PROGRAM AND ABSTRACT BOOKLET

WORKSHOP ON ORDERING AND DYNAMICS OF CORRELATED QUANTUM SYSTEMS

University of Évora, Portugal, 21-25 October 2019

The Workshop

This workshop is supported by several European and US projects and research centers. Our aim is to generate a lively exchange of ideas between researchers working in distinct but interrelated fields. Advances in recent years have witnessed an exciting and promising confluence of the areas of strongly correlated many-body quantum systems, including computational condensed matter physics and quantum information theory.

Topics to be discussed at the workshop will include: quantum chaos, quantum information dynamics, quantum criticality, thermalization and open quantum systems, ergodicity breaking, dynamically induced ordering, novel states of matter in cold atomic gases, topological photonics, and topology in condensed matter. On the theoretical side, analytical as well as computational approaches will be highlighted. On the experimental side, the focus will be on interacting quantum systems, including Bose-Einstein condensates with dipolar interactions, strongly correlated gases of Rydberg atoms, photonic crystals with symmetry-protected topological phases and many-electron systems out of equilibrium. The workshop will bring together a number of established experts, as well as many talented young scientists, to further explore, develop, and exploit the connections between these forefront areas of research.

Workshop site

Previous Évora workshops have an established tradition and have been highly successful in drawing together leading researchers and young scientists in a lively and engaging intellectual environment. A UNESCO World Heritage city, beautiful medieval town of Évora is the capital of Portugal's south-central Alentejo region, and the month of October is an ideal period for local excursions to explore both the city and its surroundings. Follow the following links to find more.
https://whc.unesco.org/en/list/361
https://en.wikipedia.g/wiki/Évora

Information on previous Évora workshops of the present series may be found at:
2008: http://hawk.fisica.uminho.pt/ccqm/
2010: http://hawk.fisica.uminho.pt/qcmca/
2012: http://hawk.fisica.uminho.pt/ccqs/
2014: http://hawk.fisica.uminho.pt/cccqs/
2016: http://www.cicqs.uevora.pt

The workshop will take place at:

Anfiteatro 131-A
Edifício do Espírito Santo
Universidade de Évora.

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PROGRAM

The lengths of both invited and contributed talks include at least 5 minutes of discussion.

Monday, 21 October

8:30 – 9:00 Registration

9:00 – 9:05 Welcome

9:05 – 9:40 Invited: **Immanuel Bloch**
Quantum matter under the microscope

9:40 – 10:00 Contributed: **Rukmani Bai**
Quantum Hall states in the 2D square optical lattices

10:00 – 10:35 Invited: **Andrew Daley**
Dissipation, correlation spreading, and scrambling in sparse spin models with cold atoms

10:35 – 10:55 Coffee break

10:55 – 11:15 Contributed: **Pranay Patil**
Hilbert space fragmentaion and Ashkin Teller criticality in fluctuation coupled Ising models

11:15 – 11:50 Invited: **Hannes Pichler**
From Many-body physics to quantum information with Rydberg atoms

11:50 – 12:10 Contributed: **Sebastian Weber**
Quantum simulation with Rydberg atoms

12:10 – 12:45 Invited: **Tilman Pfau**
A supersolid phase of dipolar atoms

12:45 Lunch break

15:00 – 16:00 Invited Colloquium: **Tilman Esslinger**
Twisted by dissipation

16:00 – 16:20 Contributed: **Carlos A. R. Sá de Melo**
Supersolid, superfluid, Wigner crystal, and hexatic phases of dipolar bosons

16:20 – 16:40 Contributed: **Jan Kumlin**
Emergent universal dynamics for an atomic cloud coupled to an optical waveguide

16.40 – 17:00 Coffee break

17:00 – 17:35 Invited: **Antoine Browaeys**
Many-body physics with arrays of individual Rydberg atoms

17:35 – 17:55 Contributed: **Izabella Lovas**
Quantized corner charges in the two-dimensional super-lattice Bose-Hubbard model

Tuesday, 22 October

9:00 – 9:35 Invited: **Andrea De Luca**
Eigenvalue correlations, chaos and localization in many-body quantum systems

9:35 – 10:10 Invited: **Achim Rosch**
Activating exotic conservation laws in driven systems: from integrability to many-body localization

10:10 – 10:30 Contributed: **Zala Lenarcic**
Critical behavior near the many-body localization transition in driven open systems

10:30 – 10:50 Coffee break

10:50 – 11:25 Invited: **Vladimir Gritsev**
Integrability for dynamics, disorder and topology

11:25 – 11:45 Contributed: **Elmer V. H. Doggen**
Many-body delocalization in large systems

11:45 – 12:05 Contributed: **Takaaki Monnai**
Relaxation to Gaussian generalized Gibbs ensembles in quadratic bosonic systems in the thermodynamic limit

12:05 – 12:25 Contributed: **Lucas Sá**
Complex spacing ratios: a signature of dissipative quantum chaos

12:25 – 12:45 Contributed: **Rachel Wortis**
Charge and spin-specific local integrals of motion in a disordered Hubbard model

12:45 Lunch break

15:00 – 16:00 Invited Colloquium: **João C. R. Magueijo**
Gravity waves and the quantum nature of gravity

16:00 – 16:35 Invited: **Anders W. Sandvik**
Scaling and diabatic effects in quantum annealing

16:35 – 16:55 Coffee break

16:55 – Poster presentations (2 minutes each) and poster session

Wednesday, 23 October

9:00 – 9:35 Invited: **Anushya Chandran**
Topological classes of quantum dynamics in quasi-periodically driven systems

9:35 – 10:10 Invited: **Adam Nahum**
Universal structures in many-body dynamics from random circuits

10:10 – 10:30 Contributed: **Dries Sels**
Quantum approximate Bayesian computation for NMR model inference

10:30 – 10:50 Coffee break

10:50 – 11:25 Invited: **Aharon Kapitulnik**
Thermalization and possible signatures of quantum chaos in complex crystalline materials

11:25 – 11:45 Contributed: **Eliska Greplova**
Hamiltonian learning for quantum error correction

11:45 – 12:20 Invited: **David K. Campbell**
Approaching equilibrium in classical and quantum systems: The dynamical glass phase

12.20 – 12:55 Invited: **Pedro Schlottmann**
Theory of electron spin resonance in heavy fermion compounds

12:55 Lunch break

15:00 Social Program

19:30 Banquet in room 129 of the University of Évora *Espírito Santo* College (XVI Century University Dining Hall)

Thursday, 24 October

9:15 – 9:50 Invited: **Juan P. Garrahan**
Kinetic constraints and their relevance to quantum dynamics

9:50 – 10:10 Contributed: **Garnett W. Bryant**
Atom-based solid-state quantum simulations: a quantum lab on a chip

10:10 – 10:45 Invited: **Roderich Moessner**
Dynamics of more or less exotic magnets

10:45 – 11:05 Coffee break

11:05 – 11:40 Invited: **Romain Vasseur**
Anomalous transport and hydrodynamics in quantum spin chain

11:40 – 12:00 Contributed: **Lenart Zadnik**
Inhomogeneous matrix product ansatz and exact steady states of boundary driven spin chains at large dissipation

12:00 – 12:20 Contributed: **Shintaro Takayoshi**
High-harmonic generation in quantum spin systems

12:20 – 12:40 Contributed: **Marko Ljubotina**
Spin transport in a discrete-time Heisenberg model

12:40 Lunch break

15:00 – 16:00 Invited Colloquium: **Ehud Altman**
Theory of entanglement transitions and natural error correction in quantum systems with measurements

16:00 – 16:35 Invited: **Marcos Rigol**
Entanglement entropy of highly excited eigenstates of many-body lattice Hamiltonians

16:35 – 16:55 Contributed: **Tiago Mendes-Santos**
Measuring entanglement in many-body systems via thermodynamics

16:55 – 17:15 Coffee break

17:15 – Poster presentations (2 minutes each) and poster session

Friday, 25 October

9:00 - 9:35 Invited: **Ryo Shimano**
Higgs spectroscopy of unconventional superconductors

9:35 - 9:55 Contributed: **Miguel M. Oliveira**
Classical and quantum liquids induced by quantum fluctuations

9:55 - 10:15 Contributed: **Tharnier O. Puel**
Mixed-order symmetry-breaking quantum phase transition far from equilibrium

10:15 - 10:35 Contributed: **Anne E. B. Nielsen**
Quasiparticles as detector of topological quantum phase transitions

10:35 - 10:55 Coffee break

10:55 - 11:30 Invited: **Henrik Johannesson**
Topological multicriticality of spin-orbit coupled electrons in one dimension

11:30 - 11:50 Contributed: **Ivan Kukuljan**
Violation of horizon by topological quantum excitations

11:50 - 12:10 Contributed: **Miguel Gonçalves**
Disorder driven multifractality transition in Weyl nodal loops

12:10 - 12:40 Summary and closing remarks: **Daniel Arovas**

12:40 Lunch

POSTERS

Poster Session I (22/10/2019)

	Name	Title
1	Pedro M. F. Alves	Extended NOON States
2	Syed T. Amin	Tracking topological phase transitions
3	João E. H. Braz	Bound-state spectrum of an impurity in a quantum vortex
4	Alexandre B. S. Correia	Excitation of Graphene Plasmons by Light Diffraction in Metallic Structures
5	Fatemeh K. Fumani	Ising in a transverse field with added transverse Dzyaloshinskii-Moriya interaction
6	João P. Gonçalves	Topological radial states in systems with rotational symmetry
7	José Gomes	Exciton-Polaritons of a 2D semiconductor layer in a cylindrical microcavity
8	Matthias Gruber	Magnetization and Entanglement after a geometric quench in the XXZ chain
9	Sayan Jana	Impact of strong correlations on a band topological insulator on the Lieb lattice
10	Luisa Madail	Compact edge states in geometrically frustrated weak topological insulators
11	Anselmo Marques	Analytical solution of open crystalline linear 1D tight-binding models
12	Ankita Negi	Investigating a disordered Chern Insulator
13	Philippe Sabella-Garnier	Thermalization/Relaxation in integrable and free field theories: an Operator Thermalization Hypothesis
14	Eduardo A. Santiago	Topological Insulators: From Conventional to Higher-Order
15	Filipe Santos	Many-body compact localized states in interacting geometrically frustrated systems
16	Niels De Vries	A scanning microscopy study on the origin of anomalous transport in corrugated graphene nanoribbons
17	Nicklas Walldorf	The antiferromagnetic phase of the Floquet-driven Hubbard model

