Student Workshop on Integrability
Scientific Program

Louvain-la-Neuve, 8 - 10 April 2019

UCLouvain

Institut de recherche en
mathématique et physique
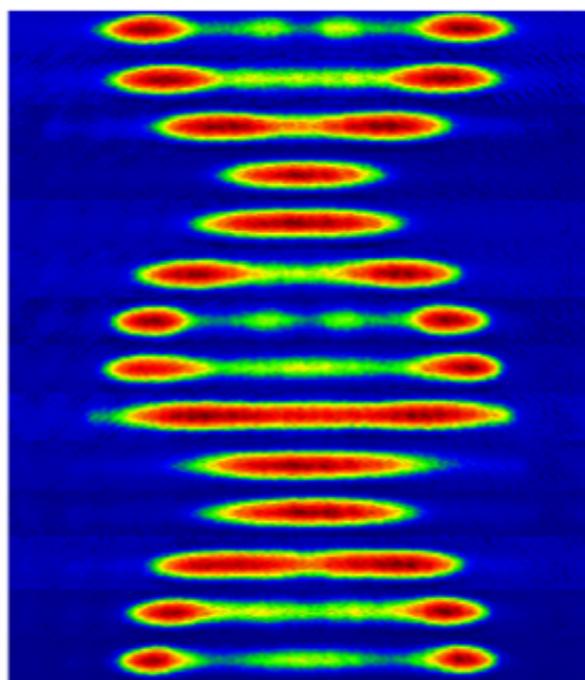
Schedule

	7/4 SUNDAY	8/4 MONDAY	9/4 TUESDAY	10/4 WEDNESDAY
09:00		Welcome Address		
09:30		Yuri van Nieuwkerk & Yuan Miao	Gilles Parez & Cecilia de Fazio	Eyzo Stouten & Arthur Hutsalyuk
10:00				
10:30				
11:00		Coffee break	Coffee break	Coffee break
11:30		Andrew Urichuk & Stefano De Nicola	Invited Talk: Jean-Sebastien Caux	Alexander Cooper & Louis Vignoli
12:00				
12:30				
13:00		Lunch	Lunch	Lunch
13:30				
14:00				
14:30		Lenart Zadnik & Sebastian Grijalva	Dennis Wagner & Katja Klobas	Bryan Debin & Etienne Garnet
15:00				
15:30				
16:00		Coffee break	Coffee break	Discussion
16:30		Sergio Tapias Arze & Philipp Jaeger	Per Moosavi & Pavel Kos	Closing Address & Best Talk Award!
17:00				
17:30				
18:00		Welcome Drinks @UCLouvain	Aleksandra Ziolkowska & Alvise Bastianello	Departure
18:30				
19:00	Arrival			
19:30		Integrable Beers	Discussion/ Free time	
20:00	Social Night @Beer Bar		Conference Dinner & Drinks @Onlywood	
evening				

General information

- With any queries contact one of the organisers:
  Aleksandra Ziolkowska: +48 605 941 024, email: `aleksandra.ziolkowska@physics.ox.ac.uk`
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  Philip Jaeger: +49 151 5630 0374, email: `jaegerp@myumanitoba.ca`

- Hotel Contact:
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- Workshop Venue:
  Auditorium **Cycl 01**, **Marc de Hemptinne** Building
  Chemin du cyclotron, 2
  1348 Louvain-la-Neuve
  Note that there is a pedestrian pathway "Boulevard Baudouin 1er" that leads to the building from "Avenue Thodore Schwann".

- Social night:
  On Sunday the 7th of April, we will have a social night in the bar "Beer bar" at 8pm
  Grand-rue, 5
  1348 Louvain-la-Neuve

- Conference Dinner:
  Tuesday, 9th of April
  Bar-Restaurant "Onlywood"
  Place des Wallons, 37
  1348 Louvain-la-Neuve

Keynote lecture

We have the pleasure of announcing a keynote lecture which will be given by Prof. J.-S. Caux.

