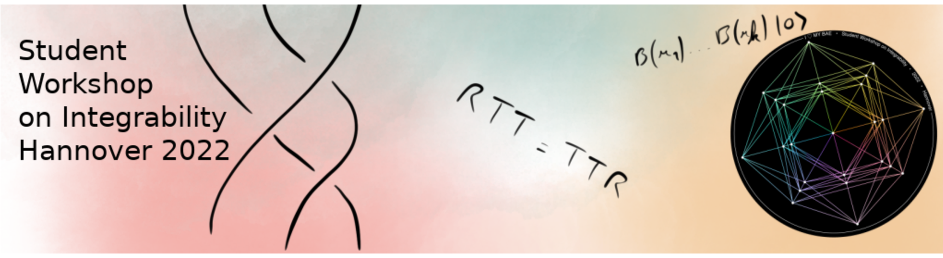
Workshop on Integrability

Sunday 27 March 2022 - Thursday 31 March 2022



Book of Abstracts

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Lattice nonlinear Schroedinger equation and applications

Authors: Dmitri Kharzeev[None]; Kun Hao [None]; Vladimir Korepin[1]

[1] *Stony Brook University*

Quantum lattice nonlinear Schroedinger equation will be explained: history, open problems and applications [including nuclear physics].

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Hydrodynamic description of multispecies TASEP

Author: Ali Zahra[None]

Exclusion processes in one dimension first appeared in the 70's and have since dragged much attention from communities in different domains: stochastic processes, out of equilibriums statistical physics and more recently integrable systems. While it is well known that the hydrodynamic limit of the single species totally asymmetric simple exclusion process (TASEP) is described by the Burger's equation, much less is known for multispecies generalizations, which present a much richer phenomenology. In this talk we shall present results for a version of the TASEP, containing two species of particles and a hierarchical dynamic depending on two parameters. By using results for the stationary measure of such model on ring domains, we shall formulate the conservations laws associated to the different kind of particles. We show an explicit non-linear decoupling of those equations which allows an in-depth discussion of their solutions (shocks, Riemann problem, etc.). Good agreement is found with numerical simulations.

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Unstable Excitations in an Integrable Quantum Field Theory

Author: Aleksandra Ziolkowska[1]

[1] *University of Oxford*

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

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

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3D Chern-Simons gravity and osp(1|2) CFT

Authors: Juan Ramos Cabezas[1]; Vladimir Belavin[1]

[1] *Ariel University*

In this talk, I will talk about the holographic description of the osp(1|2) super conformal blocks on the sphere and the torus. I will concentrate on the 2-point and 3-point conformal blocks on the sphere and the 1-point and 2-point blocks on the torus. I will present some results we have obtained in a work in process (to be published soon). It is known that the holomorphic part of primary superfields can be decomposed into two ordinary primary fields (the even (bosonic) and odd part (fermionic)), thus we can express the general correlation functions in terms of these ordinary primary fields (the obtained terms we call them component of the correlation functions). I will show how these components of the correlation functions can be obtained from the 3D Chern-Simons theory context. This idea of computing the conformal blocks from the 3D Chern-Simon theory has been proposed and developed (for some specific algebras, e.g. the sl(2) and sl(3) algebras) in some previous works of one the authors and other authors, in this talk I will talk about the case of the osp(1|2) algebra.

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Symmetry resolved entanglement in excited states in QFT

Author: Lucia Santamaria-Sanz[1]

[1] *University of Valladolid*

In this talk the excess entanglement resulting from exciting a finite number of quasiparticles above the ground state of a free integrable quantum field theory in 1+1D with an internal U(1) symmetry will be studied. It will be shown both for bosons and fermions theories that the ratio of charged moments between the excited and ground states take a extremely simple and universal form depending on the number and statistics of the excitations and on the charges associated to the underlying U(1) symmetry. The formulae obtained for this ratio of charged moments can be numerically checked for some lattice models.