POSTERS

Poster Session II (24/10/2019)

	Name	Title
1	Yu.V. Bludov	Hybrid magnon-plasmon modes in antiferromagnet heterostructures
2	Gunnar Bolmark	Dimensional crossover in quasi-1D systems
3	Aydin Deger	Determination of universal critical exponents using Lee-Yang theory
4	Yuchi He	Formation of bound states in a 1D Tomonaga-Luttinger liquid with attractive interactions
5	Zakaria Mzaouali	Discrete and generalized phase space techniques in critical quantum spin chains
6	Somayyeh Nemati	Macroscopic and microscopic functions of the ground state in spin-1/2 transverse ANNNI chains
7	Pedro A. C. Ninhos	Transport through periodically driven systems
8	Z. Okvátovity	Nuclear magnetic resonance in Weyl semimetals
9	Nilanjan Roy	Interacting fermions in one dimensional lattices with highly degenerate energy levels
10	Alexander Schuckert	Non-local emergent hydrodynamics in a long-range quantum spin system
11	Ayushi Singhania	Temperature Driven Multiple Phase Transitions and Quadrupolar Order in β-$TeVO_4$
12	Emily Townsend	Single-Particle Excitation Content as a Measure of Electronic Correlation and its Relation to Eigenstate Thermalization
13	Bart van Voorden	Quantum many-body scars from a single particle perspective

Monday, 21 October

MONDAY, 21 OCTOBER **14**
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Supersolid, superfluid, Wigner crystal, and hexatic phases of dipolar bosons 22
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QUANTUM MATTER UNDER THE MICROSCOPE

I. Bloch

Fakultät für Physik, Ludwig-Maximilians-Universität

9h05

Mon

1

More than 30 years ago, Richard Feynman outlined his vision of a quantum simulator for carrying out complex calculations on physical problems. Today, his dream is a reality in laboratories around the world. This has become possible by using complex experimental setups of thousands of optical elements, which allow atoms to be cooled to Nanokelvin temperatures, where they almost come to rest. Recent experiments with quantum gas microscopes allow for an unprecedented view and control of such artificial quantum matter in new parameter regimes and with new probes. In our fermionic quantum gas microscope, we can detect both charge and spin degrees of freedom simultaneously, thereby gaining maximum information on the intricate interplay between the two in the paradigmatic Hubbard model. In my talk, I will show how we can reveal hidden magnetic order, directly image individual magnetic polarons or probe the fractionalisation of spin and charge in dynamical experiments. For the first time we thereby have access to directly probe non-local 'hidden' correlation properties of quantum matter and to explore its real space resolved dynamical features also far from equilibrium.

QUANTUM HALL STATES IN THE 2D SQUARE OPTICAL LATTICES

Rukmani Bai[1,2], Soumik Bandyopadhyay[1,2], Sukla Pal[1], K.Suthar[1], D.Angom[1]

1 Physical Research Laboratory, Ahmedabad - 380009, Gujarat, India

2 Indian Institute of Technology Gandhinagar, Palaj, Gandhinagar - 382355, Gujarat, India

Quantum Hall (QH) states are robust and good choice to study the physics of topological effects. In the condensed matter systems, QH states have been observed experimentally. However, the observation of fractional quantum Hall (FQH) states is difficult in these systems as they require high magnetic fields (100 T or more). In this respect, ultracold atoms trapped in the optical lattices are clean and appropriate systems as synthetic magnetic fields equivalent to 100 T or more can be generated using laser fields. We study the occurrence of quantum Hall (QH) states and competing superfluid (SF) states in optical lattices for both homogeneous and inhomogeneous systems. For this, we solve Bose-Hubbard model(BHM) with synthetic magnetic field using cluster Gutzwiller mean field (CGMF) and Exact diagonalization (ED) methods. As a possible experimental signature, we calculate the two-point correlation function to distinguish the QH and SF states in CGMF. While in the case of ED method, we identify the QH and SF states based on the Penrose-Onsager criterion and von Neumann entropy [1].

9h40
Mon
2

1. Rukmani Bai, Soumik Bandyopadhyay, Sukla Pal, K. Suthar, and D. Angom Phys. Rev. A **98**, 023606 (2018).

DISSIPATION, CORRELATION SPREADING, AND SCRAMBLING IN SPARSE SPIN MODELS WITH COLD ATOMS

G. Bentsen[1], T. Hashizume[2], A. S. Buyskikh[2], F. Damanet[2], E. J. Davis[1], S. S. Gubser[3], M. Schleier-Smith[1], and A. J. Daley[2]

1 Department of Physics, Stanford University, Stanford, CA 94305, USA
2 Department of Physics and SUPA, University of Strathclyde, Glasgow G4 0NG, UK
3 Department of Physics, Princeton University, Princeton, NJ 08544, USA

10h00
Mon
3

Over the past few decades, developments with atomic, molecular and optical systems have provided opportunities to explore new regimes that are not generally accessible or controllable in other physical systems. This is especially true in the case of non-equilibrium dynamics in closed many-body quantum systems, and similarly for the introduction of dissipation with control on a microscopic level. In systems such as trapped ions and neutral atoms in optical cavities, we are also able to engineer and control spin models with variable long-range interactions. Investigating out of equilibrium dynamics in such systems opens fundamental questions about the behaviour of entanglement and correlation spreading in such systems.

In optical cavities, it is possible to engineer sparsely coupled spin models, by selectively tuning interactions as a function of distance between atoms, based on frequency control of external laser drives. This opens new opportunities towards understanding fast-scrambling and logarithmic light cones for correlation spreading (as quantified, e.g., through out of time order correlation functions). We study these systems using combinations of exact and approximate solutions for large-scale spin models, as well as Matrix Product Operator techniques to compute dynamics for realistic experimental size-scales [1]. We also study the entanglement properties of states produced by dynamics in these systems, and understand the effects of dissipation through the cavity.

1. G. Bentsen et al., arXiv:1905.11430

HILBERT SPACE FRAGMENTATION AND ASHKIN TELLER CRITICALITY IN FLUCTUATION COUPLED ISING MODELS

P. Patil[1], A. W. Sandvik[1,2]

1 Department of Physics, Boston University, 590 Commonwealth Avenue, Boston, Massachusetts 02215, USA

2 Beijing National Laboratory for Condensed Matter Physics and Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China

We present the fragmentation of Hilbert space into an exponential number of blocks with spatial structure for fluctuation coupled Ising models on general lattices. This phenomenon is observed numerically in some random unitary circuits [1] and quantum dimer models [2] where the reasons are not well understood. We discuss the implications that this structure of Hilbert space has on the dynamics of this system and present the detailed statistics of spatial patterns for the 1D case. We then consider the effects of a perturbation in terms of a transverse field which destroys the fragmented structure of Hilbert space and discuss the quantum phase transition. We argue that in general this should be in the Ashkin Teller universality class [3] and show explicit proof for the 1D case which has continuously varying critical exponents using Quantum Monte Carlo simulations. We also point out that our treatment motivates an explanation for pseudo-first order behavior seen in the frustrated $J_1 - J_2$ Ising model and the $q = 4$ Potts model in 2D [4].

10h55
Mon
4

1. V. Khemani and R. Nandkishore, arXiv:1904.04815.
2. O. Sikora, N. Shannon, F. Pollmann, K. Penc, and P. Fulde Phys. Rev. B 84, 115129 (2011).
3. Delfino, G., Grinza, P., Nuclear Physics B, 682(3), 521-550 (2004).
4. S. Jin, A. Sen, and A. W. Sandvik, Phys. Rev. Lett. 108, 045702 (2012.)

FROM MANY-BODY PHYSICS TO QUANTUM INFORMATION WITH RYDBERG ATOMS

Hannes Pichler

1 Department of Physics, Harvard University, Cambridge, MA 02138, USA
2 ITAMP, Harvard-Smithsonian Center for Astrophysics, Cambridge, MA 02138, USA
3 Division of Physics, Mathematics and Astronomy, California Institute of Technology, Pasadena, CA 91125, USA

11h15
Mon
5

Individually trapped neutral atoms provide a promising platform to engineer quantum many-body systems in a controlled, bottom-up approach. They can be readily manipulated in large numbers and interact strongly when excited to Rydberg states. In this talk I will first review the basic physics of arrays of Rydberg atoms, and the associated many-body phenomena. This includes the 1D equilibrium quantum phase diagram, as well as non-equilibrium phenomena such as quantum many-body scars. In the second part of my talk I discuss potential applications of trapped arrays of atoms for quantum information processing tasks. One approach is to encode certain combinatorial optimization problems in the ground state of the array. In particular, maximum independent set problems can be naturally realized and encoded by properly positioned atoms. This suggests that arrays of Rydberg atoms are ideally suited to directly implement various quantum optimization algorithms with no experimental overhead and study their performance for system sizes that cant be simulated on classical computers.

QUANTUM SIMULATION WITH RYDBERG ATOMS

S. Weber, H. P. Büchler

Institute for Theoretical Physics III and Center for Integrated Quantum Science and Technology, University of Stuttgart, Germany

We show that systems of Rydberg atoms can be tuned for accurate quantum simulation of various spin Hamiltonians. Using open-source software available from https://pairinteraction.github.io/, couplings between Rydberg atoms can be computed in the presence of external fields. This allows us to numerically emulate Rydberg experiments and predict experimental parameters for the realization of spin Hamiltonians, including systems with angular dependent interaction strengths or interaction which couples spin and orbital degree of freedom. By comparing experimental results and theoretical predictions for small systems, we demonstrate that spin Hamiltonians are realized accurately in the experiments. This makes Rydberg platforms promising for quantum simulations to provide insights into large many-body systems which cannot be obtained on classical computers.