- **INTEGRABILITY: FROM ANGELS ON PINS TO CONCRETE PHENOMENOLOGY**
  Jean-Sébastien Caux
  University of Amsterdam

Contributed talks

1. SIMULATING NON-EQUILIBRIUM DYNAMICS OF THE SINE-GORDON MODEL IN THEORY AND EXPERIMENT

Yuri van Nieuwkerk
University of Oxford

In this talk I will describe a self-consistent field theory for time-evolution in the sine-Gordon model, and describe how its results can be compared to measurements on pairs of one-dimensional Bose gases. The low-energy sector of such experimental set-ups is captured by two compact phase fields, describing (anti)symmetric combinations of the two Bose gas phases. I will show how, and under which circumstances, a single projective measurement of the particle density after trap release is related to the eigenvalues of both these phase fields.

The presence of tunnelling between the Bose gases has been proposed as a realization of the sine-Gordon model. Recent measurements out of equilibrium have cast doubt on this statement, although theoretical predictions to compare with have so far been scant. I will here present such theoretical predictions for time-evolution in the sine-Gordon model, using a self-consistent harmonic approximation. Starting from a class of experimentally relevant initial states, this method allows for the computation of full distribution functions of the Bose gas density. These distribution functions show strong deviations from the experimentally observed behaviour, suggesting that a pure sine-Gordon model is insufficient to explain the measurements.

Finally, I will propose an application of the self-consistent method to a sine-Gordon model coupled to a Luttinger Liquid, which could offer a more refined description of the experimental set-up.

References:
arXiv:1812.06690

2. On Classical-Quantum Correspondence of Spin Transport: Magnetic Domain Wall Dynamics as a Paradigm

Yuan Miao
University of Amsterdam

We have studied the time evolution of magnetic domain wall initial state in axially anisotropic Landau-Lifshitz (LL) magnet, i.e. a classical and continuous limit of the quantum anisotropic Heisenberg chain. Employing the analytic scattering technique, we found that spin transport of the time evolution of the magnetic domain wall state has three qualitatively different regimes, namely ballistic transport in easy-plane regime (corresponding to the gapless regime in the quantum spin chain), log-modified diffusion in isotropic point, and domain wall frozen phenomenon in the easy-axis regime (corresponding to the gapped regime in the quantum spin chain). We found that there is a remarkable classicalquantum correspondence of the spin transport, which could provide potentially deeper understanding to unsolved questions in the quantum case.
Based on works together with Oleksandr Gamayun, Yuan Miao, and Enej Ilievski
References:
arXiv: 1901.08944

3. Spin Drude weight in the XXZ Heisenberg spin chain

Andrew Urichuk
University of Manitoba and University of Wuppertal

New techniques in the context of quantum integrable systems have raised exciting possibilities for the study of transport phenomenon. The spin Drude weight, a portion of the spin current that survives to infinite times, at zero magnetic field in a 1D XXZ Heisenberg spin chain in the paramagnetic regime has had a long and contentious history, however it seems to be amenable to these new techniques. The spin Drude weight has previously been calculated as a nowhere continuous (or fractal) function of anisotropy, which frequently disagreed with DMRG numerics. Our calculations are found to be equivalent to these older results. This supports the conclusion of the fractal behaviour of the spin Drude weight and we consider the consequences this has for spin transport and how this behavior might manifest in experimental setups.

4. A Stochastic Approach to Quantum Spin Systems

Stefano De Nicola
IST Austria

In this talk, I will discuss an exact mapping between many-body quantum spin systems and classical stochastic processes. This approach can handle integrable and non-integrable systems, including those in higher dimensions, in a unified framework, and can be applied both in and out of equilibrium. Focusing on quantum quenches, I will discuss dynamical quantum phase transitions in the Loschmidt amplitude, showing that these correspond to

enhanced fluctuations and other features in the classical stochastic coordinates.

5. Inhomogeneous matrix product solutions of boundary driven spin chains

Lenart Zadnik
University of Ljubljana

Sutherland's bulk cancellation mechanism is essential in deriving the matrix product forms of the non-equilibrium steady states of boundary driven spin chains and also in proving the commutation of the integrals of motion with the Hamiltonian. It is intrinsically related to the Yang-Baxter equation related to the integrable model in consideration. I will present an inhomogeneous generalization of the Sutherland's relation, which provides exact solutions for the steady states of the dissipative XYZ and XXZ spin chains with arbitrarily polarized boundary drivings. The new cancellation mechanism can also be used to construct new integrals of motion for the XYZ and XXZ spin chain with arbitrarily directed boundary magnetic fields, therefore going beyond the known integrable structure.

