

# Report of contributions

Integrable Techniques in Theoretical Physics  
Bad Honnef Physics School  
Student Workshop on Integrability 2024

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# Local quenches in a confining spin chain

Anna Krasznai, Prof. Gábor Takács

**Abstract.** Our work is motivated by the recent discovery of real time confinement in the quantum Ising spin chain . We investigate the effect of confinement on the dynamics of local quenches using time evolving block decimation (TEBD) method to simulate the time evolution. For the case of closed systems, we observe enhanced magnitude of fronts escaping confinement. Theoretical understanding of this phenomenon is in progress . For a more realistic description of experimental systems, it is often necessary to consider an open system by coupling the model to an environment which can be accomplished by applying the Lindblad formalism . The time evolution can be implemented in the TEBD protocol by vectorising the Lindblad equation and the density operators in Liouville space. It turns out that the escaping fronts are strongly suppressed compared to the case of local quenches of closed systems.

**Type of contribution:** Talk

# Thermodynamics and transport in the sine-Gordon model

Botond Nagy, Márton Kormos and Gábor Takács

**Abstract.** The sine-Gordon model is an integrable quantum field theory that provides a low-energy effective description of several one-dimensional and gapped condensed matter systems, including recent realisations with trapped ultracold atoms. Despite this fact, its complete thermodynamic description in all its regimes has been lacking. In my presentation, I show how we fixed the form of the Thermodynamic Bethe Ansatz system of the model at generic rational values of the coupling. As a first application, we calculated the Drude weight and cumulants of the full counting statistics for the energy and the topological charge and demonstrated that the charge Drude weight shows a fractal/popcorn dependence as a function of the coupling, similar to the gapless phase of the XXZ spin chain. The TBA description of the model opens the way to new applications of generalized hydrodynamics. Employing the theory of GHD, we investigated a novel effect in the sine-Gordon model, the separation of the transport of energy and charge, that I'm also going to discuss in my presentation.

**Type of contribution: Poster**

# A master equation for power laws

Sabin Roman, Francesco Bertolotti

**Abstract.** We propose a new mechanism for generating power laws. Starting from a random walk, we first outline a simple derivation of the Fokker–Planck equation. By analogy, starting from a certain Markov chain, we derive a master equation for power laws that describes how the number of cascades changes over time (cascades are consecutive transitions that end when the initial state is reached). The partial differential equation has a closed form solution which gives an explicit dependence of the number of cascades on their size and on time. Furthermore, the power law solution has a natural cut-off, a feature often seen in empirical data. This is due to the finite size a cascade can have in a finite time horizon. The derivation of the equation provides a justification for an exponent equal to 2, which agrees well with several empirical distributions, including Richardson’s Law on the size and frequency of deadly conflicts. Nevertheless, the equation can be solved for any exponent value. In addition, we propose an urn model where the number of consecutive ball extractions follows a power law. In all cases, the power law is manifest over the entire range of cascade sizes, as shown through log–log plots in the frequency and rank distributions.

**Type of contribution: Poster**

# Relaxation and Energy Transfer in the (Double) Sine-Gordon Model

Dávid Szász-Schagrin, Izabella Lovas and Gábor Takács

**Abstract.** The sine-Gordon model is a well-known integrable field theory that provides an effective description for systems such as Josephson-coupled one-dimensional bosonic quasi-condensates. The model can be interpreted as a quantum pendulum coupled to a phononic bath of interacting oscillators. A key question is the energy transfer dynamics between these modes when the system is out of equilibrium and how the breakdown of integrability affects this process. In this study, we investigate these questions by simulating the full quantum dynamics following quantum quenches, specifically focusing on energy transfer between the modes and correlations of the phase field.

To carry out our investigation, we employ a novel truncated conformal space approach (TCSA) complemented by a mini-superspace, enabling full quantum simulations that extend closer to the experimentally accessible parameter range than previous studies. By comparing our results with semi-classical truncated Wigner approximation (TWA) simulations, we gain insights into the validity range of the two methods and identify their differences.

Through this research, we aim to enhance our understanding of relaxation and energy transfer phenomena in the (double) quantum sine-Gordon model, shedding light on the dynamics under non-equilibrium conditions and the implications of integrability breakdown.

**Type of contribution: Poster**

# Sine-Gordon theory: the fluctuating surface method

Miklós Tóth, Márton Kormos

**Abstract.** The sine-Gordon model is a paradigmatic integrable field theory in (1+1) dimension with applications in condensed matter physics, optics, or trapped ultra-cold atoms. In the classical regime, it is one of the few models admitting solitons, dispersionless wave packet solutions which regain their shapes after collisions with one another. The quantum sine-Gordon model is also interesting as it provides the low energy effective description of gapped one-dimensional systems. However, at finite temperature and/or in finite volume, it is notoriously hard to obtain analytic or accurate numerical results. In my work, I used the so-called fluctuating surface method to compute the partition function, expectation values, and correlation functions at finite temperature. In my presentation I examine this numerical method, discuss its possible weaknesses and caveats, and compare its predictions in the limit of infinite system size or zero temperature with analytical results.