11h50
Mon
6

A SUPERSOLID PHASE OF DIPOLAR ATOMS

T. Pfau

Physikalisches Institut and Center for Integrated Quantum Science and Technology IQST, Universität Stuttgart, Pfaffenwaldring 57, 70550 Stuttgart, Germany

12h10 Mon 7

A supersolid is a paradoxical state of matter in which atoms assume a rigid repeating pattern, as in many solids, and yet flow without friction, as in a superfluid. This means a supersolid should have phonon excitations like a crystal, as well as frictionless flow of atoms through that crystal. Such exotic behavior may be possible to create by leveraging the intrinsic interactions of the atoms. We describe our recent experimental and theoretical study of such a state in a magnetic quantum gas of dipolar atoms stabilized by quantum fluctuations.

1. F. Böttcher, J.-N. Schmidt, M. Wenzel, J. Hertkorn, M. Guo, T. Langen, and T. Pfau, arXiv:1901.07982. see also related work: arXiv:1811.02613, arXiv:1903.04375

TWISTED BY DISSIPATION

T. Esslinger

Department of Physics, ETH Zurich, Switzerland

Dissipative and unitary processes define the evolution of a many-body system. Their interplay gives rise to dynamical phase transitions and can lead to instabilities. We discovered a non-stationary state of chiral nature in a synthetic many-body system with independently controllable unitary and dissipative couplings. Our experiment is based on a spinor Bose gas interacting with an optical resonator. Orthogonal quadratures of the resonator field coherently couple the Bose-Einstein condensate to two different atomic spatial modes whereas the dispersive effect of the resonator losses mediates a dissipative coupling between these modes. In a regime of dominant dissipative coupling we observe a chiral evolution with regimes reminiscent of limit cycles [N. Dogra, M. Landini, K. Kroeger, L. Hruby, T. Donner, and T. Esslinger, arXiv:1901.05974].

15h00
Mon
8

SUPERSOLID, SUPERFLUID, WIGNER CRYSTAL, AND HEXATIC PHASES OF DIPOLAR BOSONS

C. A. R. Sá de Melo

School of Physics, Georgia Institute of Technology, Atlanta, GA 30332.

16h00 Mon 9

The phase diagram of two-dimensional dipolar bosons versus dipolar interaction strength is presented at finite temperatures. Several stable phases of dipolar bosons are identified including dipolar superfluid (DSF), dipolar supersolid (DSS), dipolar Wigner crystal (DWC), and dipolar normal fluid (DNF), as well as, more exotic phases such as dipolar hexatic fluid (DHF), and dipolar hexatic superfluid (DHS). For large densities or strong dipolar interactions, it is shown that a DWC exists at low temperatures, but melts into a DHF at higher temperatures, where translational crystaline order is destroyed but orientational order is preserved. Upon further increase in temperature the DHF phase melts into the DNF, where both orientational and translational lattice order are absent. Furthermore, for intermediate densities or intermediate dipolar interactions, it is shown that a DSS exists at low temperatures, but it translational crystalline order melts into a DHS at higher temperatures which preserves superfluidity and orientational order, before reaching the normal state (DNF phase). The static structure factor is presented as a way to characterize experimentally all the phases via optical Bragg scattering measurements.

1. C. A. R. Sá de Melo, in preparation, (2019).
2. Kaushik Mitra, C. J. Williams, C. A. R. Sá de Melo, Hexatic, Wigner Crystal, and Superfluid Phases of Dipolar Bosons, arXiv:0903.4655v1 (2009).
3. I. Danshita and C. A. R. Sá de Melo, Stability of superfluid and supersolid phases of dipolar bosons in optical lattices, Phys. Rev. Lett. **103**, 225301 (2009).

EMERGENT UNIVERSAL DYNAMICS FOR AN ATOMIC CLOUD COUPLED TO AN OPTICAL WAVEGUIDE

J. Kumlin[1], S. Hofferberth[2], and H. P. Büchler[1]

1 Institute for Theoretical Physics III and Center for Integrated Quantum Science and Technology, University of Stuttgart, 70550 Stuttgart, Germany

2 Department of Physics, Chemistry and Pharmacy, Physics@SDU, University of Southern Denmark, 5320 Odense, Denmark

16h20 Mon 10

We study the influence of the virtual exchange of photons on the properties of a single collective excitation in a many-body system, focusing on a setup described by an ensemble of atoms coupled to a one-dimensional waveguide. Based on a microscopic analysis, the time evolution of the collective excited state is governed by two competing terms: first, the spontaneous and strongly directed emission into the waveguide and second, an intrinsic coherent exchange interaction. Remarkably, we find that the coherent part gives rise to a universal dynamics of the collective excitation for an increasing number of emitters in the waveguide exhibiting several revivals. While this phenomenon provides an intrinsic limit on the dephasing in a collectively excited system, we also present a setup, where the universal dynamics can be explored.

1. J. Kumlin, S. Hofferberth, and H. P. Büchler, Phys. Rev. Lett **121**, 013601 (2018).

MANY-BODY PHYSICS WITH ARRAYS OF INDIVIDUAL RYDBERG ATOMS

A. Browaeys

Laboratoire Charles Fabry, Institut d'Optique Graduate School, CNRS, Université Paris-Saclay, F-91127 Palaiseau Cedex, France.

This talk will present our effort to control and use the dipole-dipole interactions between cold Rydberg atoms in order to implement spin Hamiltonians useful for quantum simulation. We trap individual atoms in arrays of optical tweezers separated by few micrometers and excite them to Rydberg states. We create almost arbitrary geometries of the arrays with unit filling in two[1] and three dimensions up to about 70 atoms[2]. We have demonstrated the coherent energy exchange in chains of Rydberg atoms resulting from their resonant dipole-dipole interaction and its control by addressable lasers. This interaction realizes the XY spin model[3]. We use this control to study elementary excitations in a di-merized spin chain featuring topological properties, thus implementing the Su-Schrieffer-Heeger model[4]. We have observed the edge states in the topological condition. We explored the regime beyond the linear response by adding several excitations, which act as hard-core bosons. Using the van der Waals interaction between atoms, we have also implemented the quantum Ising model in one-dimensional chains with periodic boundary conditions and two-dimensional arrays containing up to about 50 atoms[5]. We measure the dynamics of the excitation for various strengths of the interactions and compare the data to numerical simulations of this many-body system.

17h00
Mon
11

1. D Barredo, S de Léséleuc, V Lienhard, T Lahaye, A Browaeys, "An atom-by-atom assembler of defect-free arbitrary 2d atomic arrays", Science **354**, 1021 (2016).
2. D Barredo V Lienhard, S de Léséleuc, T Lahaye, A Browaeys, "Synthetic three-dimensional atomic structures assembled atom by atom", Nature **561**, 79 (2018).
3. S de Léséleuc, D Barredo, V Lienhard, A Browaeys, T Lahaye, "Local optical control of the resonant dipole-dipole interaction between Rydberg atoms", Phys. Rev. Lett. **119**, 053202 (2017).
4. S de Léséleuc, V Lienhard, P Scholl, D Barredo, S Weber, N Lang, HP Büchler, T Lahaye, A Browaeys, "Experimental realization of a symmetry protected topological phase of interacting bosons with Rydberg atoms", arXiv:1810.13286
5. V. Lienhard, S de Léséleuc, D Barredo, T Lahaye, A Browaeys, M Schuler, L-P Henry, A M Läuchli, "Observing the space- and time-dependent growth of correlations in dynamically tuned synthetic Ising antiferromagnets", Phys. Rev. X **8**, 021070 (2018).

QUANTIZED CORNER CHARGES IN THE TWO-DIMENSIONAL SUPER-LATTICE BOSE-HUBBARD MODEL

J. Bibo[1], I. Lovas[1], F. Grusdt[2,3], F. Pollmann[1]

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We study a two dimensional superlattice Bose-Hubbard model at half-filling, consisting of 2×2 unit cells with alternating hoppings t and $1-t$ inside and between unit cells, respectively. Relying on density matrix renormalization group simulations, we study the phase diagram of the model, finding two gapped topological phases separated by a gapless superfluid region. We demonstrate that the gapped states realize a higher order symmetry protected topological phase, protected by charge conservation and C_4 lattice symmetry, classified in terms of a $\mathbb{Z}_2$ invariant, a quantized fractional corner charge that cannot be changed by edge manipulations. We support our claims by studying the full counting statistics of the corner charge, finding a sharp distribution peaked around the quantized value. These results should be experimentally observable in ultracold atomic settings. In particular, the distribution of the fractional charge can be accessed by state of the art quantum gas microscopes, offering an ideal opportunity to study interacting higher order topological phases and their characteristic corner modes.

17h35
Mon
12

1. F. Grusdt, M. Höning, and M. Fleischhauer, Phys. Rev. Lett. **110**, 260405 (2013).
2. Y. You, T. Devakul, F. J. Burnell, and T. Neupert, Phys. Rev. B **98**, 235102 (2018).
3. M. Lohse, C. Schweizer, O. Zilberberg, M. Aidelsburger, and I. Bloch, Nature Physics **12**, 350 (2016).
4. J. Bibo, I. Lovas, F. Grusdt, and F. Pollmann, in preparation.

Tuesday, 22 October

TUESDAY, 22 OCTOBER **27**
Eigenvalue correlations, chaos and localization in many-body quantum systems 27
Activating exotic conservation laws in driven systems: from integrability to many-body localization 28
Critical behavior near the many-body localization transition in driven open systems . . . 29
Integrability for dynamics, disorder and topology 30
Many-body delocalization in large systems 31
Relaxation to Gaussian generalized Gibbs ensembles in quadratic bosonic systems in the thermodynamic limit 32
Complex spacing ratios: a signature of dissipative quantum chaos 33
Charge and spin-specific local integrals of motion in a disordered Hubbard model 34
Gravity waves and the quantum nature of gravity 35
Scaling and diabatic effects in quantum annealing 36

EIGENVALUE CORRELATIONS, CHAOS AND LOCALIZATION IN MANY-BODY QUANTUM SYSTEMS

A. Chan[1], A. De Luca[1,2], J. T. Chalker[1]

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2 Laboratoire de Physique Thèorique et Modélisation (CNRS UMR 8089), Université de Cergy-Pontoise, F-95302 Cergy-Pontoise, France

We study spectral statistics in spatially extended chaotic quantum many- body systems, using simple lattice Floquet models. Computing the spectral form factor $K(t)$ analytically and numerically, we show that it follows random matrix theory (RMT) at times longer than a many-body Thouless time, t_{Th}. The Thouless time grows with the system size and its specific behavior reflects general features of the system under consideraton, as the spatial dimension d and the presence of conserved quantities which undergo diffusive transport. By comparing different models and numerical results, we discuss the universality of these conclusions and the manifestation of ergodicity breaking induced by strong disorder.