6. Boundary modes and long-time coherence in open spin chains

Sebastián Grijalva
Paris-Sud University

I will describe the ground state structure of the XXZ spin chain with open boundary conditions, showing there's a degeneracy at the thermodynamic limit by using a Bethe Ansatz description. With this, I calculate the boundary magnetization and relate it to the large time limit of the autocorrelation function at the boundary.

7. Floquet resonances and out-of-equilibrium phase transitions in a periodically driven XY spin chain

Sergio Tapias Arze
University of Amsterdam

We consider the dynamics of an XY spin chain subjected to an external transverse field which is periodically quenched between two values. By deriving an exact expression for this out-of-equilibrium protocols Floquet Hamiltonian, we show how the parameter space of the system is characterised by alternations between local and non-local regions, corresponding respectively to the absence and presence of Floquet resonances. The boundary lines between regions are obtained analytically from avoided crossings in the Floquet quasi-energies and are observable as phase transitions in the synchronised state. The transient behaviour of dynamical averages of local observables similarly undergoes a transition, showing either a rapid convergence towards the synchronised state in the local regime, or a rather slow one exhibiting persistent oscillations in the non-local regime.

8. Thermalization and Equilibration in the Almost Integrable XXZ Model

Philipp Jaeger
University of Manitoba and University of Wuppertal

The quantum XXZ model is an integrable lattice model, hence exact solutions are available via Bethe ansatz (BA). For many ground-state properties or correlation functions, explicit expressions are available. Expectation values of observables at late times after a quench can be calculated for example using the generalized Gibbs ensemble (GGE) formalism. However, particular dynamical correlation functions (DCF) are notoriously hard to calculate from BA, and perturbations of the XXZ model can not be treated directly. Using numerics, it is possible both to obtain DCF relatively easily and to include perturbations. Here, we present numerical results obtained employing the light-cone renormalization group algorithm.

9. BIPARTITE FIDELITY OF CRITICAL DENSE POLYMERS

Gilles Parez
University of Louvain

The bipartite fidelity (BF) is an entanglement measure introduced in 2011 by Dubail and Stephan as the overlap between the groundstate (GS) of the system and the GS of the system where two complementary subsystems are decoupled. For one-dimensional quantum critical models, a conformal field theory (CFT) derivation predicts a logarithmic divergence in the system size N with a multiplicative factor proportional to the central charge. Moreover, it provides an analytical expression for the constant term in the $1/N$ expansion.
We computed the BF for the model of critical dense polymers, which is known to be critical with a central charge $c = -2$, by using the correspondence between this model and a XX spin chain with boundary conditions of Pasquier and Saleur. Our lattice calculations exactly match the CFT predictions for arbitrary aspect ratio. We were also able to extend this result in the case of a logarithmic CFT, both with lattice and field theoretical derivations. This is a joint work with Alexi Morin-Duchesne and Philippe Ruelle.
References:
arXiv:1010.3716
arXiv:1902.02246

10. ENTANGLEMENT CONTENT OF QUASIPARTICLE EXCITATIONS

Cecilia de Fazio
City, University of London

In the first part of my talk I will give a brief introduction to the main features of the Entanglement Entropy of a bipartite system in Integrable Quantum Field Theories and Conformal Field Theories. Secondly I will discuss the results my collaborators and I obtained in our two papers. In particular, I will consider the Entanglement Entropy of a single connected region of a nite bipartite system in excited states described by one-dimensional massive free theories with nite numbers of particles. I will show that in the limit of large volume and large length of the region the excess of entanglement due to the presence of the particles with respect to the ground state takes a simple form and admits a "q-bit interpretation".

