Monday 18 March
09:00 - 9:30 Welcome by the Lorentz Center organization and by the organizers
09:30 - 10:00 Self introductions participants
10:00 - 10:30 Coffee break
10:30 - 12:00 Tutorial – Quantum Integrability by Rafael Nepomechie
12:00 - 13:30 Lunch
13:30 - 15:00 Tutorial – Quantum Computing by Robert König
15:00 - 16:00 Coffee Break
16:00 - 17:30 Round Tables
- Denis Bernard - Variation on stochastic evolution of many-body quantum systems
- Bruno Bertini - Can we achieve an efficient description of quantum dynamics by exchanging the roles of space and time?
- Pasquale Calabrese - Questions for randomized measurements
- Maurizio Fagotti
- Giuseppe Mussardo - Quantum Computing and Number Theory
- Rafael Nepomechie - Quantum circuits for Bethe wavefunctions
17:30 - 18:00 Restitution of Round Tables
Evening Wine and Cheese

Tuesday 19 March – theme: state preparation, Bethe wf; integrable systems for hardware
09:00 - 9:30 Talk – Esperanza Lopez: The Bethe ansatz as a quantum circuit
Abstract - We present an approach to transform the Bethe ansatz for the periodic spin ½ XXZ chain into a quantum circuit capable of preparing the associated eigenstates. We employ a Matrix Product State (MPS) to construct the plane wave superpositions inherent in the coordinate Bethe ansatz, elucidating this process through simple diagrammatic rules. We highlight the equivalence between the MPS structures of the coordinate and algebraic versions of the Bethe ansatz, linked by a change of basis akin to the Yang-Baxter equations. We derive the complete analytical expressions for the quantum circuit gates. An efficient decomposition of these gates into elementary unitaries is feasible for the non-interacting XX chain, while for the general XXZ chain this decomposition is unknown and poses an important challenge for implementation on real quantum devices.

09:30 - 10:00 Talk – John van Dyke: Quantum State Preparation for Exactly Solved Models
Abstract: Quantum state preparation is at the heart of many algorithms for studying many-body physics on quantum computers. We contrast several methods that can be used to prepare quantum states, including tensor network-based methods, variational quantum eigensolvers, and exact Bethe ansatz state preparation algorithms. We highlight the advantages and limitations of each approach, and discuss their suitability for near-term implementation on quantum hardware.

10:00 - 10:30 Talk – Roberto Bondesan: Machine Learning for Quantum Computing
Abstract - Large scale quantum computing promises to discover new fundamental physics and solve technological challenges that enable a more sustainable future. But
how are we going to best use the data produced by quantum computers to solve the problems we care about?

This question can be analysed through the lens of machine learning, a technique that has become mainstream in both science and engineering to solve disparate tasks such as natural language processing and protein folding. Applying machine learning to quantum systems shifts the computational focus from efficient simulation to efficient learning, where the aim is to reduce sample complexity - the number of data samples to accurately solve a task - alongside runtime.

In this talk, I will present two applications of machine learning to quantum systems. The first is to design decoders of quantum error correction codes, a critical component for scaling up quantum computing. We devise a novel neural network decoder that is equivariant to the automorphism group of the quantum code, and that achieves state of the art performance for reducing logical errors in the toric code.

The second application is to predict properties of ground states of long-range quantum systems, motivated by the relevance of long-range interactions for studying molecules and materials. We compute the exact scaling of the sample complexity for learning observables across a gapped phase and substantiate our analytical results with DMRG simulations.

References:
https://arxiv.org/abs/2304.07362
https://arxiv.org/abs/2312.17019

10:30 - 11:00 Coffee break

11:00 - 11:30 Talk – Angela Foerster: Exactly solved models in the design of quantum devices
Abstract - The precise control of quantum systems will play a major role in the realization of atomtronic devices. Here we study models of dipolar bosons confined to three-well and four-well potentials. The analysis considers both integrable and non-integrable regimes within the models. Through variation of the external field, we demonstrate how the triple-well system can be controlled between various “switched-on” and “switched-off” configurations, and how the four-well system can be controlled to generate and encode a phase into a NOON state. We also briefly discuss the physical feasibility of these systems through the use of ultracold dipolar atoms in BECs (three-wells) or optical superlattices (four-wells). Our proposals showcase the benefits of quantum integrable systems in the design of quantum devices.