9h00
Tue
1

1. Amos Chan, Andrea De Luca, J. T. Chalker, : Phys. Rev. X 8, 041019 (2018).
2. Amos Chan, Andrea De Luca, J. T. Chalker, : Phys. Rev. Lett. 121, 060601 (2018).
3. Aaron J. Friedman, Amos Chan, Andrea De Luca, J. T. Chalker, arXiv:1906.07736.

ACTIVATING EXOTIC CONSERVATION LAWS IN DRIVEN SYSTEMS: FROM INTEGRABILITY TO MANY-BODY LOCALIZATION

A. Rosch

Institute for Theoretical Physics, University of Cologne, Germany

9h35
Tue
2

Systems with approximate conservation laws can be driven far from equilibrium even by weak pumping. We consider systems with an infinite set of approximate conservation laws: Heisenberg spin chains [1] or one-dimensional strongly disordered systems [2] close to a many-boldy localization transition, both coupled to phonons. Weak driving by lasers or by white light activates the exotic conservation laws as their tiny decay rates can easily be overcompensated by the pumping. We discuss that fluctuations of the local temperature serve as an experimentally accessible effective order parameter for the many-body localization transition and explore how this can be used to measure the dynamical critical exponent of the phase transition from steady-state properties.

1. F. Lange, Lenarčič, A. Rosch, Nat. Comm. **8**, 15767 (2017).
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CRITICAL BEHAVIOR NEAR THE MANY-BODY LOCALIZATION TRANSITION IN DRIVEN OPEN SYSTEMS

Zala Lenarčič[1], Ori Alberton[2], Achim Rosch[2], and Ehud Altman[1]

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2 Institute for Theoretical Physics, University of Cologne, Germany

In a many-body localized (MBL) system, the coupling to an external bath typically breaks local integrals of motion. Thus the system relaxes to a unique thermal steady state. When the bath is non-thermal or when the system is weakly driven out of equilibrium, local conservation laws can be excited far from any thermal equilibrium value. I will show how this property can be used to study the MBL phase transition in weakly open systems. Here, the strength of the coupling to the non-thermal bath plays a similar role as a finite temperature in a $T = 0$ quantum phase transition. By tuning this parameter, we can detect key features of the MBL transition: the divergence of dynamical exponent due to Griffiths effects and the critical disorder strength.

10h10 Tue 3

We propose a new order parameter, based on the fluctuations in local temperatures. For vanishing strength of coupling to the bath, fluctuations vanish on the ergodic side, while they are large on the MBL side. By increasing the coupling strength, fluctuations grow with a fractional exponent related to the inverse dynamical exponent on the ergodic side, while they decrease monotonically on the MBL side. This paves the way for studies of the MBL transition with new numerical approaches and, importantly, also with solid-state experiments.

1. Z. Lenarčič, E. Altman, and A. Rosch, Phys. Rev. Lett 121, 267603 (2018).
2. Z. Lenarčič, O. Alberton, A. Rosch, and E. Altman, in preparation.

INTEGRABILITY FOR DYNAMICS, DISORDER AND TOPOLOGY

Vladimir Gritsev

Institute for Theoretical Physics, University of Amsterdam, Netherlands

10h50
Tue
4

I will discuss exactly solvable models for Floquet dynamics, disordered interacting spin chain and topological phase transition in interacting mixed superconducting Kitaev-type chain.

MANY-BODY DELOCALIZATION IN LARGE SYSTEMS

E. V. H. Doggen[1], F. Schindler[2], K. S. Tikhonov[1,3], A. D. Mirlin[1,3,4,5], T. Neupert[2], D. G. Polyakov[1], I. V. Gornyi[1,3,4,6]

1 Institut für Nanotechnologie, Karlsruhe Institute of Technology, 76021 Karlsruhe, Germany

2 Department of Physics, University of Zurich, Winterthurerstrasse 190, 8057 Zurich, Switzerland

3 L. D. Landau Institute for Theoretical Physics RAS, 119334 Moscow, Russia

4 Institut für Theorie der Kondensierten Materie, Karlsruhe Institute of Technology, 76128 Karlsruhe, Germany

5 Petersburg Nuclear Physics Institute, 188300 St. Petersburg, Russia

6 A. F. Ioffe Physico-Technical Institute, 194021 St. Petersburg, Russia

11h25 Tue 5

Using the time-dependent variational principle as applied to matrix product states, we present state-of-the-art numerical results for the non-equilibrium dynamics in disordered, interacting spin chains, targeting the late-time behaviour close to the putative many-body localization (MBL) transition in systems of sizes inaccessible to exact diagonalization. In particular, we study the one-dimensional XXZ chain with random on-site disorder and find a value of the critical disorder that is far beyond the value predicted using smaller system sizes. Moreover, we consider quasi-periodic disorder and find a dramatic influence of the choice of periodicity on the delocalization dynamics. Our results elucidate the role of “ergodic spots” in driving the MBL transition and clarify the key differences between purely random and quasi-periodic disorder. Further, some preliminary results for higher synthetic dimensions are presented.

1. E. V. H. Doggen, F. Schindler, K. S. Tikhonov, A. D. Mirlin, T. Neupert, D. G. Polyakov, I. V. Gornyi, Phys. Rev. B **98**, 174202 (2018).
2. E. V. H. Doggen, A. D. Mirlin, arXiv:1901.06971.

RELAXATION TO GAUSSIAN GENERALIZED GIBBS ENSEMBLES IN QUADRATIC BOSONIC SYSTEMS IN THE THERMODYNAMIC LIMIT

T. Monnai[1], S. Morodome[2], K. Yuasa[2]

1 Department of Materials and Life Science, Seikei University, Tokyo, Japan
2 Department of Physics, Waseda University, Tokyo, Japan

Integrable quantum many-body systems are considered to equilibrate to generalized Gibbs ensembles (GGEs) characterized by the expectation values of integrals of motion. While there exist many studies on this issue, it remains a challenging open problem to clarify a concrete scenario of the microscopic mechanism of the relaxation to GGE.

11h45 Tue 6

In this presentation, we explore the dynamics of quadratic bosonic systems in the thermodynamic limit, and show a general mechanism for the relaxation to GGEs [1]. We show analytically and explicitly that a free bosonic system relaxes from a general (not necessarily Gaussian) initial state under certain physical (locality) conditions to a Gaussian GGE[2-5]. We also show the relaxation to a Gaussian GGE in an exactly solvable system, a harmonic oscillator linearly coupled with bosonic reservoirs.

1. T. Monnai, S. Morodome, and K. Yuasa, Phys. Rev. E **100**, 022105 (2019).
2. M. Cramer and J. Eisert, New J. Phys. **12**, 055020 (2010).
3. M. Gluza, C. Krumnow, M. Friesdorf, C. Gogolin, and J. Eisert, Phys. Rev. Lett. **117**, 190602 (2016).
4. C. Murthy and M. Srednicki, Phys. Rev. E **100**,012146 (2019).
5. M. Gluza, J. Eisert, and T. Farrelly, arXiv:1809.08268 [quant-ph].

COMPLEX SPACING RATIOS: A SIGNATURE OF DISSIPATIVE QUANTUM CHAOS

Lucas Sá[1], Pedro Ribeiro,[1,2] and Tomaž Prosen[3]

[1] *CeFEMA, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001 Lisboa, Portugal*
[2] *Beijing Computational Science Research Center, Beijing 100193, China*
[3] *Department of Physics, Faculty of Mathematics and Physics, University of Ljubljana, Ljubljana, Slovenia*

12h05 Tue 7

We introduce a complex-plane generalization of the consecutive level-spacing distribution, used to distinguish regular from chaotic quantum spectra. Our approach features the distribution of complex-valued ratios between nearest- and next-to-nearest-neighbor spacings. We show that this quantity can successfully detect the chaotic or regular complex-valued spectra. This is done in two steps. First, we show that, if eigenvalues are uncorrelated, the distribution of complex spacing ratios is flat within the unit circle, whereas random matrices show a strong angular dependence in addition to the usual level repulsion. The large-size universal fluctuations of Gaussian Unitary and Ginibre Unitary universality classes are shown to be well described by Wigner-like surmises for small-size matrices with eigenvalues on the circle and on the two-torus, respectively. To study the latter case, we introduce the Toric Unitary Ensemble, characterized by a flat joint eigenvalue distribution on the two-torus. Second, we study different physical situations where nonhermitian matrices arise: dissipative quantum systems subjected to Lindbladian or non-unitary Hamiltonian dynamics and classical stochastic processes. We show that known integrable models have a flat distribution of complex spacing ratios whereas generic cases, expected to be chaotic, conform to Random Matrix Theory predictions. Specifically, we were able to distinguish chaotic from integrable dynamics in boundary-driven dissipative spin-chain Liouvillians and differentiate localized from delocalized phases in a nonhermitian disordered many-body system.