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Bipartite fidelity in the XXZ spin chain at the combinatorial point

Author: Gilles Parez[1]

[1] *CRM, Université de Montréal*

The bipartite fidelity was introduced in 2011 by Stéphan and Dubail as an entanglement measure in quantum many-body systems. It is expressed in terms of the overlap between the groundstate of the whole system and a tensor product of groundstates for two complementary subsystems. For one-dimensional quantum critical systems, the bipartite fidelity has an interpretation in terms of conformal field theory (CFT), and its asymptotic behavior depends on the conformal data of the underlying CFT.

I will discuss the bipartite fidelity for the XXZ spin chain at $\Delta = -1/2$. The combinatorial structure of the model allows us to derive exact finite-size expressions for the overlaps, and to investigate their asymptotic behavior. In particular, our results agree with the CFT predictions of Stéphan and Dubail. This talk is based on arXiv:2111.15223, in collaboration with Christian Hagendorf.

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Weak integrability breaking and level spacing distribution

Author: Dávid Szász-Schagrin[1]

Co-authors: Gábor Takács ; Balázs Pozsgay

[1] *Budapest University of Technology and Economics, Statistical Field Theory Research Group*

Recently it was suggested that certain perturbations of integrable spin chains lead to a weak breaking of integrability in the sense that integrability is preserved at the first order in the coupling. Here we examine this claim using level spacing distribution. We find that the volume dependent crossover between integrable and chaotic level spacing statistics which marks the onset of quantum chaotic behaviour, is markedly different for weak vs. strong breaking of integrability. In particular, for the gapless case we find that the crossover coupling as a function of the volume L scales with a $1/L^2$ law for weak breaking as opposed to the $1/L^3$ law previously found for the strong case.

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Dynamics of charge-imbalance-resolved entanglement negativity after a quench in a free-fermion model

Authors: Riccarda Bonsignori[1]; Gilles Parez[2]

[1] *Ruder Boskovic Institute (Zagreb)*

[2] *Université de Montréal*

The presence of a global internal symmetry in a quantum many-body system is reflected in the fact that the entanglement between its subparts is endowed with an internal structure, namely it can be decomposed as sum of contributions associated to each symmetry sector. The study of the symmetry resolution of entanglement measures provides a formidable tool to probe the outof-equilibrium dynamics of quantum systems.
As presented in the previous edition of this Workshop by my collaborator Gilles Parez, we initiated the study of the time evolution of the symmetry-resolved entanglement entropy after a global quench in the context of free-fermion systems. In this talk, I will present the results of our subsequent study of the time evolution of its counterpart for non-complementary subsystems, namely the charge-imbalance-resolved negativity, in the same setting. We find that the charge-imbalance-resolved logarithmic negativity shows an effective equipartition in the scaling limit of large times and system size, with a perfect equipartition for early and infinite times. We also derive and conjecture a formula for the dynamics of the so-called charged
Rényi logarithmic negativities. We argue that our results can be understood in the framework of the quasiparticle picture for the entanglement dynamics, and provide a conjecture that we expect to be valid for generic integrable models.

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Riemann surfaces for the totally asymmetric exclusion process with open boundaries

Author: Ulysse Godreau[1]

[1] *Laboratoire de Physique Théorique - Université Toulouse III*

The totally asymmetric exclusion process (TASEP) is a continuous time Markov process much studied in statistical physics featuring particle with hard-core interaction hopping randomly on a one

dimensional lattice.
This talk will focus on the study of the fluctuations of the particle current in the TASEP with open boundaries in the thermodynamic limit. More precisely, the eigenvalues of a deformation of the Markov matrix of the process, connected to the cumulant generating function of the current, are computed in two different ways. The first excited states are recovered from the ground state eigenvalue (obtained by matrix product ansatz) by analytic continuation. They are then compared with the asymptotics of the Bethe ansatz equations. The eigenstates are put in correspondance with the sheets of a Riemann surfaces, which is the maximal domain of definition of the analytic continuation of the ground states. Connections are made with KPZ universality and previous results on the TASEP with periodic boundary conditions.
This work was done in collaboration with Sylvain Prolhac (LPT Toulouse)