11. NEURAL NETWORK STATES OF QUANTUM INTEGRABLE MODELS

Dennis Wagner
University of Wuppertal and University of Manitoba

The Variational Monte Carlo method has been used for decades in quantum many-body physics. Quite recently, Artificial Neural Networks have been considered to speed up this multidimensional optimization process. In my talk, I will focus on a well-known StochasticNeural Network, the so called Restricted Boltzmann Machine (RBM), which has proven to be a useful tool to calculate ground state energies and correlation functions of spin chains. Furthermore, the Entanglement Entropy and the connections to Tensor Networks will be discussed. However, the non-local structure of Neural Network States and its simple extension to 2D systems are the most interesting features of this approach and will therefore form the main part of my talk.

12. Time-dependent matrix product ansatz for interacting reversible dynamics

Katja Klobas
University of Ljubljana

I will present an explicit time-dependent matrix product ansatz (tMPA) which describes the time-evolution of any local observable in an interacting and deterministic lattice gas, specifically for the rule 54 reversible cellular automaton of [Bobenko et al., Commun. Math. Phys. 158, 127 (1993)]. The construction is based on an explicit solution of real-space real-time inverse scattering problem. I will discuss two applications of this tMPA; the exact and explicit computation of the dynamic structure factor, and the solution of the extremal case of the inhomogeneous quench problem. Both of these exact results rigorously demonstrate a coexistence of ballistic and diffusive transport behaviour in the model, as expected for normal fluids.

13. Diffusive heat transport in random conformal field theory

Per Moosavi
KTH Royal Institute of Technology Stockholm

Conformal field theory (CFT) has recently been used to study closed one-dimensional quantum many-body systems out of equilibrium and is known to exhibit only purely ballistic heat transport. In this talk I will present exact analytical results for CFT with random position-dependent velocity that emerges as an effective description of quantum many-body systems with certain static random impurities, and which elucidates how the purely ballistic heat waves in standard CFT can acquire normal and anomalous diffusive contributions due to our impurities.
Based on works together with K. Gawdzki and E. Langmann.

14. Solving Chaotic Quantum Many-body System

Pavel Kos
University of Ljubljana

When talking about solvable models, we usually have in mind free and integrable models. These models have many special properties, which are different from those of the generic models that are chaotic. I will demonstrate how using a special property of the duality point of the kicked Ising spin chain, we managed to compute the spectral form factor and the time evolution of the entanglement entropy for a chaotic quantum many-body system.

The spectral form factor shows that the model behaves chaotically for any disorder in the magnetic field in the z direction. The dynamics of the entanglement entropy indicates that the information spreads with a maximal speed and saturates to the maximum value.

15. Markovian Open Quantum Systems and Their Links to Integrability

Aleksandra Ziolkowska
University of Oxford

Time-evolution of Markovian open quantum systems is governed by the so called Lindblad equation. As a form of an introduction, I will present a microscopic derivation of this equation and its relation to the integro-differential Redfield equation. Then, I will show how links with integrability offer a unique possibility of obtaining exact analytical results for interacting open quantum systems with Lindbladian dynamics. I will also comment on the methodology of finding mappings between open systems an integrable models.

16. Hydrodynamic exploration of parameter-space in integrable models

Alvise Bastianello
University of Amsterdam

The relentless hunt to a better understanding of closed one-dimensional systems out-of-equilibrium found the most recent trophy in the Generalized Hydrodynamics (GHD). Immediately after its first formulation, GHD has been promptly extended to include certain smooth perturbations of the Hamiltonian, which nevertheless locally leave the set of (quasi)local conserved charges the same. Integrable systems are usually characterized by a set of couplings and retain their integrability for arbitrary values of the latter, making natural to wonder if smooth changes in this parameter space can be still described by hydrodynamics.

In the first part of my talk, I analyze a first step into this direction, considering the XXZ spin chain coupled to a magnetic flux. While the model is integrable for any value of the flux, the latter strongly affects the set of commuting charges. I consider homogeneous, but with slow time dependence, magnetic fluxes testifying the emergence of a hydrodynamic description. Particular emphasis is dedicated to the reversibility properties of this protocol: the infinitely many conserved charges of the model protect the dynamics which, even in the absence of an energy gap, can be fully reversible. This hugely depends on the value of the interaction: for $|\Delta| < 1$, the reversibility is broken due to a recombination of bound states, which must be supplemented to GHD for a correct description.