CHARGE AND SPIN-SPECIFIC LOCAL INTEGRALS OF MOTION IN A DISORDERED HUBBARD MODEL

Rachel Wortis, Brandon Leipner-Johns

Department of Physics and Astronomy, Trent University, Peterborough, Ontario, Canada

12h25 Tue 8

While many-body localization has primarily been studied in systems with a single local degree of freedom, experimental studies of many-body localization in cold atom systems motivate exploration of the disordered Hubbard model. With two coupled local degrees of freedom it is natural to ask how localization in spin relates to disorder in charge and vice versa. Most prior work has addressed disorder in only one of these sectors and often has not used measures of localization which distinguish between charge and spin. Here we explore localization in the Hubbard model with a wide range of independent values of charge and spin disorder, using measures of localization based on charge and spin-specific integrals of motion. Our results demonstrate symmetry between the response of the spin to charge disorder and vice versa, and we find very weak disorder in one channel, so long as the disorder in the other channel is sufficiently strong, results in localization in both channels. The strength of disorder required in the less disordered channel declines as the system size increases. Further, the weaker the disorder in the less-disordered channel, the longer the time scale at which localization appears in the dynamics of this degree of freedom.

GRAVITY WAVES AND THE QUANTUM NATURE OF GRAVITY

João C. R. Magueijo

Faculty of Natural Sciences, Department of Physics, Imperial College

Gravity waves were first predicted by Einstein as part of the proposal of the theory of General Relativity. I explain how this novelty arises, in contrast with Newtonian's theory of gravity. The process that led to their direct observation, however, was long and arduous. Even more tantalizing is the prospect of these waves having a quantum nature, and an associated quantum particle, the graviton. I review mathematical attempts to quantize gravity and why they have stumbled or fallen into several traps and inconsistencies. If gravity waves were tough to detect, the graviton is even more elusive; and yet it contains the secret of the unification of Quantum Mechanics and General Relativity.

15h00
Tue
9

SCALING AND DIABATIC EFFECTS IN QUANTUM ANNEALING

Anders W. Sandvik

Department of Physics, Boston University, Boston, MA 02215, USA
Beijing National Laboratory of Condensed Matter Physics and Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China

16h00 Tue 10

Quantum annealing has been envisioned as a technique for effectively solving hard optimization problems, and devices already exist that claim to accomplish this by implementing an Ising model with programmable couplings (corresponding to an optimization problem) and transverse field (which introduces quantum fluctuations into the classical Ising spin configurations). It is still not clear, however, what degree of quantum speedup can be achieved for various problems of interest. Quantum annealers can also be used more broadly as laboratories for out-of-equilibrium quantum dynamics. Here I will discuss experiments carried out on an annealing device programmed to emulate the standard 2D ferromagnetic Ising model on $L \times L$ lattices with L up to 32. By varying the annealing time and the lattice size, the interplay between ideal quantum annealing and noise from couplings to the environment of the qubits can be systematically investigated through the properties of the final classical state reached after the annealing process. I will discuss how such results can be analyzed with a phenomenological scaling ansatz, which can be applied also to numerical results for model systems [1].

[1] P. Weinberg, M. Tylutki, J. M. Rönkkö, J. Westerholm, J. A. Åström, P. Manninen, P. Törmä, and A. W. Sandvik (unpublished).

Wednesday, 23 October

WEDNESDAY, 23 OCTOBER **38**
Topological classes of quantum dynamics in quasi-periodically driven systems 38
Universal structures in many-body dynamics from random circuits 39
Quantum approximate Bayesian computation for NMR model inference 40
Thermalization and possible signatures of quantum chaos in complex crystalline materials 41
Hamiltonian learning for quantum error correction 42
Approaching equilibrium in classical and quantum systems: The dynamical glass phase . . 43
Theory of electron spin resonance in heavy fermion compounds 44

TOPOLOGICAL CLASSES OF QUANTUM DYNAMICS IN QUASI-PERIODICALLY DRIVEN SYSTEMS

Anushya Chandran

Boston University

9h00
Wed
1

Advances in the isolation and control of quantum systems has brought driven quantum phases into the laboratory. In periodically driven systems, new phases occur when the steady states, determined by Bloch-Floquet theorem, have novel spatio-temporal or topological order.

In this talk I show how the Bloch-Floquet theorem is generalized to cases when the drives are quasi-periodic. I apply this framework to the simplest case of a few level system, and show that steady state dynamics admit a topological classification. When the classification is non-trivial the system exhibits a quantized pumping of energy, and a sensitivity to initial conditions, neither of which is present in the trivial case. I further discuss the stability of this classification, the behavior near the critical point where the topological class changes, and experimental results in diamond defect centers.

UNIVERSAL STRUCTURES IN MANY-BODY DYNAMICS FROM RANDOM CIRCUITS

Adam Nahum

Rudolf Peierls Centre for Theoretical Physics, Oxford University

9h35
Wed
2

I will talk about quantum-classical mappings for real-time observables in some simple many-body systems (random unitary circuits). I will discuss how (1) entanglement entropy growth and (2) two-point correlation functions in these systems can be related to simple partition functions for random walks. I will use these mappings to motivate more general phenomenological pictures for entanglement and correlation functions.

QUANTUM APPROXIMATE BAYESIAN COMPUTATION FOR NMR MODEL INFERENCE

Dries Sels, Eugene Demler

Department of Physics, Harvard University, 17 Oxford st., Cambridge, MA 02138, USA

10h10 Wed 3

Recent technological advances may lead to the development of small scale quantum computers capable of solving problems that cannot be tackled with classical computers. A limited number of algorithms has been proposed and their relevance to real world problems is a subject of active investigation. Analysis of many-body quantum system is particularly challenging for classical computers due to the exponential scaling of Hilbert space dimension with the number of particles. Hence, solving problems relevant to chemistry and condensed matter physics are expected to be the first successful applications of quantum computers. In this talk, I will discuss another class of problems from the quantum realm that can be solved efficiently on quantum computers: model inference for nuclear magnetic resonance (NMR) spectroscopy, which is important for biological and medical research. Our results are based on the cumulation of three interconnected studies. Firstly, we use methods from classical machine learning to analyze a dataset of NMR spectra of small molecules. We perform a stochastic neighborhood embedding and identify clusters of spectra, and demonstrate that these clusters are correlated with the covalent structure of the molecules. Secondly, we propose a simple and efficient method, aided by a quantum simulator, to extract the NMR spectrum of any hypothetical molecule described by a parametric Heisenberg model. Thirdly, we propose an efficient variational Bayesian inference procedure for extracting Hamiltonian parameters of experimentally relevant NMR spectra.

THERMALIZATION AND POSSIBLE SIGNATURES OF QUANTUM CHAOS IN COMPLEX CRYSTALLINE MATERIALS

Aharon Kapitulnik[1,2]

1 Departments of Physics and Applied Physics, Stanford University, Stanford, CA 94305,USA.
2 Geballe Laboratory for Advanced Materials, Stanford University, Stanford, CA 94305, USA

Analyses of thermal diffusivity data on complex insulators and on strongly correlated electron systems hosted in similar complex crystal structures suggest that quantum chaos is a good description for thermalization processes in these systems, particularly in the high temperature regime where the many phonon bands and their interactions dominate the thermal transport. Here we observe that for such systems diffusive thermal transport is controlled by a universal Planckian time scale $\tau \sim \hbar/k_B T$, and a unique (butterfly) velocity v_B. Specifically, $v_B \approx v_{ph}$ for complex insulators, and $v_{ph} \lesssim v_B \ll v_F$ in the presence of strongly correlated itinerant electrons (v_{ph} and v_F are the phonons and electrons velocities respectively). For the complex correlated electron systems we further show that charge diffusivity, while also reaching the Planckian relaxation bound, is largely dominated by the Fermi velocity of the electrons, hence suggesting that it is only the thermal (energy) diffusivity that describes chaos diffusivity [1,2,3].

10h50 Wed 4

1. Jiecheng Zhang, E. M. Levenson-Falk, B. J. Ramshaw, D. A. Bonn, R. Liang, W. N. Hardy, S. A. Hartnoll, A. Kapitulnik, PNAS May 23, **114**, 5378 (2017).
2. Jiecheng Zhang, Erik D. Kountz, Eli M. Levenson-Falk, Dojoon Song, Richard L. Greene, Aharon Kapitulnik, arXiv:1808.07564 (2018).
3. Kamran Behnia, Aharon Kapitulnik, arXiv:1905.03551 (2019).

HAMILTONIAN LEARNING FOR QUANTUM ERROR CORRECTION

Eliska Greplova[1], Agnes Valenti[1], Evert van Nieuwenburg[2], Sebastian Huber[1]

1 Institute for Theoretical Physics, ETH Zurich, CH-8093, Switzerland
2 Institute for Quantum Information and Matter, Caltech, Pasadena, 91125 California, USA

11h25
Wed
5

The efficient validation of quantum devices is critical for emerging technological applications. In a wide class of use-cases the precise engineering of a Hamiltonian is required both for the implementation of gate-based quantum information processing as well as for reliable quantum memories. Inferring the experimentally realized Hamiltonian through a scalable number of measurements constitutes the challenging task of Hamiltonian learning. In particular, assessing the quality of the implementation of topological codes is essential for quantum error correction. Here, we introduce a neural net based approach to this challenge. We capitalize on a family of exactly solvable models to train our algorithm and generalize to a broad class of experimentally relevant sources of errors. We discuss how our algorithm scales with system size and analyze its resilience towards various noise sources.

APPROACHING EQUILIBRIUM IN CLASSICAL AND QUANTUM SYSTEMS: THE DYNAMICAL GLASS PHASE

David K. Campbell

Department of Physics, Boston University, Boston, Massachusetts

11h45 Wed 6

The approach to equilibrium, and the deviations around equilibrium, in both classical and quantum systems have been extensively studied in recent years. Typically, the classical many-body interacting systems exhibit chaotic behavior, this microcanonical dynamics ensures that time averages and phase space averages are identical, in agreement with the assumption of ergodicity. We show that near an integrable limit the manner in which the nonintegrable perturbations are coupled, that is, network in action space coupling the nonintegrable perturbations determines whether : i) the ergodization time scales remain on the order of the Lyapunov times, or whether: ii) the system fragments into chaotic regions and regular regions, which consist of coherent localized excitations with anomalously large lifetimes. In this latter case, the ergodization time scales become much longer than the Lyapunov times. We are that in this case the system enters a dynamical glass (DG) phase at a finite distance to the integrable limit. To quantify the properties of the DG phase, we focus on a set of observables which turn into conserved quantities in the integrable limit. We show that using a generalized sectioning of a typical trajectory by equilibrium Poincare manifolds allows us to detect the coherent excitations, whose behavior controls the ergodization time scales and hence signals the onset of the DG phase. We argue that our studies may apply to quantum models, where the DG phase is likely related to the many-body localized phase.