11:30 - 12:00 Talk – Dirk Schuricht: Phase diagram of an extended parafermion chain
Abstract - We study the phase diagram of an extended parafermion chain, which, in addition to terms coupling parafermions on neighbouring sites, also possesses terms involving four sites. Via a Fradkin–Kadanoff transformation the parafermion chain is shown to be equivalent to the non-chiral Z3 axial next-nearest neighbour Potts model. We discuss a possible experimental realisation using hetero-nanostructures. The phase diagram contains several gapped phases, including a topological phase where the system possesses three (nearly) degenerate ground states, and a gapless Luttinger-liquid phase.
Abstract - Understanding quantum many-body systems remains a formidable challenge, motivating the development of quantum computers. Within this domain, exactly solved models stand out, offering a gateway to explore the complexities of the quantum many-body landscape beyond mere perturbative approaches. This has facilitated unique insights into eigenstates, especially ground states, which are of key importance in quantum computing, as well as provided benchmarks for quantum devices and classical simulation techniques alike.

Quantum computers are variationally bound, and by preparing and measuring, for example, ground states of exactly solved models, we can better understand traditionally inaccessible quantities, such as correlation functions with arbitrary ranges and higher orders. In a somewhat dual approach, there has been an increasing interest in the certification of quantum many-body properties through convex relaxations, which are not variationally bound. This can be understood as building mathematical proofs of lower bounds, e.g., for the ground-state energy. Good certificates, like elegant mathematical proofs, are extremely hard to come by, but they offer provable guarantees and unique insights. For instance, in variational quantum eigensolvers, they quantify how close a quantum state is to the ground state energy; or in adiabatic quantum state preparation, by providing lower bounds to the spectral gap, a key performance parameter.

In this talk, I will discuss what we should look for in a good certificate, and which physics we can learn from building it, from the point of view of how we can apply them to quantum computing. Interestingly, physical properties such as correlation lengths and entanglement entropies seem to play a key role in building more effective certificates; i.e., yielding tighter bounds for the same computational effort. Recent works have suggested intriguing synergies between variational solutions and lower-bound certificates. For instance, a good matrix product state representation of a ground state can be used to build state-of-the-art lower bounds, although, a priori, there is no clear reason why there should be such a connection. Consequently, exactly solved models present a unique opportunity to shed light on the crafting of effective relaxations, an avenue that has hardly been explored so far.
Abstract - I will discuss some examples of quantum simulations of integrable (and possibly non-integrable) models, and would like to discuss some open problems and possible applications.

09:30 - 10:00 Talk – Yuan Miao: The iso-BAE system: new dualities in open spin chains
Abstract - I will outline a phenomenon that a family of integrable spin chains with open boundary conditions share part of the spectra, subject to a continuous deformation parameter. Integrability plays an important role, guaranteeing the solvability of the complete spectra. While we have explicitly broken the global symmetry, a "non-invertible" Z_2 symmetry emerges, adding more features to the spectra of those open spin chains. Possible applications to quantum information will be briefly mentioned too.

10:00 - 10:30 Talk – Alexandre Faribault: Integrability and dark states in XX central spin models.
Abstract - A central spin 1/2, feeling a z-oriented magnetic, and inhomogeneously coupled to a bath of other spins via an XX coupling in the xy-plane, leads to a Hamiltonian which was recently shown to be integrable. An important fraction of its eigenstates can then be shown to be "dark states" in which the central spin stays completely unentangled with the bath creating a sub-space in which the central spin is protected from decoherence due to the bath.

In the talk, we first demonstrate that the spin-1/2 model stays integrable in the presence of an arbitrarily-oriented field and that dark states can still emerge in this system, but only at strong enough coupling. These results are then generalized to the central spin-1 case, by proving the integrability of the spin 1 model in an arbitrarily oriented field and constructing polynomial relations between the conserved charges which allows one to study the fate of the dark states.