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Integrability as a new method for exact results on quasinormal modes of black holes

Authors: Daniele Gregori[1]; Davide Fioravanti[2]

[1] *University of Bologna*

[2] *INFN Bologna*

In this talk, I will show a new connection we found between quantum integrable models and black holes perturbation theory. After a brief introduction to quasinormal modes and their role in gravitational waves observations, I will connect their mathematically precise definition with the integrability structures derived from the differential equation associated to the black hole perturbation. More precisely, I will derive the full system of functional and non linear integral equations (Thermodynamic Bethe Ansatz) typical of quantum integrability and prove that the quasinormal modes verify different equivalent exact quantization conditions. As a consequence, it follows a new simple and effective method to numerically compute quasinormal modes, namely the Thermodynamic Bethe Ansatz, which I will compare with other methods. I will also give a mathematical explanation of the recently found connection between quasinormal modes and N=2 supersymmetric gauge theories, through the further connection we previously found of these to quantum integrable models. All this I will show for a generalization of extremal Reissner-Nordström (charged) black holes, but in the end I will explain how it should be possible to generalize it to many other black holes, branes, fuzzballs, etc. and thus provide a new effective tool for the study of quantum gravity and gravitational waves. (Based on: ArXiv:2112.11434)

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Integrability breaking in the one dimensional Bose gas: Atomic losses and energy loss

Author: Arthur Hutsalyuk[1]

Co-author: Balázs Pozsgay [2]

[1] *Eötvös Loránd University (ELTE)*

[2] *ELTE*

The one dimensional δ-function interacting Bose gas (the Lieb-Liniger model) is an integrable system, which can model experiments with ultra cold atoms in one dimensional traps. Even though the model is integrable, integrability breaking effects are always present in the real world experiments. In this work we consider the integrability breaking due to atomic loss, which is the most relevant effect in the experiments. We set up a framework for the exact computation of the losses of the canonical charges of the model, and compute an exact result for the energy loss due to the local K-body processes, valid for arbitrary K.

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The open U(sl(2))-invariant staggered six-vertex model and the CFT behind it

Author: Sascha Gehrmann[None]

Co-author: Holger Frahm

The finite-size spectrum of the critical alternating Z2-staggered spin-1/2 XXZ model with quantum group invariant boundary conditions is presented. For all values of the staggering parameter the continuum limit has been found to be described in terms of the non-compact SU(2, R)/U(1) Euclidean black hole conformal field theory (CFT) whose scaling dimensions include a continuous component. In addition, we find that levels from the discrete part of the spectrum of this CFT emerge as the anisotropy is varied. The finite size amplitudes of both the continuous and the discrete levels are related to the corresponding eigenvalues of a quasi-momentum operator which commutes with the Hamiltonian and the transfer matrix of the model.

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Ergodicity of dual unitary permutation circuits

Author: Márton Borsi[1]

[1] *Eötvös Loránd University, Budapest*

One class of exactly solvable quantum many-body systems is the set of dual unitary quantum circuits, whose fundamental quantum gate is also unitary in the space direction. In these models the infinite temperature dynamical correlation functions can be calculated exactly both for integrable and chaotic systems. For local dimension N=2 the complete classification is known, and multiple general construction procedures were studied in the case of higher N. One special class is formed by classical cellular automata corresponding to cases when the quantum gate is simply a permutation. Our recent study with Balázs Pozsgay focused on these models and led to some unexpected results. The presence of conserved quantities induces non-ergodic behaviour, which we studied by investigating the recurrence time. We found models lacking the Yang-Baxter integrability structure but still possessing an infinite number of charges. We also observed that maximally chaotic circuits can show signs of non-ergodicity if they are constructed from a linear map over finite fields.