THEORY OF ELECTRON SPIN RESONANCE IN HEAVY FERMION COMPOUNDS

Pedro Schlottmann

Department of Physics, Florida State University, Tallahassee, Florida, USA

The electron spin resonance (ESR) line width for localized moments are studied within the framework of the Kondo lattice model. Only for a sufficiently small Kondo temperature can an ESR signal be observed for a Kondo impurity (e.g., $\underline{A}uYb$ [1]). On the other hand, for a Kondo lattice representing a heavy fermion compound, short-range ferromagnetic correlations (FM) between the localized among Ce or Yb moments are crucial to observe a signal [2]. The spin relaxation rate (line width) and the static magnetic susceptibility are inversely proportional to each other. The FM enhance the susceptibility and hence reduce the line width [3,4]. For most of the heavy fermion systems displaying an ESR signal the FM order arises in the *ab*-plane from the strong lattice anisotropy [2].

12h20 Wed 7

CeB_6 is a heavy fermion compound with *cubic* symmetry having a Γ_8 ground-quartet. Four transitions are expected for individual Ce ions with a Γ_8 ground-multiplet, but only one has been observed [5]. Antiferro-quadrupolar order (AFQ) arises below 4 K due to the orbital content of the Γ_8-quartet. We address the effects of the interplay of AFQ and FM on the ESR line width and the phase diagram [6]. For CeB_6 an itinerant picture within the AFQ phase is necessary to explain the electron spin resonances. The ESR results are also discussed in the context of some inelastic neutron scattering experiments [7].

1. Y. von Spalden, et al., Phys. Rev. B **28**, 24 (1984).
2. J. Sichelschmidt, et al., Phys. Rev. Lett. **91**, 156401 (2003); C. Krellner, et al., Phys. Rev. Lett. **100**, 066401 (2008).
3. E. Abrahams and P. Wölfle, Phys. Rev. B **78**, 104423 (2008); P. Wölfle and E. Abrahams, Phys. Rev. B **80**, 235112 (2009).
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7. P. Schlottmann, Review to appear as Book-Chapter in *Rare-Earth Borides*, ed. Dmytro Isonov (Pan Stanford Publishing Pte. Ltd.).

Thursday, 24 October

THURSDAY, 24 OCTOBER **46**
Kinetic constraints and their relevance to quantum dynamics 46
Atom-based solid-state quantum simulations: a quantum lab on a chip 47
Dynamics of more or less exotic magnets 48
Anomalous transport and hydrodynamics in quantum spin chain 49
Inhomogeneous matrix product ansatz and exact steady states of boundary driven spin chains at large dissipation 50
High-harmonic generation in quantum spin systems 51
Spin transport in a discrete-time Heisenberg model 52
Theory of entanglement transitions and natural error correction in quantum systems with measurements 53
Entanglement entropy of highly excited eigenstates of many-body lattice Hamiltonians . . 54
Measuring entanglement in many-body systems via thermodynamics 55

KINETIC CONSTRAINTS AND THEIR RELEVANCE TO QUANTUM DYNAMICS

Juan P. Garrahan

School of Physics and Astronomy, University of Nottingham, Nottingham, NG7 2RD, UK

9h15 Thu 1

I will describe the rich dynamics that emerges in simple models endowed with kinetic constraints. I will consider the classification of stochastic kinetically constrained models (KCMs), and the range of behaviour that they can display. I will discuss how these classical ideas can be adapted to the problem of slow thermalisation and (apparent) non-ergodicity in quantum systems in the absence of quenched disorder. Particular focus will be put on the so-called quantum East model as a paradigmatic quantum KCM displaying slow dynamics and breakdown of thermalisation.

ATOM-BASED SOLID-STATE QUANTUM SIMULATIONS: A QUANTUM LAB ON A CHIP

G. W. Bryant, E. Townsend

Nanoscale Device Characterization Division and Joint Quantum Institute, National Institute of Standards and Technology and University of Maryland, Gaithersburg, Maryland, USA

Atom arrays in solid-state systems, such as dopants in Si[1], atoms on surfaces[2] or dangling bond arrays[3] provide exciting new opportunities to perform quantum simulations. Solid-state systems provide the opportunity to do simulations atom-by-atom with atomically precise placement, complex geometries and unit cells, local gates, applied fields and strong hopping that allow the low T limit to be reached. Here we describe theoretical simulations done for small arrays of atoms used to implement extended range Fermi-Hubbard models appropriate for the atom-based solid-state simulators that we are now making.

We discuss three simulations of the dynamics of collective quantum excitations to study transport and dispersion of quantum resources in interacting systems. We consider an array of atoms with qubits attached to opposite ends of the array. This can model, for example, the dynamics of long-range exchange between two qubits mediated by an intermediate many-body quantum dot [4]. We show how many-body excitations in the intermediate dot are launched from an excited qubit. This determines how excitations can be transferred between qubits through the mediator QD. We analyze and discuss the transfer of quantum information via the many-body excitations. As a second example, a third qubit is attached to the chain 9h50
to act as a bath that takes information out of the system. This provides a simple model for the effects of
weak dissipation. Finally, we consider a system where both qubits are initially excited and each launches Thu
a many-body excitation into the chain. This allows us to simulate the collision and quantum interference 2
of two collective excitations and understand how quantum information is maintained during such quantum processes. Simulations are done as a function of the electron-electron interaction to test the limits of weak and strong interaction, and with and without a spin/valley degree of freedom. Implications for using atom-based solid-state arrays as a quantum lab on a chip are discussed.

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3. J. Wyrick, X. Wang, P. Namboodiri, S. W. Schmucker, R. V. Kashid, and R. M. Silver, Nano Lett. **18**, 7502 (2018).
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DYNAMICS OF MORE OR LESS EXOTIC MAGNETS

Roderich Moessner
Max Planck ICS, Dresden

10h10 Thu 3

The dynamics of quantum spin systems beyond the 'universal' low-energy/long-wavelength regime is only poorly explored, despite the fact that plenty of experimental data has become available thanks to recent advances in neutron scattering technology. This talk focuses on 'generic' properties of the intermediate energy regime, in particular properties of magnets in or near topological phases.

ANOMALOUS TRANSPORT AND HYDRODYNAMICS IN QUANTUM SPIN CHAIN

Romain Vasseur[1] and Sarang Gopalakrishnan[2]

[1] *Department of Physics, University of Massachusetts, Amherst, MA 01003, USA*

[2] *Department of Physics and Astronomy, CUNY College of Staten Island, Staten Island, NY 10314; Physics Program and Initiative for the Theoretical Sciences, The Graduate Center, CUNY, New York, NY 10016, USA*

11h05 Thu 4

In this talk, I will discuss the nature of spin transport in XXZ spin chains at finite temperature. I will explain how to calculate the diffusion constant using a kinetic picture based on generalized hydrodynamics combined with Gaussian fluctuations, and comment on the isotropic limit which shows superdiffusion.

1. Kinetic Theory of Spin Diffusion and Superdiffusion in XXZ Spin Chains, S. Gopalakrishnan and R. Vasseur, Phys. Rev. Lett. 122, 127202 (2019).

INHOMOGENEOUS MATRIX PRODUCT ANSATZ AND EXACT STEADY STATES OF BOUNDARY DRIVEN SPIN CHAINS AT LARGE DISSIPATION

V. Popkov[1,2], T. Prosen[1], L. Zadnik[1]

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2 Bergisches Universität Wuppertal, Gauss Str. 20, D-42097 Wuppertal, Germany

11h40 Thu 5

I will present a novel inhomogeneous Lax structure and demonstrate exact solvability of a driven anisotropic Heisenberg spin-1/2 chain, coupled to Lindblad baths that induce arbitrary polarisations of the boundary degrees of freedom. The matrices that constitute the ansatz for the steady state of the dissipative protocol satisfy a simple linear recurrence that can be interpreted as a generalisation of the quantum group relations. The latter are the essential ingredients of the integrability structure, therefore our results are expected to have further fundamental applications in the construction of nonlocal integrals of motion for the open Heisenberg model with arbitrary boundary fields.

1. V. Popkov, T. Prosen, L. Zadnik, arXiv:1905.09273 (preprint).

HIGH-HARMONIC GENERATION IN QUANTUM SPIN SYSTEMS

Shintaro Takayoshi[1], Yuta Murakami[2], Philipp Werner[3]

1 Max Planck Institute for the Physics of Complex Systems, Dresden, Germany
2 Department of Physics, Tokyo Institute of Technology, Tokyo, Japan
3 Department of Physics, University of Fribourg, Fribourg, Switzerland

Strong light-matter coupling provokes a lot of intriguing phenomena. One of the technologically important examples is the high-harmonic generation (HHG) in quantum systems, which has the potential application for ultrafast phenomena such as the generation of atto-second science. HHG stems from the highly nonlinear dynamics of electrons excited by strong laser fields, and it has been studied for decades in atomic and molecular gases. Recent observations of HHG in semiconductors and liquids have stimulated the community of the condensed matter physics to extend its exploration to various materials such as graphene and Mott insulators. In this work, we propose the novel possibility of HHG in quantum spin systems and elucidate its mechanism. While the conventional HHG is generated in electron systems driven by laser electric field, we focus on the HHG radiated from magnetic dipoles driven by laser magnetic field. Since the HHG reflects the dynamics of magnetic excitations, it can be used to obtain information on the low-energy excitation spectrum as well as it may provide a new laser source in the THz frequency regime. In particular, we consider the two types of specific ferromagnetic spin chain models, the Ising model with static longitudinal field and the XXZ model. Through these models we can investigate how the existence of external field and quantum fluctuation affects the HHG spectra. Our results demonstrate that the HHG radiation spectra can capture the property of elementary excitations, magnons, in these systems [1].

12h00
Thu
6

[1] S. Takayoshi, Y. Murakami, and P. Werner, Phys. Rev. B **99**, 184303 (2019).