**Type of contribution:** Poster

# Hilbert-space geometry of Quantum Chaos

Rustem Sharipov, Anastasiia Tiutiakina, Alexander Gorsky, Vladimir Gritsev and Anatoly Polkovnikov

**Abstract.** The quantum geometric tensor (QGT) characterises the Hilbert-space geometry of eigenstates of parameter-dependent Hamiltonian. The real symmetric part of QGT is proportional to the Riemann geometric tensor on the space of quantum states while its imaginary antisymmetric part gives rise to the Berry curvature. In recent years both parts of QGT and related quantities have found extensive theoretical and experimental utility, in particular for quantifying quantum phase transitions at and out of equilibrium. Here we consider symmetric part of the QGT for different multi-parametric matrix Hamiltonians and discuss the possible indication of ergodic or integrable behaviour via system size dependence of induced geometry on the parameter space. We found in examples with two-dimensional parameter space that while the ergodic phase corresponds to the smooth manifold, the integrable limit marks itself as a singular geometry with conical defect. Our study thus provides more support that landscape of the parameter space yields the information on ergodic-nonergodic transition in complex quantum systems.

**Type of contribution: Talk**

# Bethe Ansatz for the Propagator of the Multi-Species Totally Exclusion Process

Ali Zahra and Luigi Cantini

**Abstract.** We explore the dynamics of the N-species totally asymmetric simple exclusion process (N-TASEP) on a one-dimensional lattice, where different species of particles exhibit hierarchical dynamics depending on arbitrary parameters. We employ the Algebraic Bethe Ansatz method to establish a framework that enables the calculation of finite-time conditional probabilities for the positions of a finite number of particles across multiple species. This formalism is analogous to a propagator operator for quantum spin chains and can be viewed as a stochastic vertex model, leading to explicit formulas which simplify to a determinantal form in particular situations, generalising thus the work of Schütz et al. for the single-species case. The formalism relies on a new method of Baxterization for R-matrices that depends on two separate spectral parameters with a braid-like algebra that was proposed by Ragoucy et al. This is a joint work with Luigi Cantini.

Type of contribution: Talk

# Truncated free fermion space approach method for Ising model in the presence of a magnetic field

Stepanova Khristina

**Abstract.** As is well known the Ising model free energy exhibits a singularity at the critical point  $H = 0, T = T_c$ . This singularity is described in terms of the Euclidian quantum field theory known as the Ising Field Theory (IFT). In this research work, we study the analytical properties of the free energy in Ising Field Theory within the framework of a magnetic field. We consider a two-dimensional IFT in finite-size geometry, with one of the two Euclidian coordinates compactified on a circle of circumference  $R, x + R - x$ , and the other  $y$  is treated as Euclidian time, which goes along the cylinder. To construct energy levels, the Truncated Free Fermion Space Approach (TFFSA) was used, which is one of the Hamiltonian truncation methods family. In the process of research, we consider only those eigenvalues of the total Hamiltonian that is less than chosen UV cutoff. In the course of the work, graphs of energy levels were obtained depending on the circumference  $R$  of the base of the cylinder for various values of the parameter (the scaling parameter) connecting the deviation from the critical value of the temperature with the deviation from the critical value of the magnetic field. The analysis of the obtained graphs is still in the process.

Type of contribution: Poster

# The Bethe Ansatz as a Quantum Circuit.

Roberto Ruiz, Alejandro Sopena, Max Hunter Gordon, Germán Sierra, and Esperanza López

**Abstract.** The Bethe Ansatz is an analytical method to address exactly solvable models in quantum mechanics. It has been shown that the states of the Bethe Ansatz can be prepared by a deterministic quantum circuit whose quantum gates were determined numerically. We report our progress in recasting the Bethe Ansatz as a deterministic quantum circuit. We present the analytical expressions of the quantum gates. Formulae rely upon diagrammatic rules that define the wave functions of the Bethe Ansatz by matrix-product states. Based on the analytical expressions, we prove the unitarity of the quantum gates. We use our results to clarify on the equivalence between the coordinate and algebraic Bethe Ansätze in light of matrix-product states.

**Type of contribution:** Talk

# Topology of interacting fermionic chains.

Emanuele Di Salvo, Anouar Moustaj, Chen Xu, Lars Fritz, Andrew Mitchell, Cristiane Morais Smith and Dirk Schuricht

**Abstract.** A fully analytical study of topological invariants in presence of interaction is carried when integrable fermionic chains are considered. Taking Su-Schrieffer-Heeger chain with Hubbard interaction as our paradigmatic model, we develop a formalism to study our problem without relying on perturbation theory. We also point out at possible generalizations to different topological classes and non-integrable models.

Type of contribution: Poster

# Entanglement Hamiltonian for inhomogeneous free fermions

Riccarda Bonsignori and Viktor Eisler

**Abstract.** We study the entanglement Hamiltonian for the ground state of one-dimensional free fermions in the presence of an inhomogeneous chemical potential. In particular, we consider a lattice with a linear, as well as a continuum system with a quadratic potential. It is shown that, for both models, formal field theory predicts a Bisognano-Wichmann form for the entanglement Hamiltonian of a half-infinite system. Furthermore, despite being nonrelativistic, this result is inherited by our models in the form of operators that commute exactly with the entanglement Hamiltonian. After appropriate rescaling, they also yield an excellent approximation of the entanglement spectra, which becomes asymptotically exact in the bulk of the trapped Fermi gas. For the gradient chain, however, the formal result is recovered only after taking a proper continuum limit.

