaftskolleg)

Universal Cooling Dynamics towards a Quantum Critical Point

Abstract: Signatures of equilibrium phase transitions can be imprinted into the nonequilibrium dynamics of many-body quantum systems, resulting in the emergence of universal scaling laws out of equilibrium, as exemplified by the Kibble-Zurek mechanism. In a similar spirit, but novel setting, I report scaling and universality in open nonequilibrium quantum systems that are cooled towards a quantum critical point. The excess excitation density, which quantifies the degree of adiabaticity of the dynamics, is found to obey scaling laws in the cooling velocity as well as in the initial and final temperatures of the cooling protocol. The scaling laws are universal, governed by the critical exponents of the quantum phase transition. The validity of these statements is shown analytically for a Kitaev quantum wire coupled to Markovian baths, and subsequently argued to be valid under rather general conditions. Remarkably, these results establish that quantum critical properties can be probed dynamically at finite temperature, without even varying the control parameter of the quantum phase transitions.

Christian Maes (KU Leuven)

Nernst Law for Nonequilibrium Systems

Abstract: We generalize a version of the Third Law of Thermodynamics to nonequilibrium processes described as Markov jump dynamics on a finite connected graph. Interpretations of heat, work and dissipation are possible thanks to the condition of local detailed balance, which also assumes that the system is weakly coupled to a thermal bath at temperature T. There is a stationary heat flux, and there is an excess heat during relaxation after a small change in an external parameter. We give the low-temperature properties of that excess heat, including an extended Nernst theorem stating conditions under which the nonequilibrium specific heat vanishes at the absolute zero. The Theorem comes with an interpretation of that excess heat in terms of dominant states and their accessibility, thus generalizing the connection between Clausius' and Boltzmann's notion of entropy to stationary nonequilibria. Joint work with Faezeh Khodabandehlou and Karel Netocny.

Jamir Marino (Mainz JGU)

Kinetically Constrained Quantum Dynamics in Superconducting Circuits

Abstract: We study the dynamical properties of the bosonic quantum East model at low temperature. We show that a naive generalization of the corresponding spin-1/2 quantum East model does not posses analogous slow dynamical properties. In particular, conversely to the spin case, the bosonic ground state turns out to be not localized. We restore localization by introducing a repulsive nearest-neighbour interaction term. The bosonic nature of the model allows us to construct rich families of many-body localized states, including coherent, squeezed and cat states. We formalize this finding by introducing a set of superbosonic creation-annihilation operators which satisfy the bosonic commutation relations and, when acting on the vacuum, create excitations exponentially localized around a certain site of the lattice. Given the constrained nature of the model, these states retain memory of their initial conditions for long times. Even in the presence of dissipation, we show that quantum information remains localized within decoherence

times tunable with the system's parameters. We propose a circuit QED implementation of the bosonic quantum East model based on state-of-the-art transmon physics, which could be used in the near future to explore kinetically constrained models in superconducting quantum computing platfoms.

Vieri Mastropietro (Università degli Studi di Milano)

Some Rigorous Result on Drude Weights in Nonsolvable Many-Body Systems

Abstract: We present some rigorous results on the T=0 Drude weight in two class of nonsolvable many body systems. The first are spin chains with nonintegrable perturbations, like next-to-nearest neighbor interactions; the Drude weight is proven to verify the Luttinger liquid relations even close to the quantum critical point where the quadratic irrelevant terms dominate. The second are interacting fermions on Zd with a strong quasi periodic disorder, where the Drude weight is vanishing assuming a Diophantine condition on the frequencies. The result are based on convergent expansions, constructive RG methods and number theoretical properties.

Aditi Mitra (New York University)

Critical Properties of Prethermal Floquet Time Crystals

Abstract: The critical properties characterizing the formation of the Floquet time crystal in the prethermal phase are investigated analytically in the periodically driven $O(N)$ model. In particular, we focus on the critical line separating the trivial phase with period synchronized dynamics and absence of long-range spatial order from the non-trivial phase where long-range spatial order is accompanied by period-doubling dynamics. In the vicinity of the critical line, with a combination of dimensional expansion and exact solution for $N \to \infty$, we determine the exponent ν that characterizes the divergence of the spatial correlation length of the equal-time correlation functions, the exponent β characterizing the growth of the amplitude of the order-parameter, as well as the initial-slip exponent θ of the aging dynamics when a quench is performed from deep in the trivial phase to the critical line. The exponents ν, β, θ are found to be identical to those in the absence of the drive. In addition, the functional form of the aging is found to depend on whether the system is probed at times that are small or large compared to the drive period. The spatial structure of the two-point correlation functions, obtained as a linear response to a perturbing potential in the vicinity of the critical line, is found to show algebraic decays that are longer ranged than in the absence of a drive, and besides being period-doubled, are also found to oscillate in space at the wave-vector $\omega/(2v)$, v being the velocity of the quasiparticles, and ω being the drive frequency.