SPIN TRANSPORT IN A DISCRETE-TIME HEISENBERG MODEL

M. Ljubotina, L. Zadnik, M. Znidaric, T. Prosen

Department of Physics, Faculty of Mathematics and Physics, University of Ljubljana

12h20 Thu 7

I will present an integrable Trotterization of the Heisenberg spin chain. Specifically, I will focus on the spin transport properties of the model where one can observe diffusion, superdiffusion and ballistic transport, similar to what is seen in the continuous time case. Curiously, in this model ballistic transport also occurs in the easy-axis regime, which I will explain and show a lower bound for the spin Drude weight, which shows fractal behaviour. Lastly, I will show numerical results which suggest that our numerical results in the superdiffusive regime can be described by scaling functions arising from the Kardar-Parisi-Zhang equation.

1. M. Ljubotina, L. Zadnik and T. Prosen, Phys. Rev. Lett. **122**, 150605 (2019).
2. M. Ljubotina, M. Znidaric and T. Prosen, Phys. Rev. Lett. **122**, 210602 (2019).

THEORY OF ENTANGLEMENT TRANSITIONS AND NATURAL ERROR CORRECTION IN QUANTUM SYSTEMS WITH MEASUREMENTS

Ehud Altman

Department of Physics, University of California, Berkeley

A many-body quantum system generally gets increasingly entangled as it evolves under unitary time evolution, reaching a steady state with volume law entanglement entropy. At the same time, measuring the system locally, disentangles the measured qubits. It is natural to ask how many measurements it take to collapse the state into one with only area law entanglement. Recent work suggests that this collapse occurs as a sharp phase transition at a critical rate of measurement. In this talk I will review recent progress in understanding the nature of the measurement induced phase transition. First, I will frame the effect in terms of quantum communication theory as a phase transition in the quantum channel capacity, i.e. the ability of the circuit to transmit coherent quantum information in spite of the measurements. This viewpoint suggests new manifestations of the transition that are more tangible, and perhaps more easily measured than the entanglement entropy. Second, I will present a mapping of the circuit dynamics to a classical statistical mechanics model that can give some more information about the nature of the phase transition and even allow exact solution in a certain limit.

15h00
Thu
8

ENTANGLEMENT ENTROPY OF HIGHLY EXCITED EIGENSTATES OF MANY-BODY LATTICE HAMILTONIANS

M Rigol

Department of Physics, Pennsylvania State University, University Park, Pennsylvania 16802, USA

16h00 Thu 9

The average entanglement entropy of subsystems of random pure states is (nearly) maximal [1]. In this talk, we discuss the average entanglement entropy of subsystems of highly excited eigenstates of integrable and nonintegrable many-body lattice Hamiltonians. For translationally invariant quadratic models (or spin models mappable to them) we prove that, when the subsystem size is not a vanishing fraction of the entire system, the average eigenstate entanglement exhibits a leading volume-law term that is different from that of random pure states [2]. We argue that such a leading term is universal for translationally invariant quadratic models [3]. For the quantum Ising model, we show that the subleading term is constant at the critical field for the quantum phase transition and vanishes otherwise (in the thermodynamic limit); i.e., the critical field can be identified from subleading corrections to the average (over all eigenstates) entanglement entropy [3]. For random pure states with a fixed particle number (away from half filling) and normally distributed real coefficients, we prove that the deviation from the maximal value grows with the square root of the system's volume when the size of the subsystem is one half of that of the system. The behavior of the entanglement entropy of highly excited eigenstates of a particle number conserving quantum chaotic model is found to agree with the analytical results for the random canonical states [4].

1. D. N. Page, Phys. Rev. Lett. 71, 1291 (1993).
2. L. Vidmar, L. Hackl, E. Bianchi, and M. Rigol. Phys. Rev. Lett. **119**, 020601 (2017).
3. L. Vidmar, L. Hackl, E. Bianchi, and M. Rigol. Phys. Rev. Lett. **121**, 220602 (2018).
4. L. Vidmar and M. Rigol. Phys. Rev. Lett. **119**, 220603 (2017).

MEASURING ENTANGLEMENT IN MANY-BODY SYSTEMS VIA THERMODYNAMICS

T. Mendes-Santos[1], G. Giudici[1,2,3], R. Fazio[1,4], M. Dalmonte[1,2]

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2 SISSA, via Bonomea 56, 34151 Trieste, Italy
3 INFN, sezione di Trieste, 34136 Trieste, Italy
4 NEST, Scuola Normale Superiore & Istituto Nanoscienze-CNR, I-56126 Pisa, Italy

Over the last years, the von Neumann entropy (VNE) has become a paradigmatic quantity in the characterization of quantum many-body wave-functions. However, the measurement of the VNE is presently inaccessible to both large scale numerical methods (that do not have a direct access to the wave-function, $|\psi\rangle$) such as quantum Monte Carlo simulations, and to cold atom experiments, where measurement of VNE requires tomographic access to $|\psi\rangle$, which becomes prohibitive beyond few qubits. In this work, we present a method to measure the VNE entropy of ground states of quantum many-body systems which does not require access to the system wave function, and is thus scalable to large system sizes. The technique is based on a direct thermodynamic study of entanglement Hamiltonians, whose functional form is available from field theoretical insights. The method is applicable to classical simulations such as quantum Monte Carlo methods, and to experiments that allow for thermodynamic measurements such as the density of states, accessible via quantum quenches. We benchmark our technique on critical quantum spin chains, and apply it to several two-dimensional quantum magnets, where we are able to unambiguously determine the onset of area law in the entanglement entropy, the number of Goldstone bosons, and to check a recent conjecture on geometric entanglement contribution at critical points described by strongly coupled field theories.

16h35
Thu
10

Friday, 25 October

FRIDAY, 25 OCTOBER **57**
Higgs spectroscopy of unconventional superconductors 57
Classical and quantum liquids induced by quantum fluctuations 58
Mixed-order symmetry-breaking quantum phase transition far from equilibrium 59
Quasiparticles as detector of topological quantum phase transitions 60
Topological multicriticality of spin-orbit coupled electrons in one dimension 61
Violation of horizon by topological quantum excitations 62
Disorder driven multifractality transition in Weyl nodal loops 63

HIGGS SPECTROSCOPY OF UNCONVENTIONAL SUPERCONDUCTORS

R. Shimano[1,2]

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2 Department of Physics, The University of Tokyo, Tokyo, Japan

Superconductors (SCs) driven out-of-equilibrium has attracted growing interests over decades. Aims of these studies are the elucidation of the pairing mechanisms, the understanding of interplay between competing orders, and the revealing of hidden phases. The study of collective excitations arising from fluctuations of amplitude or phase of superconducting order parameter is important for these perspectives as they provides the direct information on the order parameters in equilibrium/non-equilibrium states. Recent developments of ultrafast spectroscopy in the low energy terahertz (1THz∼4meV) frequency range, have enabled the access to these collective modes in a time-resolved manner. In particular, the time-resolved observation of amplitude mode of the order parameter in superconductors, termed as the Higgs mode, in s-wave SCs [1,2] and d-wave T_c cuprate SCs[3] has paved a new pathway to study the nonequilibrium dynamics of SCs. In this presentation, after a brief review of Higgs mode in s-wave SCs, we report on our recent study of Higgs spectroscopy in high-T_c cuprate SCs and iron-based SCs in equilibrium and in nonequilibrium.

9h00
Fri
1

1. R. Matsunaga, Y. I. Hamada, K. Makise, Y. Uzawa, H. Terai, Z. Wang, and R. Shimano, Phys. Rev. Lett. **111**, 057002 (2013).
2. R. Matsunaga, N. Tsuji, H. Fujita, A. Sugioka, K. Makise, Y. Uzawa, H. Terai, Z. Wang, H. Aoki, and R. Shimano, Science **345**, 1145 (2014).
3. K. Katsumi, N. Tsuji, Y. I. Hamada, R. Matsunaga, J. Schneeloch, R. D. Zhong, G. D. Gu, H. Aoki, Y. Gallais, and R. Shimano, Phys. Rev. Lett. **120**, 117001 (2018).

CLASSICAL AND QUANTUM LIQUIDS INDUCED BY QUANTUM FLUCTUATIONS

Miguel M. Oliveira[1], Pedro Ribeiro[1,2], Stefan Kirchner[3]

1 CeFEMA, Instituto Superior Técnico, Universidade de Lisboa Av. Rovisco Pais, 1049-001 Lisboa, Portugal
2 Beijing Computational Science Research Center, Beijing 100193, China
3 Zhejiang Institute of Modern Physics, Zhejiang University, Hangzhou, Zhejiang 310027, China

9h35
Fri
2

Geometrically frustrated interactions may render classical ground-states macroscopically degenerate. The connection between classical and quantum liquids and how the degeneracy is affected by quantum fluctuations is, however, not completely understood. We study a simple model of coupled quantum and classical degrees of freedom, the so-called Falicov-Kimball model, on a triangular lattice and away from half-filling. For weak interactions the phase diagram features a charge disordered state down to zero temperature. We provide compelling evidence that this phase is a liquid and show that it is divided by a crossover line that terminates in a quantum critical point. Our results offer a new vantage point to address how quantum liquids can emerge from their classical counterparts.

1. M. M. Oliveira, P. Ribeiro, S. Kirchner, Phys. Rev. Lett. **122**, 197601 (2019).

MIXED-ORDER SYMMETRY-BREAKING QUANTUM PHASE TRANSITION FAR FROM EQUILIBRIUM

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1 Beijing Computational Science Research Center, Beijing 100193, China
2 CeFEMA, Instituto Superior TÃ©cnico, Universidade de Lisboa, 1049-001, Portugal
3 Zhejiang Institute of Modern Physics, Zhejiang University, 310027, China
4 Zhejiang Province Key Laboratory of Quantum Technology and Devices, Zhejiang University, 310027, China
5 Department of Physics, Beijing Normal University, Beijing 100875, China

The generalization of quantum phase transitions to non-equilibrium conditions raises a number of questions, in particular, if and how out-of-equilibrium critical phenomena can be categorized into universality classes, in analogy with thermal equilibrium. We explore the non-equilibrium steady-state of a transverse magnetic field Ising chain coupled at its ends to magnetic thermal reservoirs. We generalize the phase diagram to non-equilibrium conditions obtained by applying a magnetization bias to the reservoirs [1]. Upon increasing the bias we observe a discontinuous jump of the magnetic order parameter that coincides with a divergent the correlation length. While the first observation is a signature of a first-order transition, in equilibrium, the second arises only for continuous transitions. Thus, our findings show that out-of-equilibrium conditions allow for novel critical phenomena not possible at equilibrium. Moreover, for steady-states with a non-vanishing conductance, the entanglement entropy at the zero temperature was found to have logarithmic corrections that differ from the well-known equilibrium case.