**Type of contribution:** Talk

# Same-gate quantum circuits

Urban Duh, Marko Žnidarič

**Abstract.** In 2401.09708, we study Floquet systems with translationally invariant nearest-neighbor 2-site gates. Depending on the order in which the gates are applied on an  $N$ -site system with periodic boundary conditions, there are factorially many different circuit configurations. We prove that there are only  $N - 1$  spectrally different classes which can be viewed either as a generalization of the brick-wall or of the staircase configuration. Every class, characterized by two integers, has a nontrivial space-time symmetry with important implications for the level-spacing distribution – a standard indicator of quantum chaos. Namely, in order to study chaoticity one should not look at the eigenphases of the Floquet propagator itself, but rather at the spectrum of an appropriate root of the propagator. Preliminary results on the integrability of different classes will also be presented.

**Type of contribution: Poster**

# Quantum complexity phase transitions in monitored random circuits

Ryotaro Suzuki, Jonas Haferkamp, Jens Eisert, Philippe Faist

**Abstract.** Recently, the dynamics of quantum systems that involve both unitary evolution and quantum measurements have attracted attention due to the exotic phenomenon of measurement-induced phase transitions. The latter refers to a sudden change in a property of a state of  $n$  qubits, such as its entanglement entropy, depending on the rate at which individual qubits are measured. At the same time, quantum complexity emerged as a key quantity for the identification of complex behaviour in quantum many-body dynamics. In this work, we investigate the dynamics of the quantum state complexity in monitored random circuits, where  $n$  qubits evolve according to a random unitary circuit and are individually measured with a fixed probability at each time step. We find that the evolution of the exact quantum state complexity undergoes a phase transition when changing the measurement rate. Below a critical measurement rate, the complexity grows at least linearly in time until saturating to a value exponential in  $n$ . Above, the complexity does not exceed  $\text{poly}(n)$ . In our proof, we make use of percolation theory to find paths along which an exponentially long quantum computation can be run below the critical rate, and to identify events where the state complexity is reset to zero above the critical rate. We lower bound the exact state complexity in the former regime using recently developed techniques from algebraic geometry. Our results combine quantum complexity growth, phase transitions, and computation with measurements to help understand the behavior of monitored random circuits and to make progress towards determining the computational power of measurements in many-body systems.

**Type of contribution: Poster**

# Completing the Bootstrap Program for $\overline{\text{TT}}$ -Deformed Massive Integrable Quantum Field Theories

Fabio Sails

**Abstract.** I will summarise some of the results obtained in two papers (with O. Castro-Alvaredo and S. Negro) where we developed a form factor program for  $\overline{\text{TT}}$ -perturbed integrable quantum field theories (IQFTs). Following the introduction on Form Factors that is already part of the schedule, I will try to extend this program to the case in which non-minimal solutions of the S-matrix Bootstrap are taken into account, i.e. when CDD factors deform the S-matrix of a given model. From the RG-flow point of view this kind of deformation can be seen as an irrelevant perturbation of a IQFT or as models coupled to a non-trivial background. Therefore we will see how useful information about the physics behind this particular kind of deformation can be extracted from the form factor expansion of correlation functions. This allows us to establish connections with previous results obtained through other standard integrability techniques such as thermodynamic Bethe ansatz and the theory of generalised hydrodynamics.

**Type of contribution: Poster**

# Duality and integrability for the multi-species stirring process with open boundaries

Francesco Casini

**Abstract.** To construct a model for non-equilibrium statistical mechanics, the system is typically brought into contact with two thermodynamic baths, referred to as boundary reservoirs. These reservoirs impose their own density of particles at the system's boundary, generating a current. In the long-time limit, a non-equilibrium steady state sets in, characterized by a stationary value of the current. Currently, there is a growing interest for multi-component systems, i.e. models where many different species of particle (sometimes called colours) are present. In addition to the occupation of available spaces, interactions between different species become possible. Starting from the models explored in, this presentation focuses on the boundary-driven multi-species stirring process on the geometry of a general connected graph. This process is a natural extension of the symmetric exclusion process (SEP) when multiple species of particles are considered. Its dynamics involve the exchange of positions between a particle and a hole or between two colours of particles, both occurring at a rate of 1. In addition to this 'bulk' dynamics, the system is put in contact with boundary reservoirs that inject and remove particles. After describing the process's generator using a suitable representation of the  $\mathfrak{gl}(N)$  Lie algebra, we establish the existence of an absorbing dual process defined on an enlarged graph, in which each boundary is replaced by an absorbing extra-site. This dual process shares the same dynamics in the bulk, but the extra-sites absorb particles, voiding the graph. Considering the integrable version (on a chain with hard-core exclusion) of the multi-species stirring process, we combine absorbing duality and the matrix product ansatz (that was proven in ) to derive closed expressions for the non-equilibrium steady-state multi-point correlations of the process. Consequently, we formulate exact expressions for the non-equilibrium steady state. Finally, we discuss some extensions to the non-integrable chain. This presentation is based on recent joint work with Rouven Frassek and Cristian Giardinà.