10:30 - 11:00 Coffee break

11:00 - 11:30 Talk – Tomaz Prosen: Deformed Rule 54: Unusual Integrable Model
Abstract - The rule 54 reversible cellular automaton has served as a fruitful exactly solvable toy model of non-equilibrium statistical mechanics where several time-dependent and non-equilibrium phenomena can be analysed without approximations and assumptions. In this talk I will introduce a rich set of deformations of rule 54, which can be treated either as a quantum or stochastic cellular automaton. I will present analytic and numerical evidence for integrability of these families of models, and in particular, an explicit construction of the non-equilibrium steady state of boundary driven deformed rule 54. The model appears rather unusual, as the integrability structures seem not expressible in terms of finite-dimensional auxiliary space.

11:30 - 12:00 Talk - Rhine Samardar: Dynamical universality of spin diffusion in the Heisenberg model
Abstract - Understanding universal aspects of quantum dynamics is a central problem of statistical mechanics. In particular, the infinite-temperature spin dynamics of the
1D Heisenberg model have been conjectured to belong to the Kardar-Parisi-Zhang (KPZ) universality class, which was originally introduced to describe the stochastic, nonlinear dynamics of driven interfaces and has now proven to apply to a wide range of classical systems. Much progress regarding KPZ universality has been made based on exactly solvable models in this class, including predictions about the fluctuations of the height function and all its associated moments. Motivated by this information, we study spin transport in the Heisenberg model by analyzing the full probability distribution—rather than just the mean—of magnetization transfer across the center of a 1D chain. While the first two moments demonstrate superdiffusive behavior, a detailed exploration of the full counting statistics (FCS) challenges the KPZ conjecture, allowing for the identification of alternative dynamic universality classes. Additionally, we introduce an exact and scalable protocol for measuring FCS, applicable to experiments or tensor-network simulations, which faithfully captures FCS starting from number-indefinite initial states or in the presence of noisy dynamics.

12:00 - 13:30 Lunch

13:30 - 14:00 Vision talk – Pieter Claeys: Questions and directions in dual-unitary circuit dynamics

Dual-unitary circuits present exactly solvable models of many-body dynamics characterized by an underlying space-time duality, allowing for analytical results on quantum chaos as well as integrable dynamics. In this talk I will review recent advances of the field, highlighting some of the pathologies and limitations of current approaches, and present current open questions and future directions.

14:00 - 15:30 Topical session on quantum hardware and experiments
   Liam Bond – Quantum computing with trapped ions
   Kai-Niklas Schymik – NV Center platforms
   Eline Raymenants and Irene Fernandez de Fuentes – Spin qubit platforms

15:30 - 16:00 Coffee break
16:00 - 18:00 Free discussions
Evening Dinner

Thursday 21 March – solvable quantum circuits and dynamics
09:00 - 09:30 Talk: Richard Jozsa: Noninteracting fermions = matchgates in quantum computing
Abstract: Matchgates (MGs) are a class of 2-qubit gates introduced into quantum computing by Valiant in 2001, from considerations of classical algorithms for counting perfect matchings in weighted graphs. He showed that they provide a surprising new class of quantum circuits that are classically efficiently simulatable. This property was then soon elucidated (by Terhal & DiVincenzo and Knill) as being essentially equivalent to the solvability of noninteracting fermions.
In this talk we will review the definition of MGs and their relation to noninteracting fermions, and give a summary account of some further interesting quantum computational properties of MG circuits, in particular (a) a notion of magic states for them that elevates their computing power to universal quantum, and (b) we outline how the MG formalism leads to a way of simulating the evolution of noninteracting fermions on a quantum computer of exponentially smaller size than the original system.

09:30 - 10:00 Talk – Ananda Roy: Soliton Confinement in a Quantum Circuit
Abstract - Confinement of topological excitations into particle-like states - typically associated with theories of elementary particles - are known to occur in condensed matter systems, arising as domain-wall confinement in quantum spin chains. However, investigation of confinement in the condensed matter setting has rarely ventured beyond lattice spin systems. Here we analyze the confinement of sine-Gordon solitons into mesonic bound states in a perturbed quantum sine-Gordon model. The latter describes the scaling limit of a one-dimensional, quantum electronic circuit (QEC) array, constructed using experimentally-demonstrated QEC elements. The scaling limit is reached faster for the QEC array compared to spin chains, allowing investigation of the strong-coupling regime of this model. We compute the string tension of confinement of sine-Gordon solitons and the changes in the low-lying energy spectrum. These results, obtained using the density matrix renormalization group method, could be verified in a quench experiment using state-of-the-art QEC technologies.