Tomaž Prosen (University of Ljubljana)

Random Matrix Spectral Fluctuations in Quantum Lattice Systems

Abstract: I will discuss the problem of unreasobable effectivenes of random matrix theory for description of spectral fluctuations in extended quantum lattice systems. A class of interacting spin systems has been recently identified where the spectral form factor is proven to match with gaussian or circular ensembles of random matrix theory. The key ideas of novel methodology needed in the proofs will be discussed which are very different than the standard periodic-orbit based methods in quantum chaos of few body semiclassical systems.

Paola Ruggiero (King's College London)

Entanglement Rényi Entropies from Ballistic Fluctuations Theory: The free Fermionic Case

Abstract: Recently, a new framework dubbed Ballistic Fluctuation Theory (BFT) has been proposed, which gives access to the full statistics of fluctuations of ballistically transported conserved quantities within homogeneous, stationary states [1]. The formalism, based on large deviation theory (LDT), is expected to apply to generic one-dimensional systems with an Euler hydrodynamic description. One of its most interesting application is to correlation functions of twist fields, which can be introduced any time the system possesses a symmetry. A particularly important example are branch-point twist fields associated to the Zn symmetry in a n-copies replicated theory, whose correlations functions provide the starting point for computing Rényi entanglement entropies within the replica approach [2]. In this talk, focusing on free fermionic systems, we apply the formalism to correlation functions of branch-point twist fields and show that both the equilibrium behavior and the dynamics of Rényi entanglement entropies can be simply derived from a unique formula, thus providing a unified interpretation of the two results [3].

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[1] B. Doyon and J. Myers, Fluctuations in ballistic transport from Euler hydrodynamics, Ann. Henri Poincaré 21, 255 (2020)

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[3] G. Del Vecchio Del Vecchio, B. Doyon, and P. Ruggiero, In preparation

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Shinsei Ryu (Princeton University)

Non-Equilibrium Dynamics of (1+1)D Conformal Field Theory with Sine-Square Deformation

Abstract: We study quantum quench processes in (1+1)-dimensional conformal field theory (CFT). As a post-quench Hamiltonian, we consider in our quench protocols spatially inhomogeneous Hamiltonians, the so-called Möbius and sine-square-deformed (SSD) Hamiltonians. When the system is initially prepared as the thermal Gibbs state, we found that, when quenched by the SSD Hamiltonian, almost all the degrees of freedom are asymptotically gathered at a single point, resulting in a point-like excitation that carries as much information as the total thermal entropy, which we dub a black-hole-like excitation. For the quench by the Möbius Hamiltonian we instead found an eternal periodic oscillation of physical quantities such as von Neumann entropy for subsystems. Other choices of initial conditions are also discussed. Finally, we also discuss the holographic dual descriptions of the quench problems.

Lea F. Santos (Yeshiva University)

Equilibration Time in Many-Body Quantum Systems

Abstract: A major open question in studies of nonequilibrium quantum dynamics is how long it takes for an isolated many-body quantum system to reach equilibrium. We show that there is not a single answer for this question. The equilibration time depends not only on the model and the initial state, but also on the quantity and the dynamical features considered. We discuss a recent NMR experiment, where we measured a new entropy – the correlation Rényi entropy – and showed that it keeps growing even after the evolution of the entanglement entropy has already saturated. We also discuss the case of chaotic models, where the equilibration time can scale either exponentially or polynomially with system size depending on whether dynamical manifestations of spectral correlations in the form of the correlation hole ("ramp") are taken into account or not.

Tomohiro Sasamoto (Tokyo Institute of Technology)

Integrability of the Macroscopic Fluctuation Theory for the Symmetric Exclusion Process

Abstract: It has been known for a long time that large deviations of symmetric simple exclusion process(SEP) are described by macroscopic fluctuation theory (MFT), initiated and developed by Jona-Lasinio et al in 2000's [1]. The basic equations of the theory, MFT equations, are coupled nonlinear partial differential equations and have resisted exact analysis except for stationary situation. In this talk we introduce a novel generalization of the Cole-Hopf transformation and show that it maps the MFT equations for SEP to the classically integrable AKNS system. This allows us to solve the equations exactly in time dependent regime by adapting standard ideas of inverse scattering method.