**Type of contribution: Poster**

# On multipoint correlation functions in the 1+1 dimensional quantum Sinh-Gordon model

Alex Simon

**Abstract.** The S-matrix bootstrap program offers a unique possibility to compute explicitly the form factors of local operators in integrable quantum field theories. We shall build on those results so as to compute, in terms of explicit series of multiple integrals, the multipoint correlation functions in the Sinh-Gordon 1+1 dimensional quantum field theory, which is a simple case where the S-matrix is scalar and there is only one kind of particle. In particular, our expressions allow us to explicitly check the causality principle on the level of the correlation functions. This is a joint work with K. Kozłowski, Y. Potaux.

**Type of contribution: Poster**

# Semiclassical Trace Formula for Lieb-Liniger model

David Martin, Dr Remy Dubertrand

**Abstract.** In quantum chaos, an important tool to study the correspondence between a quantum system and its classical limit is the trace formula. This relates the energy density of a quantum model to the properties of the periodic solution of its classical limit. Here we apply the trace formula to the Lieb-Liniger model for a finite number of particles. This model has played a central role in mathematical physics and, we aim to show, is particularly relevant for studying classical/quantum correspondence. The model deals with  $N$  1-Dimensional Bose particles trapped in a box, interacting via a two-body potential chosen as the Dirac delta “function”. We consider the repulsive large interaction strength regime in our derivations.

The original treatment by Lieb and Liniger uses the Bethe ansatz to find the energy spectrum and the corresponding eigenstates. The oscillating part of the trace formula will relate the quantum energy spectrum to the classical periodic trajectories. We test our trace formula in two ways. First by solving numerically the Bethe equations for  $N$ , computing a long sequence of levels to get their density and comparing with the asymptotic Weyl’s law. Then comparing the obtained density with a sum over the periodic classical solutions.

**Type of contribution: Poster**

# Generalised hydrodynamics for homogeneous integrable systems with weak two-body interaction

Leonardo Biagetti, Maciej Lebek, Milosz Panfil, Jacopo De Nardis

**Abstract.** We derive hydrodynamic equations for a generic homogeneous integrable system with weak two-body (non-integrable) interaction. In particular we explicitly write the evolution equations for the connected one, two and three body function. To do so we propose an alternative way to derive BBGKY equations. This innovative formalism permits to generalize BBGKY equations to the case of systems with ultra local non-trivial correlation, i.e. integrable models. To make a numerical comparison, we specialize to the Hard Rods gas with  $1/r^3$  and  $1/r^6$  potentials and show that the dynamics of the system is well described by the solution of the equations that we have derived.

**Type of contribution: Poster**

# Entanglement asymmetry in the ordered phase of many-body systems: the Ising Field Theory

Capizzi Luca

**Abstract.** Global symmetries of quantum many-body systems can be spontaneously broken. Whenever this mechanism happens, the ground state is degenerate and one encounters an ordered phase. In this study, our objective is to investigate this phenomenon by examining the entanglement asymmetry of a specific region. This quantity, which has recently been introduced in the context of  $U(1)$  symmetry breaking, is extended to encompass arbitrary finite groups  $G$ . We also establish a field-theoretic framework in the replica theory using twist operators. We explicitly demonstrate our construction in the ordered phase of the Ising field theory in  $1+1$  dimensions, where a  $\mathbb{Z}_2$  symmetry is spontaneously broken, and we employ a form factor bootstrap approach to characterise a family of composite twist fields. Analytical predictions are provided for the entanglement asymmetry of an interval in the Ising model as the length of the interval becomes large. We also propose a general conjecture relating the entanglement asymmetry and the number of degenerate vacua, expected to be valid for a large class of states. This is a joint work with Michele Mazzoni, recently published as JHEP 2023, 144 (2023).

**Type of contribution:** Poster

# Measurements of ballistic correlations in a recirculating optical fibre loop

Elias Charnay, Alvise Bastianello, Adrien Escoubet, Thibault Bonnemain,  
Benjamin Doyon, Stéphane Randoux, François Copie, and Pierre Suret

**Abstract.** Generalised Hydrodynamics has proven successful to describe thermodynamics and hydrodynamics of integrable systems [see Castro-Alvaredo, O. et al. Phys. Rev. X 6, 041065 (2016)]. It predicts the existence of ballistic two-point space-time correlations for the infinitely many conserved quantities in integrable systems. In particular, the mass in the focusing (attractive) Nonlinear Schrödinger Equation (fNLS) is conserved and its connected correlation at large scale, starting from an equilibrium state, takes a ballistic form [for the detailed formula, see Koch, R. et al. Phys. A : Math. Theor. 55, 134001 (2022)].

We present here our experimental results in a recirculating optical fibre loop [see Kraych A. E. et al. Phys. Rev. Lett. 122, 054101 (2019)] allowing measurements of these hydrodynamic correlations. The setup enables the propagation of arbitrary initial condition without much losses. At each roundtrip, the signal propagates inside 5km of standard optical fibre where losses are compensated via counterpropagating Raman amplification. We then extract 10% of this light to reconstruct the full intensity space-time dynamics. Computing the intensity correlations naturally follows the reconstruction. We show that they do follow a ballistic behaviour with a coefficient that can be computed numerically from statistics of the initial field.