Reference: Ananda Roy and Sergei L. Lukyanov, Nature Communications volume 14, Article number: 7433 (2023)

10:00 - 10:30 Talk – Aditi Mitra: Topological Defects in Floquet Circuits
Abstract - I will discuss how one may construct Floquet models from a fusion category, and how this formalism is a natural way to construct topological defects: non-local operators that can be deformed in the space and time direction without changing the physics.
One of these topological defects is the "duality defect" that implements the Kramers-Wannier duality transformation and is a "non-invertible symmetry" as it projects out states of a given parity.
I will highlight the consequence of the duality defect on Floquet time-evolution, first for the exactly solvable Floquet-Ising model, and then by adding integrability breaking perturbations to the model.

10:30 - 11:00 Coffee break

11:00 - 11:30 Talk – Katja Klobas: Solvable dynamics in the deterministic East model
Abstract - I will discuss the dynamics of the Floquet east model (a Trotterized version of the kinetically constrained east model) at its deterministic point. Even though the dynamics is generated by permutation gates, the model exhibits many non-trivial features both in the classical and quantum setting, while its simplicity allows for exact solutions. The talk is based on [1,2].
11:30 - 12:00 Talk - Joris Kattemölle: *Generalized brickwork quantum circuits*

Abstract - Quantum circuits with a brickwork-like structure, defined on a 1D chain of qubits, form the basis of many recent studies on exactly solved models. Going beyond qubits on a 1D chain to qubits on general D-dimensional lattice graphs necessitates the definition of generalized brickwork circuits on the latter and a method to find those circuits, which becomes a nontrivial task. We define generalized brickwork circuits using the well-known concept of minimal, or nearly-minimal, edge colorings of graphs. Furthermore, we introduce and implement an algorithm that actually finds these edge colorings for infinite lattice graphs (and thereby minimal-depth or nearly-minimal-depth generalized brickwork circuits) [1].

We use the algorithm to minimal edge color a myriad of infinite 2D lattice graphs, including all $k$-uniform lattice graphs for $k \leq 6$. We find these infinite lattice graphs are all Vizing class I. In the context of quantum circuits, this means these infinite lattice graphs each allow brickwall quantum circuits with a depth equal to the maximum degree of the lattice graph. In ongoing work, we develop an algorithm that finds the optimal qubit swapping strategy to implement a generalized brickwork quantum circuit when there is a mismatch between the connectivity in the lattice graph on which the generalised brickwork circuit is defined and the connectivity of the quantum computer on which the generalized brickwork circuit is to be executed. For example, the algorithm finds the optimal swapping strategy for implementing a 1D brickwork circuit additionally including gates between next-nearest-neighbor qubits on a 1D quantum computer that only allows two-qubit gates between nearest neighbors.


12:00 - 13:30 Lunch

13:30 - 14:00 Vision talk – Amira Abbas: *Title*

Abstract

14:00 - 14:30 Rump session 2
14:30 - 16:00 Poster session 2
16:00 - 18:00 Free discussions

Friday 22 March - **theme: quantum dynamics and hydronamics**

09:00 - 9:30 Talk: Lenart Zadnik: *Casimir spin pumps*

Abstract - I will describe a novel class of exactly solvable quantum unitary circuits on qudits. Their key feature is architecture that breaks parity and time reversal symmetries, while retaining the combined PT symmetry. A consequence of this chirality is a spin transport with a finite drift: the circuit acts as a quantum spin
pump. The drift velocity is universal in that it depends only on the Casimir invariant of the local quantum spaces and survives non-integrable perturbations of the circuit. I will comment on connection to integrable Trotterizations and, if time permits, discuss spin transport coefficients and hydrodynamics.

09:30 - 10:00 Talk – Stefano Scopa: Quantum fluctuations in low-temperature 1D gases
Abstract: Quasi-1D ultracold atomic gases are nowadays routinely realized in actual experiments with different techniques. On the theory side, integrability and hydrodynamics permitted great strides in the understanding of their (mean) properties at and out of equilibrium. In this talk, my focus will be instead on fluctuations, specifically those of quantum nature that dominate the low-temperature behavior of the gas. I discuss recent proposals to include these effects in the established hydrodynamic picture and some future perspectives.