The talk is based on a joint work with Kirone Mallick and Hiroki Moriya [2].

References:

[1] L. Bertini, A. De Sole, D. Gabrielli, G. Jona-Lasinio, and C. Landim, Macroscopic fluctuation theory, Rev. Mod. Phys. 87, 593 (2015)

[2] K. Mallick, H. Moriya, and T. Sasamoto, Exact solution of the macroscopic fluctuation theory for the symmetric exclusion process, arXiv:2202.05213 (2022)

Imke Schneider (TU Kaiserslautern)

Nonequilibrium Floquet Steady States of Time-Periodic Driven Luttinger Liquids

Abstract: We study the interplay of Floquet states and strong correlations considering the exactly solvable Lieb-Liniger model of quasi-1D bosons with time-periodically modulated interactions. By developing a time-periodic operator algebra for Luttinger liquids, we are able to obtain and analyze the complete set of explicit steady state solutions in terms of a Floquet-Bogoliubov ansatz and known analytic functions. When the driving frequency is lowered below the Luttinger liquid cutoff energy, a dramatic change of behavior is observed which is signaled by the appearance of strong resonant density waves. We include damping effects and compare with state-of-the art experiments. Finally, we compare with numerical simulations.

Dries Sels (NYU-Flatiron)

On the Absence of Many-Body Localization

Abstract: Disordered quantum systems are believed to form an exception to the rule that short range integrable models are unstable to integrability breaking upon infinitesimal deformation of the model. It's been extensively argued that these disordered systems remain localized, and non-ergodic, at finite values of the interaction strength in the thermodynamic limit. In this talk I will argue that MBL is a transient phenomenon that does not survive in the thermodynamic limit.

Spyros Sotiriadis (FU Berlin)

Tunnel-Coupled One-Dimensional Bose Gases as Quantum Field Simulators

Abstract: Ultracold atom experiments have demonstrated their potential as "quantum simulators" of QFT models. Tunnel-coupled one-dimensional Bose gases, in particular, have been successfully used to implement strongly interacting models of QFT and study their equilibrium and dynamical properties. I will discuss two fundamental theoretical predictions that have been recently observed in such experiments, the area law of mutual information and the light-cone propagation of correlations after a quench. Based on the framework of Luttinger liquid theory and using a version of quantum tomography suitable for continuous fields, we achieve a detailed reconstruction of the system's quantum state, allowing measurements of the von Neumann entropy and mutual information. Moreover, studying quench dynamics in a finite size system, we verify theoretical results for the propagation of correlations and their recurrences.

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Gábor Takácz (Budapest University of Technology and Economics)

Quench Dynamics of Quantum Fields in One Spatial Dimension

Abstract: I review some recent results obtained for the quench dynamics of 1+1 dimensional quantum field theories using Hamiltonian truncation. In the first part, I consider the sine-Gordon model in inhomogeneous situations, where the dynamics interpolates between behaviour characteristic of bosonic, and a different one characteristic of fermionic, degrees of freedom. In the second part I switch to the ϕ^4 theory and discuss the decay of the false vacuum, where we can perform a very efficient test of existing theoretical predictions, confirming them in many aspects, but also leaving us with some open problems.

Contributed talks

Alvise Bastianello (TU Munich)

Nonequilibrium Metastability of the Attractive One-Dimensional Bose Gas

Abstract: Many-body quantum systems out-of-equilibrium host phases of matter that simply do not exist in equilibrium scenarios: the one-dimensional Bose Gas (1dBG) with contact attractive interactions is an outstanding example of this dichotomy. The 1dBG is a ubiquitous effective description of many cold atoms experiments, where the presence of Feshbach resonances allows for a dynamical exploration of the whole interactions' range. On the theory side, a hallmark of the 1dBG is its integrability, which hinders thermalization and allows for analytical and exact insight. Within the attractive phase, the 1dBG forms bound states with arbitrary large negative binding energy, critically harming the stability of the gas at equilibrium. On the other hand, integrability prevents thermalization and enhances the stability of the gas. In this talk, I discuss how, by slowly changing the interactions from positive to negative, it is possible to engineer a stable nonequilibrium phase. I build on new developments in the hydrodynamic theory of integrable models and provide an exact analytical solution of the protocol directly at the many-body level, showing the controlled formation of bound states and creating a far-richer scenario than the well-known Super Tonks-Girardeau phase. Experimental signatures in realistic settings of this new nonequilibrium phase are discussed.