**Type of contribution:** Talk

# Navier-Stokes equations for nearly integrable quantum gases

Maciej Łebek

**Abstract.** The Navier-Stokes equations are paradigmatic equations describing hydrodynamics of an interacting system with microscopic interactions encoded in transport coefficients. In this work we show how the Navier-Stokes equations arise from the microscopic dynamics of nearly integrable 1d quantum many-body systems. We build upon the recently developed hydrodynamics of integrable models to study the effective Boltzmann equation with collision integral taking into account the non-integrable interactions. We compute the transport coefficients and find that the resulting Navier-Stokes equations have two regimes, which differ in the viscous properties of the resulting fluid. We illustrate the method by computing the transport coefficients for an experimentally relevant case of coupled 1d cold-atomic gases.

**Type of contribution: Poster**

# Generalized Gibbs ensembles in weakly interacting dissipative systems and quantum computers

Iris Ulčakar and Z. Lenarčič

**Abstract.** Integrable systems offer rare examples of solvable many-body problems in the quantum world. Due to the fine-tuned structure, their realization in nature and experiment is never completely accurate, therefore effects of integrability are observed only transiently. As suggested by recent studies, one way to overcome this limitation is to weakly couple nearly integrable systems to baths and driving: these will stabilize integrable effects up to arbitrary time and encode them in the stationary state approximated by a generalized Gibbs ensemble (GGE). Here, we focus on more manageable non-interacting models coupled to baths where thermodynamically large systems can be considered. We review and compare different approaches, mainly, the time evolution of the GGE and the iterative scheme to construct the leading conserved quantities in a truncated GGE description previously proposed by us [1]. Finally, we suggest how such highly non-thermal GGEs could be observed in a digital quantum computer, involving (non-interacting) integrable trotterized dynamics and ancilliary qubits reset protocol [2] that was realized recently.

**Type of contribution: Talk**

# The overlap gap property limits limit swapping in QAOA

Mark Goh

**Abstract.** The Quantum Approximate Optimization Algorithm (QAOA) is a quantum algorithm designed for Combinatorial Optimization Problem (COP). We show that if a COP with an underlying Erdős–Rényi hypergraph exhibits the Overlap Gap Property (OGP), then a random regular hypergraph exhibits it as well. Given that Max-q-XORSAT on an Erdős–Rényi hypergraph is known to exhibit the OGP, and since the performance of QAOA for the pure q-spin model matches asymptotically for Max-q-XORSAT on large-girth regular hypergraph, we show that the average-case value obtained by QAOA for the pure q-spin model for even q is bounded away from optimality even when the algorithm runs indefinitely. This suggests that a necessary condition for the validity of limit swapping in QAOA is the absence of OGP in a given combinatorial optimization problem. Furthermore, the results suggests that even when sub-optimised, the performance of QAOA on spin glass is equal in performance to classical algorithms in solving the mean field spin glass problem providing further evidence that the conjecture of getting the exact solution under limit swapping for the Sherrington–Kirkpatrick model to be true.

**Type of contribution: Poster**

# Modeling ultracold spinor Bose gases with the quantum matrix non-linear Schrödinger equation

Hannes Köper and Thomas Gasenzer

**Abstract.** The quantum matrix non-linear Schrödinger equation describes an integrable model of two non-relativistic  $SU(2)$  multiplets with quartic interaction between their coupled states. Due to the matrix structure of the field operators involved, the interaction includes spin changing processes not captured by ordinary density-density scattering. In spite of the complexity of these spin changing terms for the general  $\mathfrak{m} \times \mathfrak{n}$  matrix field, symmetry analysis reveals a very simple picture in terms of Casimir operators of an associated Jordan-Schwinger representation of  $SU(n)$ . We investigate in particular the case where one of the multiplets is a spin  $1/2$  doublet which we interpret as an electron coupling to the nuclear multiplet of some atom. The model is thus expected to describe the interaction between different hyperfine states in a gas of said atoms. Indeed, we find that standard Hamiltonian descriptions of spinor Bose gases in certain parameter regimes are recovered and generalized by the quantum matrix non-linear Schrödinger equation. This enables the use of quantum integrable techniques in the field of ultracold spinor Bose gases.

**Type of contribution: Poster**

# Schur indices for $\mathcal{N} = 4$ super-Yang-Mills with more general gauge groups

Baoning Du, Minxin Huang and Xin Wang

**Abstract.** As a type of topological invariants, the Witten index is a very powerful non-perturbative tool for supersymmetric theories. In the context of superconformal quantum field theories, such indices are called superconformal indices. When taking the Schur limit, they are referred to as Schur indices, and have some further nice mathematical properties. For example, in some cases it can be computed from the  $q$ -deformed 2d Yang-Mills. For the case of  $\mathcal{N} = 4$  supersymmetry, besides a universal fugacity parameter denoted as  $q$ , the Schur index may have an extra flavor fugacity from the symmetry  $SU(2)_F \subset SU(4)_R$ . We generalize the results for  $\mathcal{N} = 4$ ,  $A_n$  gauge groups to more gauge groups  $B_n, C_n, D_n, G_2$ .