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Anomalous fluctuations in integrable systems

Author: Žiga Krajnik[1]

[1] *University of Ljubljana*

We discuss anomalous fluctuations recently observed in the (anisotropic) Landau-Lifhsitz model in equilibrium, a paradigmatic integrable model of interacting classical spins. Typical fluctuations of the time-integrated spin current on sub-ballistic scales are non-Gaussian and the cumulants are found to grow with different (algebraic) exponents, unlike in the "standard" scenario of the theory of large deviations, where the existence of a scaled cumulant generating functions implies finite scaled cumulants.

Similar phenomenology is observed in a simple interacting cellular automaton, where an analytical computation of the full counting statistics is feasible. Asymptotic analysis of the exact solution gives access to the current distribution on all scales and explicit cumulant asymptotics. The scaled

cumulant generating function does not generate scaled cumulants. Our findings hint at novel types of dynamical universality classes in deterministic many-body systems.

1. Ž. Krajnik, E. Ilievski, T. Prosen, *Absence of Normal Fluctuations in an Integrable Magnet*, arXiv:2109.13088 (2021)
2. Ž. Krajnik, J. Schmidt, V. Pasquier, E. Ilievski, T. Prosen, *Exact anomalous current fluctuations in a deterministic interacting model*, arXiv:2201.05126 (2022)

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Sausage Model and the Generalised Hydrodynamic Formalism

Author: Mario Flores[None]

On this talk we'll review the basic concepts of non-linear sigma models and in
particular the one-parameter integrable deformation of the 2d O(3) sigma model.
We'll explore the solutions of this system via thermodynamic bethe ansatz, Y-systems and Dynkin TBA and how to apply this techniques on a Field theory as the one we are dealing with here.
In the second part of this presentation we'll construct a partition protocol with two semi-infinite, disconnected, reservoirs at different temperatures at t_0 that became connected at some later time t that realize non-equilibrium states on the sausage model. We'll discuss the numerical results of this simulation.

Furthermore, the deformed O(3) sigma model exhibits an outstanding characteristic that will be stress during the talk:
its duality with sine-Liouville theory and its interpretation as a 2d black hole.

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Measurement catastrophes in quantum jammed states

Author: Saverio Bocini[1]

[1] *LPTMS - Université Paris-Saclay*

Local measurements can sometimes lead to unexpected macroscopic behaviours. Such "measurement catastrophes" in integrable models go beyond generalized hydrodynamics, that is arguably the most effective large-scale description of dynamics in integrable models in the presence of inhomogeneities. A noteworthy occurrence of this phenomenon is found in systems exhibiting quantum jamming. I will provide a simple and solvable example by considering a particular class of the jammed states of the large-anisotropy limit of the Heisenberg magnet. That will allow me to present the microscopic dynamics behind the emergence of ballistic profiles of local observables following a local measurement in that particular model.

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Integrability and Yangian Symmetry in 4-dimensional QFTs

Author: Julian Miczajka[1]

[1] *Max-Planck-Institut fuer Physik*

In this talk I provide an overview on the appearance of integrability - especially in the form of Yangian symmetry - in the context of several different quantities in four-dimensional quantum field theories. In particular, I discuss how superconformal Yangian symmetry shows up in different forms in the context of planar N=4 super-Yang-Mills (SYM) theory, whose spectral problem famously maps to an integrable spin-chain.
I proceed by describing how these structures leave imprints on more generic quantum field theories. Recently, it was found that Yangian symmetry survives certain double-scaling deformations of planar N=4 SYM theory, and shows up in certain ubiquitous classes of massless and massive Feynman integrals. I sketch how we connected these surprising symmetry structures to a - presumably integrable - massive fishnet theory and how they can be used to set up a bootstrap algorithm that allows to calculate the integrals from scratch.