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Oksana Chelpanova (Johannes Gutenberg-Universität Mainz)

Competition Between Lasing and Superradiance under Spintronic Pumping

Abstract: We consider a platform featuring the minimal ingredients relevant both to a driven-dissipative cavity quantum optics system and to a spintronically pumped magnon condensate. We extend the Dicke model for a bosonic mode collectively coupled to a coherent spin ensemble, by weakly coupling it to an out-of-equilibrium spin bath which is tunable by incoherent pumping. Our model exhibits competition between coherent couplings and dissipative channels, which leads to various collective quantum behaviors, static and dynamic, depending on the interplay of spin-boson interactions and spin pump/loss rates. Our analysis exposes a hybrid lasing-superradiant regime which does not take place in an ordinary pumped Dicke spin ensemble. We interpret the resultant non-equilibrium phase diagram from both a quantum optics and a spintronics standpoint, supplying a conceptual bridge between the two fields. The implications of our results concern dynamical control in spintronics and frequency-dependent gain media in quantum optics.

Youness Diouane (SISSA)

Critical Behavior of Two-Dimensional Systems in the Presence of Local Symmetries

Abstract: We use the recently introduced scale invariant scattering theory to exactly determine the renormalization group fixed points of RP^{N-1} and CP^{N-1} models in two dimensions, which

differ from vector models for an additional local symmetry: respectively the liquid crystal head-tail symmetry and a U(1) symmetry. We show that, also due to subtle degeneracies at specific values of N, above a threshold value N_c there is only a zero-temperature critical point of $O(N(N+1)/2-1)$ type for RP^{N-1} and of $O(N^2-1)$ type for CP^{N-1}. Below N_c new branches of fixed points emerge which are relevant for criticality in gases of loops with crossings. For liquid crystals $N_c = 2.24421...$, and a topological transition of Berezinskii-Kosterlitz-Thouless type exists only for $N = 2$. For CP^{N-1} $N_c = 2$ and no topological transition occurs for N integer.

Shachar Fraenkel (Tel Aviv University)

Extensive Long-Range Entanglement in a Nonequilibrium Steady State

Abstract: Entanglement measures constitute powerful tools in the quantitative description of quantum many-body systems out of equilibrium. We study entanglement in the current-carrying steady state of a paradigmatic one-dimensional model of noninteracting fermions at zero temperature in the presence of a scatterer. In our previous work [1] we found an unusual scaling law for the entanglement entropy of a subsystem that is far away from the scatterer. Our exact results showed that the entanglement entropy of such a subsystem obeys an extensive (volume-law) scaling along with an additive logarithmic correction.

In this new work, we show that disjoint intervals located on opposite sides of the scatterer and within similar distances from it display volume-law entanglement regardless of their separation, as measured by their fermionic negativity [2] and coherent information [3]. We employ several complementary analytical methods to derive exact expressions for the extensive terms of these quantities and, given a large separation, also for the subleading logarithmic terms. Remarkably, our results imply in particular that far-apart intervals that are positioned symmetrically relative to the scatterer are more strongly entangled than if we had reduced the distance between them by choosing one of these intervals to be closer to the scatterer.

The strong long-range entanglement is generated by the coherence between the transmitted and reflected parts of propagating particles within the bias-voltage window, despite the fact that only single particles are scattered independently. The generality and simplicity of the model suggest that this behavior should characterize a large class of nonequilibrium steady states.

References:

[1] S. Fraenkel and M. Goldstein, Entanglement measures in a nonequilibrium steady state: Exact results in one dimension, SciPost Phys. 11, 85 (2021)

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Simon B. Jäger (TU Kaiserslautern)

Lindblad Master Equations for Quantum Systems Coupled to Dissipative Bosonic Modes

Abstract: We present a general approach to derive Lindblad master equations for a subsystem whose dynamics is coupled to dissipative bosonic modes. The derivation relies on a Schrieffer-Wolff transformation which allows to eliminate the bosonic degrees of freedom after self-consistently determining their state as a function of the coupled quantum system. We apply this formalism

to the dissipative Dicke model and derive a Lindblad master equation for the atomic spins, which includes the coherent and dissipative interactions mediated by the bosonic mode. This master equation accurately predicts the Dicke phase transition and gives the correct steady state. We also discuss further applications of the Lindblad master equation to time-periodically driven systems and to interaction and dissipation engineering.