Type of contribution: Poster

# Fermionic Basis in Conformal Field Theory and Thermodynamic Bethe Ansatz for Excited States

Adler Sergei and Hermann Boos

**Abstract.** For the XXZ spin chain, a fermionic basis consisting of two sets of anti-commuting creation-annihilation operators can be constructed. Its key advantage is the factorization of the physical and algebraic structures. The fermionic basis is constructed by means of the representation theory of the quantum group  $U_q(\hat{\mathfrak{sl}}_2)$  and is independent of any physical data such as the magnetic field, temperature or boundary conditions. There are only two transcendental functions  $\rho(\zeta; \kappa, \kappa')$  (ratio of transfer matrix eigenvalues) and  $\omega(\zeta, \zeta'; \kappa, \kappa')$  (nearest neighbour correlator) that contain all the physical information. Finding explicit representations for these functions is very important.

We consider these functions in the context of the scaling limit of the XXZ spin chain. For  $\omega(\zeta, \zeta'; \kappa, \kappa')$  an integral representation exists, allowing us to extract certain properties, such as, for example, the  $\kappa \leftrightarrow \kappa'$  symmetry of  $\omega(\zeta, \zeta'; \kappa, \kappa')$ . However, it does not allow for the explicit representation. It can only be obtained in the case  $\kappa = \kappa'$  with the help of the Wiener-Hopf technique. Recently, we were able to show that in this rather special case the function  $\omega(\zeta, \zeta'; \kappa, \kappa')$  can also be found as a perturbation of the free fermionic solution by action of a dressing operator.

We believe this to be an important and useful observation. In the free fermionic case we are also able to explicitly construct a so-called master function  $\Phi(\zeta, \zeta'; \kappa, \kappa')$  which is related to  $\omega(\zeta, \zeta'; \kappa, \kappa')$  in a simple way. We hope to use the dressing operator (suitably modified for the function  $\Phi(\zeta, \zeta'; \kappa, \kappa')$ ), generalising the above construction for the case  $\kappa = \kappa'$  as well.

Type of contribution: Poster

# Integrable long-range spin chains with extended symmetries

Adel Ben Moussa

**Abstract.** Quantum spin chains are usually studied under the assumption that only nearest neighbouring spins interact, like in the Heisenberg spin chain. However, in reality spins that are further apart may interact as well. Such long-range interactions are for example important in cold atom experiments, and possibly for quantum computing too.

The special class of long-range spin chains that are exactly solvable/quantum integrable offer the exciting opportunity to test analytically which paradigms for nearest-neighbour models survive in the presence of long-range interactions. An important example was found independently by Haldane and by Shastry in 1988. From a physical point of view this is one of the simplest models that exhibits fractional statistics in one dimension. The energy spectrum of this Haldane-Shastry spin chain is remarkably simple, and the corresponding wave functions can be given exactly and explicitly in terms of so-called Jack polynomials, all thanks to a remarkable mathematical structure related to the Calogero-Sutherland model. A few years ago, my team has made progress in solving a XXZ-like (partially isotropic) generalisation of the Haldane-Shastry spin chain, resulting in a whole family of exactly solved models. The hamiltonian is more complicated, but in such a way that the key algebraic properties of the Haldane-Shastry spin chain are preserved. I can explain in a talk/poster how surprisingly easily the solution to the HS spin chain and its XXZ-like version is expressed compared to the usual Bethe Ansatz. If time allows it, I can go into a more recent result that explores the physical significance of this deformed HS chain: in exact analogy with the usual XXZ Heisenberg spin chain, we discovered that our model possesses a free-fermion point. We obtain a new model that is non-trivial, free-fermionic, with a lot a symmetries and non-unitary but of physical significance thanks to PT symmetry. This is interesting considering how rare are non-unitary models that are actually tractable.

**Type of contribution: Talk**

# Integrability of Casimir setup in sine-Gordon backgrounds

Lucia Santamaria-Sanz

**Abstract.** The quantum vacuum interaction energy between a pair of semitransparent two-dimensional plates embedded in the topological background of a sine-Gordon kink is studied through the transfer matrices, the Green's function, and the scattering data of the theory. Thus, an extension of the TGTG-formula (firstly developed by O. Kenneth and I. Klich in the scattering approach) for such topological background is obtained. The plates are represented by Dirac delta potentials and its first derivative. Quantum vacuum oscillations around the sine-Gordon kink solutions are interpreted as an integrable quantum scalar field theory in the spacetime of a domain wall.

**Type of contribution: Poster**

# Measurement-induced phase transitions in Gaussian fermions and matrix product states

Hugo Loio

**Abstract.** In out-of-equilibrium quantum many-body systems, unitary dynamics tend to scramble the local degrees of freedom causing a growth of entanglement. On the other hand, when measuring the state gets projected, potentially revealing information that destroys entangling superpositions. Recently, studying the competing effect of unitary and monitoring dynamics led to the discovery of a new class of dynamical phase transitions, named measurement-induced phase transitions (MIPTs). MIPTs can be seen either as a transition in the extension of the entanglement growth of an initial pure state or as a transition in the purification timescale of an initially mixed state. In Gaussian fermion evolution, the transition has a particular nature, since it presents an extended critical phase. In those systems, the existence of the transition is dependent on global symmetries, as we will exemplify numerically with two systems with distinct conserved quantities. In generic interacting models, we can probe the MIPT using matrix product state (MPS) techniques. Here, the MIPT can be interpreted as a transition in the classical simulatability of the system, since MPSs are known to be good approximations only when entanglement is not extensive (area law). We show that quantum monitored dynamics projected on an MPS manifold of constant bond dimension can still reveal a MIPT, allowing us to probe the transition in systems of arbitrarily large size.