In the second part of the talk, I provide a further generalization considering slow time-space variations of arbitrary parameters in the integrable model, obtaining the proper GHD equations. The changes in these interactions cause the appearance of new force terms into the hydrodynamic equations, which have never been considered in previous studies. This last finding provides the most general pure-hydrodynamic equation for integrable models, whose parameter space can now be fully explored.

References:

A. Bastianello, A. De Luca, arXiv:1811.07922, 2018.

A. Bastianello, V. Alba, J.-S. Caux, in preparation.

17. Derivation, application and numerical evaluation of the Non-Linear Integral Equations in the Quantum Transfer Matrix formalism

Eyzo Stouten
University of Wuppertal

We will be continuing the work started in the lectures of Frank Göhmann at Les Houches. In these lectures a diagrammatic method was used to derive the reduced density matrix and an overview was given of what correlation functions are calculated with it up to now. The second part of the lectures where focused on the derivation single integral equation for the Quantum Transfer Matrix and it was shown how this function enters the free energy. This talk will mainly be a continuation of the second topic, we will calculate the Non-Linear Integral Equations (NLIE) using a much simpler derivation which involves the fusion hierarchy. Then we will show how the numerical integration of these equations is obtained.

18. (Semi)Numerical calculation of the correlation function by means Algebraic Bethe Ansatz

Arthur Hutsalyuk
University of Wuppertal

Algebraic Bethe ansatz is convenient method of calculation of the correlation functions in the integrable systems. Using form factors expansions it is possible to calculate two point dynamical correlator using method of numerical summation of form factor.
For sl(2) algebra based models such an approach was developed by J.S.Caux et al. Method allows obtain result for wide class of systems like spin chains, Bose/Fermi gases etc. Recent progress in calculation of the form factors via ABA allows to obtain such a correlators for algebra sl(3) based models that means from physical point of view multi component system or system with internal degree of freedom like gas of particles with the spin.

19. Baxter's TQ-Relation and the Bethe Ansatz

Alexander Cooper
Heriot-Watt University

The Bethe Ansatz is a useful construction for diagonalisation of the transfer matrix in Quantum Integrable Systems. In this talk I will discuss a different approach to this task, the TQ-Relation, its relationship to the Bethe Ansatz, and the situations in which it is useful. If there is time, I may also briefly discuss its derivation from the representation theory for the quantum-deformed algebra, $U_q(sl_2)$ (from which we may solve the Hamiltonian for the closed, spin-1/2, XXZ chain).

20. Modern quantum Separation of Variables

Louis Vignoli
ENS Lyon

The Bethe Ansatz is used in various forms to solve the eigenvalue problem of integrable

systems. However, it suffers from non-negligible flaws stifling the complete resolution. Among them are i) the completeness of the spectrum as to be proven separately, and ii) it gets intricate for higher rank models because of a nested structure.

This motivated the development of the quantum Separation of Variables (qSoV), inspired from the classical case. I will present a modern way to perform qSoV, as developed by the Lyon group, relying on simple algebra and representation theory features. I will then show how it is used to tackle integrable systems with higher rank symmetry of physical interest.

21. USING THE TANGENT METHOD TO COMPUTE ARCTIC CURVES

Bryan Debin
University of Louvain

The study of the arctic phenomenon is often performed by evaluating bulk observables. We present another approach, called the tangent method, due to Colomo and Sportiello. We illustrate this method in a particular random tiling problem, defined in the scaling limit by an arbitrary piece-wise continuous function. A single arctic curve is observed for a generic choice of this function, but other additional pieces of arctic curve appear when this function has specific features. We explicitly compute the parametric equation of one of these using the tangent method, and sketch the computation for all other portions.

22. SERIES EXPANSIONS FOR SPIN CHAINS IN A MAGNETIC FIELD

Etienne Garnet
IPhT Saclay

Integrable models in a magnetic field h, such as the XXZ spin chain, involve linear and non-linear integral equations that can only be solved numerically. We show how to derive analytical series expansions for physical quantities such as the spontaneous magnetization or the critical exponents, as a function of $\sqrt{h_c - h}$ where h_c is the smallest field for which it is fully polarized.

List of participants

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