Bastien Lapierre (University of Zurich)

Marginal Quenches and Drives in Tomonaga-Luttinger Liquids

Abstract: In this talk I will discuss the physics of Tomonaga-Luttinger liquids (TLLs) thrown out-of-equilibrium by marginal deformations, i.e., interaction modulations. I will show that the quench dynamics starting from generic initial states exhibit rich physics, with periodic exact zeros in the Loschmidt echo time evolution. I will then discuss the Floquet dynamics of TLLs and show how the su(1,1) structure of the periodic drive can be used to derive the stroboscopic time evolution of various physical observables, which is dictated by an exactly derived stability diagram. Finally using the non-equilibrium tools developed previously, I will show that the Renyi divergence between two TLLs can be non-perturbatively obtained as a quench in Euclidean space-time, providing a measure of relative entropy between two TLLs.

Alessio Lerose (University of Geneva)

Influence Matrix Approach to Quantum Many-Body Dynamics

Abstract: In this talk I will introduce an approach to study the non-equilibrium dynamics of extended quantum many-body systems, inspired by the Feynman-Vernon influence functional description of quantum baths. We take an open-quantum-system viewpoint and describe evolution of a local subsystem in terms of an influence matrix (IM) - an operator acting on the space of temporal trajectories of the subsystem. The IM fully encodes the effects of the many-body system on its local subregions, and thus characterizes its ability (or failure) to behave as an efficient bath.

I will show that this complementary angle of attack on quantum many-body dynamics offers many advantages, both conceptually and practically. In one spatial dimension, space-time duality allows to write an exact linear self-consistency equation for the IM. This equation possesses remarkable solutions in a class of maximally chaotic quantum circuits corresponding to perfect Markovian dephasing dynamics of subsystems. Away from such special points, quantum many-body systems exert a non-Markovian influence on subsystems, associated with temporal entanglement (TE) in the IM. Analyzing a wide range of models with analytical methods and numerical matrix-product-state computations, we study the scaling of TE in several dynamical regimes, ranging from strongly chaotic to (quasi-)integrable and many-body localized.

Blagoje Oblak (École Polytechnique)

Hydrodynamical Drift as a Berry Phase

Abstract: I consider a model of fluid motion closely related to the Korteweg-de Vries equation that governs shallow water waves. Upon reformulating this model as a geodesic in an infinite-dimensional group, the fluid's drift velocity can be recast as an ergodic rotation number. The latter is sensitive to Berry phases, inspired by conformal field theory and gravity, that are produced by adiabatic deformations. Along the way, I show that the topology of coadjoint orbits of wave profiles affects drift in a dramatic manner: orbits that are not homotopic to a point yield quantized rotation numbers. These arguments rely on the general structure of Euler equations, suggesting the existence of other applications of infinite-dimensional geometry to nonlinear waves.

Silvia Pappalardi (École Normale Supérieure)

Eigenstate Thermalization Hypothesis and Free Probability

Abstract: The general form of the Eigenstate Thermalization Hypothesis (ETH), describing all the relevant correlations of matrix elements, may be derived on the basis of a 'typicality' argument of invariance with respect to local rotations involving nearby energy levels. In this talk, I will discuss the close relation between ETH and Free Probability theory, as applied to a thermal ensemble or an energy shell. This mathematical framework allows one to express in an unambiguous way high order connected correlation functions (here identified as free cumulants) in terms of standard correlation functions. This perspective naturally incorporates the consistency property that local functions of ETH operators also satisfy ETH. The present results open a direct connection between quantum thermalization and the mathematical structure of Free Probability, thus offering the basis for insightful analogies and new developments.

Reference:

S. Pappalardi, L. Foini, and J. Kurchan, arXiv:2204.11679 (2022)

Lorenzo Rossi (Politecnico di Torino)

Non-Linear Current and Dynamical Quantum Phase Transitions in the Flux-Quenched Su-Schrieffer-Heeger Model

Abstract: I will talk about the dynamical effects of a magnetic flux quench in the Su-Schrieffer-Heeger model in a one-dimensional ring geometry. I will describe how, even when the system is initially in the half-filled insulating state, the flux quench induces a time-dependent current that eventually reaches a finite stationary value. Such persistent current, which exists also in the thermodynamic limit, cannot be captured by the linear response theory and is the hallmark of nonlinear dynamical effects occurring in the presence of dimerization. Moreover, I will show that, for a range of values of dimerization strength and initial flux, the system exhibits dynamical quantum phase transitions, despite the quench is performed within the same topological class of the model.