**Type of contribution: Poster**

# Dynamical symmetry restoration and the quantum Mpemba effect in free models

Konstantinos Chalas

**Abstract.** Local relaxation after a quench in 1-D quantum many-body systems is a well known and very active problem with rich phenomenology. Except for pathological cases, the local relaxation is accompanied by the local restoration of the symmetries broken by the initial state that are preserved by the unitary evolution. Recently, the entanglement asymmetry has been introduced as a probe to study the interplay between symmetry breaking and relaxation in an extended quantum system. In particular, using the asymmetry, it has been shown that the more a symmetry is initially broken, the faster it may be restored. This surprising effect, which has been also observed in trapped-ion experiments, can be seen as a quantum version of the Mpemba effect and is manifested by the crossing at a finite time of the entanglement asymmetry curves of two different initial symmetry breaking configurations. In this talk, I will discuss how, by tuning the initial state, the symmetry dynamics in free fermionic systems can display much richer behaviour than seen previously. In particular, for certain classes of initial Hamiltonians containing long-range couplings, the entanglement asymmetries can even exhibit multiple crossings, which illustrates that the existence of the quantum Mpemba Effect can only be inferred by examining the late time behavior of the entanglement asymmetry.

**Type of contribution: Talk**

# Elusive phase transition in the replica limit of monitored systems

Guido Giachetti

**Abstract.** We study an exactly solvable model of monitored dynamics in a system of  $N$  spin-1/2 particles with pairwise all-to-all noisy interactions, where each spin is constantly perturbed by weak measurements of the spin component in a random direction. We make use of the replica trick to account for the Born's rule weighting of the measurement outcomes in the study of purification and other observables, with an exact description in the large- $N$  limit. We find that the nature of the phase transition strongly depends on the number  $n$  of replicas used in the calculation, with the appearance of non-perturbative logarithmic corrections that destroy the disentangled/purifying phase in the relevant  $n \rightarrow 1$  replica limit. Specifically, we observe that the purification time of a mixed state in the weak measurement phase is always exponentially long in the system size for arbitrary strong measurement rates.

Type of contribution: Poster

# Limit shape phenomenon in free fermionic models: merging of arctic circles

Andrea Maroncelli

**Abstract.** We consider a free fermion formulation of a statistical model exhibiting a limit shape phenomenon. The model is known to have a phase transition that can be visualized as the merger of two arctic circles. We compute the density profile with the techniques of orthogonal polynomials on the unit circle and study its edge behaviour by varying the coupling parameter, which modules the distance of the arctic circles. We try to extend the presented model in the case of a different dispersion relation, which brings to a more sophisticated edge behaviour.

**Type of contribution: Poster**

# Overlap computations in the open XXZ spin chain

Charbel Abetian

**Abstract.** We consider the open XXZ spin chain after a local boundary quench: changing of the first site magnetic field. Using Algebraic Bethe Ansatz, we compute an exact expression of the overlap between the ground states before and after the quench when the system size tends to infinity.

**Type of contribution: Poster**

# Dynamical quantum phase transition and limit shapes

Yasser Bezzaz

**Abstract.** A dynamical quantum phase transition (DQPT) is a phase transition that occurs over time. The central object for studying DQPT is the Loschmidt echo:  $|\langle \psi(0) | \psi(t) \rangle|^2$ , which represents the return or survival probability. Using the Coulomb gas method, I have uncovered a third-order DQPT occurring in a system of 1D free fermions, in complex time ( $t = a + i\tau$ ). Within this framework, the momentum density of fermions exhibits a limit shape phenomenon, with both gapped and gapless phases. This phenomenon was previously known and studied in imaginary time (Gross-Witten-Wadia model). However, in real time and more general complex time, I present the full behavior of this DPQT for the first time.

Type of contribution: Poster

# The Search for Soliton-Like Robustness: Localized Superpositions of Type II States in the Lieb-Liniger Model

Anahita Sarvi

**Abstract.** Starting with bosons in 1D interacting via a repulsive delta-function potential (the Lieb-Liniger model), we construct superpositions of Type II (hole-like) states and study their time evolution. We aim for states whose dynamics possess key features of classical solitons: localized excitations that preserve their shape, such as shallow water (Korteweg-de Vries) solitons. Focusing on the Tonks-Girardeau (infinite-strength interaction) regime, we show that using a carefully selected subset of eigenstates improves the lifetime of the excitation, allowing for a closer correspondence between the quantum wavepacket and a classical soliton.