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The relevant excitations for the one-body function in the Lieb-Liniger model

Author: Felipe Sant'Ana[1]

[1] *Faculty of Physics, University of Warsaw*

We study the ground state one-body correlation function in the Lieb-Liniger model. In the spectral representation, correlations are built from contributions stemming from different excited states of the model. We aim to understand which excited states carry significant contributions, specifically focusing on the small energy-momentum part of the dynamic one-body function. We conjecture that relevant excitations take form similar to two-spinon states known from XXZ spin chain. We validate this hypothesis by numerical evaluation of the correlator with ABACUS algorithm and by analytical computations in the strongly interacting regime.

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Bound state production in the 1d Bose gas

Authors: Rebekka Koch[None]; Alvise Bastianello[1]; Jean-Sebastien Caux[None]

[1] *Technical University of Munich*

Out-of-equilibrium phases of matter have triggered a lot of attention in the last decade, since new and interesting physical phenomena with no equilibrium counter parts can arise. The 1d interacting Bose-gas for example possesses bound states for attractive interactions but is experimentally highly unstable at equilibrium. However, these bound states become stable out-of-equilibrium since the 1d Bose-gas is integrable and thus, thermalization is absent.
Strongly interacting systems are notoriously hard to tackle, but due to integrability we can analytically investigate slow interaction changes from the repulsive to the attractive regime using the framework of Generalized Hydrodynamics (GHD). We obtain exact predictions for the bound state production and completely characterize the non-equilibrium state.
While in the quantum realm numerical checks are often absent, we can translate this protocol to the semi-classical analogue of the 1d Bose-gas – the non-Linear-Schroedinger equation (NLS) – and exploit Monte Carlo methods for numerical benchmarks. By taking the semi-classical limit new technical challenges arise, but they are accompanied with new insight into the thermodynamical description of the NLS model.
Finally, as the 1d interacting Bose-gas is realized in state-of-the art experiments with cold atoms, our analytic results can already be applied to describe signatures of bound-states.

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Folded XXZ model and hard rod deformations

Author: Levente Pristyák[None]

Integrable models are special quantum many-body systems because they posses a large number of conserved charges, which enables one to treat these models with analytic tools. However, in usual integrable systems (e.g. XXZ model) certain computations - for example the calculation of correlation functions - are very difficult to tackle exactly. Therefore in recent years „simpler" integrable models were constructed and treated. In my talk I will consider one such system, the so called folded XXZ model. I will present some results regarding the dynamics of this system and its connection to hard rod deformations and other simple integrable systems.

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Ballistic Fluctuation theory: correlation functions and entanglement entropy

Author: Giuseppe Del Vecchio Del Vecchio[1]

[1] *King's College London*

In integrable models when an operator couples to a conserved charge its decay will be algebraic along rays in spacetime due to few-body scattering processes giving rise to 'sound waves' ballistically propagating. There are example of operators that do not produce these waves but still encode fundamental information. Remarkable examples are the so called twist fields, present whenever there is an internal symmetry. Twist fields are responsible for exponential decay of order parameter dynamical correlation functions in spin chains and are directly related to entanglement entropy. Ballistic Fluctuation Theory(BFT) is the theory of large deviations for ballistic transport. When a conserved charge is transported through the system, Euler equations for macroscopic densities and currents give a hydrodynamic description of the quasi-particle excitations. For integrable models BFT provides an exact expression of current fluctuations which in turn determine the spacetime behavior of correlations of the aforementioned twist fields. As a simple demonstration, I will show the application of these ideas to two cases: the calculation of dynamical correlation functions of order parameters in the XX model and computation of entanglement entropies in free theories. If time allows I will sketch the more complicated situation of interacting theories.

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Generalized Hydrodynamics of the staircase model and higher spin currents

Author: Michele Mazzoni[1]

[1] *City University of London*

The staircase model is an integrable modification of the sinh-Gordon model, obtained by complexifying the coupling constant. A key feature of this theory is the fact that the scaling function displays a roaming behaviour, that is, it visits all the unitary minimal conformal models when varying the temperature.
Via the generalized hydrodynamics (GHD) approach to iQFT, we develop a more physical picture of interaction in the theory, both at and away from equilibrium, relating this model to massless flows between consecutive unitary minimal models.
Using this model as a case-study, we also investigate the average currents and densities of higher spin conserved quantities in the partitioning protocol, deriving a universal scaling law which relates the spin to powers of the temperatures of the quenched systems.