Aleksandra Ziolkowska (University of Oxford)

Unstable Excitations in an Integrable Quantum Field Theory

Abstract: Scattering processes in integrable theories are traditionally associated with particle number conservation. This is indeed the case for asymptotic states, yet at intermediate time-scales decaying excitations are allowed. The family of homogeneous sine-Gordon (HSG) models provides a rare example of an integrable quantum field theory where both stable and unstable particles are present in the spectrum.

In my talk, I will present a study of a particular member of this family, the $SU(3)_2$-HSG model, following a non-equilibrium quench. At high temperatures, physical intuition suggests that unstable particles are constantly formed and destroyed, and thus exist in finite proportions. As such, they may be expected to have a strong effect on the dynamics far from equilibrium and at finite densities. Adopting the generalized hydrodynamic approach, we identified the key signatures of unstable excitations which may serve as hallmarks for the finite-lived bound states formation. Furthermore, we explored in considerable detail quantitative and qualitative dependence of the instability signatures on the quench parameters.

The talk is based on two preprints:

O. A. Castro-Alvaredo, C. De Fazio, B. Doyon, and A. A. Ziolkowska, Tails of instability and decay: a hydrodynamic perspective, arXiv:2103.03735 (2021)

O. A. Castro-Alvaredo, C. De Fazio, B. Doyon, and A. A. Ziolkowska, Generalised hydrodynamics of particle creation and decay, arXiv:2112.05462 (2021)

Lecture on Wednesday afternoon

Tomohiro Sasamoto (Tokyo Institute of Technology)

Physics and Mathematics of the Kardar-Parisi-Zhang (KPZ) Equation

Abstract: In 1986, Kardar, Parisi and Zhang introduced a model equation for a growing surface, in the form of a nonlinear partial differential equation with noise [1]. In the original paper they applied a dynamical renormalization group analysis to demonstrate its universal nature, which is one of the first identified non-equilibrium universality classes (KPZ universality class). Since then their equation (KPZ equation) has been accepted as a standard model in non-equilibrium statistical mechanics.

In this lecture, we focus on its one dimensional version because it has attracted particular attention in the last decade or so. Mathematically there had been an issue of well-definendness of the equation itself, which was solved by a few different ideas. There is also a high precision experiment using liquid crystal. An important step was the discovery of an exact solution in 2010 [2], which confirmed that the height fluctuation is of $O(t^{1/3})$ and its universal distribution is given by the Tracy-Widom distribution from random matrix theory. Since then there have been a large amount of studies on its generalizations, which now forms a field of "integrable probability". The activity still continues. Universal behaviors for general initial conditions can now be studied ("KPZ fixed point"). Very recently we have found a direct connection between KPZ systems and free fermion at finite temperature [3].

A remarkable aspect of one dimensional KPZ is its unexpectedly wide universality. For example, KPZ universality is expected to appear in long time behaviors of many one-dimensional Hamiltonian dynamical systems such as anharmonic chains [4]. This is surprising because time-evolution of such systems are deterministic and there are apparently no growing surface with noise. More recently people have observed appearance of KPZ behaviors in dynamical properties of quantum spin chains [5], first in numerical simulations but more recently in real experiments. These discoveries have been attracting considerable attention but theoretical foundations are not yet satisfactory.

In the lecture we start from recalling basics of KPZ and then explain these recent developments.

References:

[1] M. Kardar, G. Parisi, and Y. C. Zhang, Phys. Rev. Lett. 56, 889 (1986)
[2] T. Sasamoto and H. Spohn, Phys. Rev. Lett. 104, 230602 (2010); G. Amir, I. Corwin, and J. Quastel, Comm. Pure Appl. Math. 64, 466 (2011)
[3] T. Imamura, M. Mucciconi, and T. Sasamoto, arXiv:2204.08420
[4] H. Spohn, J. Stat. Phys. 154, 1191 (2014)
[5] M. Ljubotina, M. Znidaric, and T. Prosen, Phys. Rev. Lett. 122, 210602 (2019)