**Type of contribution: Poster**

# Entanglement-based approaches in studying highly correlated 1D spin systems using DMRG

Jędrzej Wardyn, Clio Agrapidis, Satoshi Nishimoto, Miłosz Panfil

**Abstract.** First part shows joined work with Clio Agrapidis and Satoshi Nishimoto we investigate the low-energy properties of the dimerized frustrated ferromagnetic (FM)  $J_1-J_1-J_2$  model with the density matrix renormalization group method. We show the ground state phase diagram spanned by a wide range of  $J'_1/J_1$  and  $J_2/|J_1|$  features ferromagnetic phase and valence bond solid (VBS) phases that are continuations from the  $J'_1/J_1$  limits of the model. In the limit  $J'_1/J_1 = 1$  we recover FM  $J_1 - J_2$  model hosting  $\mathcal{D}_3$ -VBS state where valence bonds form between third-neighbor spins. The other VBS phase named mixed-VBS features both second- and third neighboring spins that continue from the  $J'_1/J_1 = 0$  limit. We show that both phases feature hidden antiferromagnetic order and twofold degeneracy in the entanglement spectrum characterizing them as Haldane states. Remarkably, we encounter a nontrivial quantum phase transition between two topological VBS states, where at the boundary of phases VBS stability is enhanced. We discuss results in the context of other spin chain models and edge-sharing cuprate materials.

Second part shows current cooperative work with Miłosz Panfil. We study the q-deformed Majumdar-Ghosh model. Beside magnetisation, energy gap or dimer order parameter we look how entanglement observables like Renyi entropy, entanglement gap, central charge change under the influence of magnetic field. These measurements gave different perspectives on an unique system where commutation relations are broken by design and offer a bridge between: transverse field Ising (integrable model) and Majumdar- Ghosh model (Heisenberg system projected from spin-3/2 to spin 1/2).

**Type of contribution: Poster**

# BetheFluid: Numerical solution of Generalized Hydrodynamics

Antoni Lis, Miłosz Panfil

**Abstract.** Generalized Hydrodynamics (GHD) uses the infinite number of conserved charges in integrable models to explain transport phenomena, relaxation dynamics, and quantum quenches, attracting considerable theoretical and experimental attention. The GHD equation, which governs the evolution of the quasi-momentum density  $(x, t)$ . This partial differential equation is highly non-linear due to the dependence of the velocity  $v$  and diffusion operator  $D$  on the state via integral equations. Consequently, the analysis of state evolution is in general feasible only through numerical solutions. In our work, we aimed to develop a tool for easy and convenient solution of such problems, resulting in the creation of a Python package called BetheFluid. While our work focused primarily on the Lieb-Liniger model, we designed the code structure to be easily extensible to other models. Emphasizing object-oriented programming and adherence to PEP 8 style guidelines, our package comprises two main modules: Solver, for obtaining the solution, and Observable, for deriving macroscopic observables such as energy or entropy. In my poster presentation, I will demonstrate the structure of our code, guide users on how to utilize it effectively, and showcase the results we have obtained. These results include the calculation and analysis of velocity and diffusion operators, as well as the evolution of physically relevant initial states.

**Type of contribution: Poster**

# Higher-Point Loop Integrands and Ten-Dimensional Null Limits

Till Bargheer, Albert Bekov, Carlos Bercini, Frank Coronado

**Abstract.** Applying twistor Feynman rules to determinant operators, we compute the integrands of generating functions for correlators of arbitrary single-trace half-BPS operators in  $\mathcal{N} = 4$  super Yang-Mills theory. The generating functions are obtained for five-point correlators up to two loops and six-point correlators at one loop order. Taking the so-called ten-dimensional null limit of the generating functions results in the simplest correlators that are conjectured to be related to scattering amplitudes on the Coulomb branch. Applying the Feynman rules directly to a subset of graphs generated by the determinant operators, we were able to compute the even part of the Coulomb branch amplitudes up to two loops for any number of external particles. The data obtained in this work might clear up systematics in the integrability-based hexagonalization procedure.

**Type of contribution:** Poster

# Measurement-induced phase transitions by matrix product states scaling

Guillaume Cecile, Hugo Lóio, Jacopo De Nardis

**Abstract.** We study the time evolution of long quantum spin chains subjected to continuous monitoring projected on matrix product states (MPS) with fixed bond dimension, by means of the Time-Dependent Variational Principle (TDVP) algorithm. The latter gives an effective unitary evolution which approximates the real quantum evolution up to the projection error. We show that such error displays, at large times, a phase transition in the monitoring strength, which can be well detected by scaling analysis with relatively low values of bond dimensions. Moreover, in the presence of  $U(1)$  global spin charge, we show the existence of a charge-sharpening transition well separated from the entanglement transition which we detect by studying the charge fluctuations of a local sub-part of the system at large times. Our work shows that quantum monitored dynamics projected on MPS manifolds contains relevant information on measurement-induced phase transitions and provides a new method to identify measured-induced phase transitions in systems of arbitrary dimensions and sizes.

**Type of contribution: Poster**

# Hydrodynamic Limit Shapes for Finite Temperature Formation Probabilities

Dylan Edwards, Dimitri Gangardt

**Abstract.** The emptiness formation probability (EFP) measures the likelihood of observing a string of consecutive spins in the ground state of a spin chain, or empty sites in the equivalent fermionic model. In the large  $N$  limit this can be related to the shape of an instanton which dominates the imaginary time path integral with suitable boundary conditions, an example of the "limit shape" phenomenon observed in some integrable statistical models. At finite temperatures we argue that this shape is obtained by minimizing a certain hydrodynamic action over a cut cylinder, and that phase transitions in the large deviations of EFP coincide with a geometric transition in the form of the limit shape.

Type of contribution: Poster