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Absence of string excitations in the low-T spectrum of the quantum transfer matrix of the XXZ chain

Author: Saskia Faulmann[1]

[1] *Bergische Universität Wuppertal*

The eigenvalues of the quantum transfer matrix (QTM) of the XXZ spin-1/2 chain in the Trotter limit are parameterized by solutions of non-linear integral equations (NLIEs). We analyze these equations in the low-temperature limit for the model in the antiferromagnetic massless regime at finite magnetic field. To leading order in T the solutions of the NLIEs are determined by the dressed energy, which, in turns, is the solution of a linear Fredholm integral equation of the second kind. A rigorous characterization of the properties of the dressed energy in different regions of the complex plane, in conjuction with a thorough study of the subsidiary conditions that determine the excitation parameters in the solutions of the NLIEs, allows us to show that the excited states of the QTM are all of particle-hole type and that there are no string excitation in the low-T limit, as long as the magnetic field is kept finite.

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On the critical behaviour of the inhomogeneous six-vertex model

Authors: Gleb Kotousov[1]; Sergei Lukyanov[2]

[1] *DESY*

[2] *Rutgers University*

The inhomogeneous six-vertex model is a multi-parametric integrable 2D statistical system. With the anisotropy parameter |q|=1, the model is critical and is expected to exhibit a variety of interesting universal behaviour. In this talk we discuss the scaling limit of the homogeneous and so-called staggered cases and mention some applications to QFT. We also describe a conjecture from arXiv:2106.01238 that predicts the critical behaviour of the general inhomogeneous six-vertex model and its spin J = 1, 3/2, 2, … generalizations in a certain regime of the anisotropy q.

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Universality and conformal invariance in percolation models

Author: Alexi Morin-Duchesne[1]

[1] *Ghent University*

In this talk, I will describe our investigations of the universal behaviour of two critical percolation models: site percolation on the triangular lattice and bond percolation on the square lattice. Both are Yang-Baxter integrable models that can in principle be solved exactly. In the scaling limit, they are conformally invariant and described by non-unitary representations of the Virasoro algebra. I will describe our calculation of the models' partition functions on the cylinder and torus. This is joint work with A. Klümper and P.A. Pearce.

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Solvable models in discrete space-time

Author: Balázs Pozsgay[None]

We will discuss models on discrete 1+1 dimensional space-time, which display different versions of solvability. The models include both classical and quantum mechanical systems. The two main mechanisms underlying solvability are the traditional forms of integrability, and the more recent idea of dual unitarity. We will explore these ideas and survey a number of different integrable models.

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Integrable matrix models in discrete space-time: A paradigm of Kardar-Parisi-Zhang physics

Author: Tomaz Prosen[1]

[1] *University of Ljubljana*

I will discuss a class of very simple integrable dynamics on a discrete space-time lattice, which is generated by a 2-site matrix-valued rational map.
The phase spaces of the matrix variable can be selected from diverse families of symmetric spaces, e.g. complex Grassmannians, and are equipped with a natural symplectic structure.
This precise form of the map follows from a simple consistency condition for a parallel transport (aka Lax zero curvature condition) on a space-time lattice using
a minimalistic Lax operator, which is linear in the spectral and matrix variables. I will discuss the Yang-Baxter property and conservation laws of these maps.

Physically, the model represents an integrable discretization and SU(N) generalization of Landau-Lifshitz magnet. Using numerical computations, we have demonstrated that the
transport of Noether charges follows Kardar-Parisi-Zhang universality with superdiffusive dynamical exponent 3/2. Most interesting open questions will be discussed.

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Welcome Adress

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