10:00 - 10:30 Talk: Vincenzo Alba: Bound-state confinement after trap-expansion experiments in integrable systems
Abstract - Integrable systems possess stable families of quasiparticles, which are composite objects (bound states) of elementary excitations. Motivated by recent quantum computer experiments, we investigate bound-state transport in the spin-1/2 anisotropic Heisenberg chain (XXZ chain). Specifically, we consider the sudden vacuum expansion of a finite region A prepared in a non-equilibrium state. In the hydrodynamic regime, if interactions are strong enough, bound states remain confined in the initial region. Bound-state confinement persists until the density of unbound excitations remains finite in the bulk of A. Since region A is finite, at asymptotically long times bound states are “liberated” after the “evaporation” of all the unbound excitations. Still, fingerprints of confinement are visible in the space-time profiles of local spin-projection operators. To be specific, here we focus on the expansion of the p-Neel states, which are obtained by repetition of a unit cell with p up spins followed by p down spins. Upon increasing p, the bound-state content is enhanced. In the limit \( p \to \infty \) one obtains the domain-wall initial state. The scenario of bound-state confinement leads to a hierarchy of timescales at which bound state of different sizes are liberated, which is also reflected in the dynamics of the von Neumann entropy.

10:30 - 11:00 Coffee break

11:00 - 11:30 Talk – Mari-Carmen Banuls: Converting entanglement into mixture: a new algorithm for long-time dynamics with tensor networks
Abstract - In out-of-equilibrium quench scenarios, fast degrees of freedom contribute to long-range entanglement that hinders their simulation with tensor networks. Local observables, on the other hand, are not sensitive to such long-range correlations, but only to their contribution to the reduced state at the level of the local subsystem. We have introduced a tensor network method that identifies long-range entanglement structures in the time-evolved quantum many-body state and efficiently transforms them into mixture. In this way, we obtain an effective description of the time-evolved state as a density matrix that captures the long-time behavior of local properties for
systems in which quasiparticles (exact or not) are responsible for the entanglement spreading.

11:30 - 12:00 Talk – Max McGinley: *Deep thermalization and complexity transitions in shallow 2D circuits*

Abstract - Over the last few years, there have been a number of works highlighting how measurements can be used to engineer new kinds of quantum dynamics and to synthesise highly entangled quantum states — a well-known example being the measurement-induced phase transition arising from competition between unitary entangling dynamics and non-unitary disentangling measurements. In this talk, I will be focusing on a related phenomenon dubbed `deep thermalization': the observation that certain complex ensembles of states (namely quantum state designs) can emerge when a generic many-body wavefunction is measured. I will describe how this phenomenon can arise when one measures a quantum state generated by shallow (i.e. O(1) depth) 2D circuits. Despite the short-range entangled nature of such wavefunctions, the post-measurement states can be highly entangled and have high state complexity. I will outline some ongoing work towards demonstrating that this phenomenon is a generic, in that there is a robust phase within which high-complexity states are generated upon measurement, with a sharp transition into a low-complexity phase. These results provide some physical intuition into the mechanisms that make shallow 2D circuits hard to sample from, with consequences for the pursuit of quantum computational advantage.

12:00 - 13:30 Lunch

13:30 - 14:00 Vision talk - Alvise Bastianello: *Generalized Hydrodynamics and cold atoms*

Abstract - Integrability is a cornerstone in our understanding of out-of-equilibrium and transport in one-dimensional quantum systems, providing at the same time a wealth of intriguing phenomena. The advent of Generalized Hydrodynamics (GHD) marked a turning point in the field, greatly broadening integrability's range of applicability and knocking at the door of the most recent experiments: in front of us, lays the unprecedented chance of providing quantitative and exact semi-analytical predictions for analog quantum simulators, far beyond the reach of classical numerical methods. In this talk, I will introduce the rudiments of GHD emphasizing its concrete potential in the lab: I will review past experiments, discuss some work in progress, and finally outline what, in my opinion, are the main challenges for the future.

14:00 - 15:00 Grand restitution

15:00 - 18:00 Free discussions