9h55
Fri
3

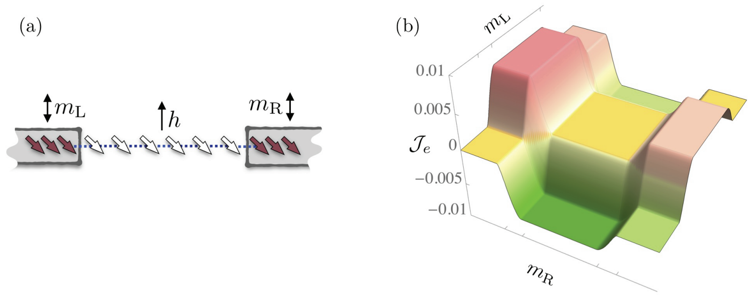

Fig.1: (a) Sketch of the model â transverse field Ising chain coupled at its edges to magnetic reservoirs, L and R, held at magnetizations m_L and m_R respectively. (b) Energy current, $\mathcal{J}_\rceil$, flowing through the chain as function of mL and mR.

1. T. O. Puel and S. Chesi and S. Kirchner and P. Ribeiro, Physical Review Letters 122, 235701 (2019).

* This work was supported by NSFC China, FCT Portugal, and National Key R&D Program of the MOST of China.

QUASIPARTICLES AS DETECTOR OF TOPOLOGICAL QUANTUM PHASE TRANSITIONS

A. E. B. Nielsen

Max-Planck-Institut für Physik komplexer Systeme, D-01187 Dresden, Germany

10h15 Fri 4

Phases and phase transitions provide an important framework to understand the physics of strongly correlated quantum many-body systems. Topologically ordered phases of matter are particularly challenging to investigate, because they are characterized by long-range entanglement and go beyond the Landau-Ginzburg theory. A few tools have been developed to study topological phase transitions, but the needed computations are generally demanding, they typically require the system to have particular boundary conditions, and they often provide only partial information. There is hence a high demand for developing further probes. Here [1], we propose to use the study of quasiparticle properties to detect phase transitions. Topologically ordered states support anyonic quasiparticles with special braiding properties and fractional charge. Being able to generate a given type of anyons in a system is a direct method to detect the topology, and the approach is independent from the choice of boundary conditions. We provide three examples, and for all of them we find that it is sufficient to study the anyon charge to detect the phase transition point. This makes the method numerically cheap.

1. S. Manna, N. S. Srivatsa, J. Wildeboer, and A. E. B. Nielsen, arXiv:1909.02046.

TOPOLOGICAL MULTICRITICALITY OF SPIN-ORBIT COUPLED ELECTRONS IN ONE DIMENSION

Henrik Johannesson

Department of Physics, University of Gothenburg, SE 412 96 Gothenburg, Sweden

The theory of quantum phase transitions (QPTs) is one of the corner stones in the study of quantum matter. A central tenet is that a nonanalyticity in the ground state energy in the thermodynamic limit is a marker of a QPT. In this talk I will report on a finding that challenges this assertion [1]. The phase diagram of a one-dimensional multiband insulator with spin-orbit coupled electrons supports trivial and topological gapped phases separated by intersecting critical surfaces. The intersections define multicritical lines across which the ground state energy becomes nonanalytical but with no phase transition occurring. I propose a simple picture for how multicriticality gives rise to this anomaly.

10h55
Fri
5

[1] M. Malard, D. Brandao, P. E. de Brito, and H. Johannesson, *to appear*.

VIOLATION OF HORIZON BY TOPOLOGICAL QUANTUM EXCITATIONS

I. Kukuljan[1], S. Sotiriadis[1], G. Takács[2]

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2 BME "Momentum" Statistical Field Theory Research Group & BME Department of Theoretical Physics, H-1117 Budapest, Budafoki út 8, Hungary

One of the fundamental principles of relativity is that a physical observable at any space-time point is determined only by events within its past light-cone. In non-equilibrium quantum field theory this is manifested in the way correlations spread through space-time: starting from an initially short-range correlated state, measurements of two observers at distant space-time points are expected to remain independent until their past light-cones overlap, which is usually called the "horizon effect". Surprisingly, we find that in the presence of topological excitations correlations can develop outside of horizon - even between infinitely distant points. We demonstrate this effect in the sine-Gordon model, showing that it can be attributed to the non-local nature of its topological excitations and interpret it as dynamical emergence of entanglement between distant regions of space.

11h30
Fri
6

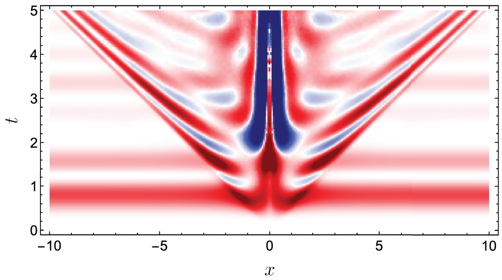

Fig. 1: Horizon violating correlations in the quantum sine-Gordon model emerging from entangled topological excitations.

1. I. Kukuljan, S. Sotiriadis, G. Takács, arXiv:1906.02750 [cond-mat.stat-mech] (2019).

DISORDER DRIVEN MULTIFRACTALITY TRANSITION IN WEYL NODAL LOOPS

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2 Beijing Computational Science Research Center, Beijing 100084, China
3 Centro de Física das Universidades do Minho e Porto, Departamento de Física e Astronomia, Faculdade de Ciências, Universidade do Porto, 4169-007 Porto, Portugal
4 Departamento de Física, Universidade de Évora, P-7000-671, Évora, Portugal

The robustness of certain material properties to perturbations is arguably the most appealing property of topological matter. Topological insulators stood out as an important class of topological materials [1,2] whose stability with respect to interactions and disorder is by now fairly well established [3,4]. Gapless systems can, however, also support non-trivial momentum-space topology and are expected to be less robust to such effects. Among these, are the Weyl nodal loop semimetals, for which the valence and conduction bands linearly touch along one-dimensional (1D) loops in the three-dimensional (3D) momentum space [5]. In this work, we study the effect of short-range disorder in Weyl nodal loop semimetals by numerically exact means. For arbitrary small disorder, a novel semimetallic phase is unveiled for which the momentum-space amplitude of the ground-state wavefunction is concentrated around the nodal line and follows a multifractal distribution. At a critical disorder strength, a semimetal to compressible metal transition occurs, coinciding with a multi- to single-fractality transition. The universality of this critical point is characterized by the correlation length and dynamical exponents. At considerably higher disorder, an Anderson metal-insulator transition is shown to take place. Our results show that the nature of the semimetallic phase in non-clean samples is fundamentally different from a clean nodal loop semimetal.

11h50
Fri
7

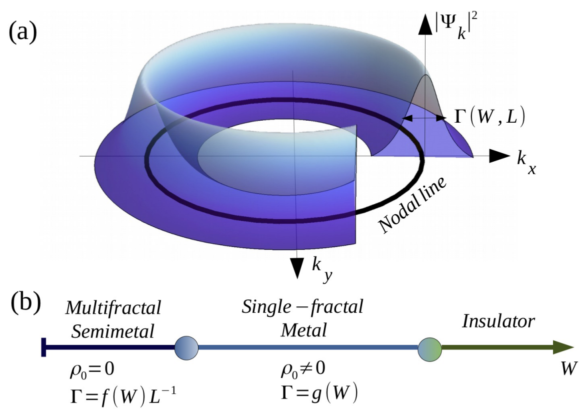

Fig. 1:(a)The Fermi surface of the Weyl nodal loop is a continuous line in the plane $k_z = 0$. The ground-state wavefunction has a width $\Gamma(W, L)$ around the loop, for fixed linear system size (L) and disorder strength (W). (b) Schematic phase diagram as a function of W. For small W, the DOS at $E = 0$ vanishes, $\rho_0 = 0$, and Γ vanishes with L^{-1} – the system is in a multifractal semimetallic phase. For W larger than a critical disorder strength, $\rho_0 \neq 0$ and Γ is L-independent – the system enters a single-fractal metallic phase. For larger W the system becomes an Anderson insulator.

1. M. Z. Hasan and C. L. Kane, Rev. Mod. Phys. **82**, 3045 (2010).
2. X.-L. Qi and S.-C. Zhang, Rev. Mod. Phys. **83** 1057 (2011).
3. C. K. Chiu, J. C. Teo, A. P. Schnyder, and S. Ryu, Rev. Mod. Phys. **88**, 035005 (2016).
4. S. Rachel, Reports Prog. Phys. **81**, 116501 (2018).
5. N. P. Armitage, E. J. Mele, and A. Vishwanath, Rev. Mod. Phys. **90**, 015001 (2018).

ABSTRACTS OF THE POSTER PRESENTATIONS

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EXTENDED NOON STATES

P. F. Alves, A. M. Marques, R. G. Dias

Department of Physics & I3N, University of Aveiro, 3810-193 Aveiro, Portugal

In the context of tight-binding models, there has been recent proposal on the realization of NOON states in a linear chain [1]. These are N-particles bound states characterized by having finite and equal amplitudes only at the end sites of both edges of the chain. Here, we introduce the concept of extended NOON states, denoted by $NOON_L$, where L is the number of edges on which the state is distributed. We show that the generation of these states can be achieved using exact analytical tools [2]. We will focus on the particular
PS-I case of the generation of single-particle $NOON_4$ states in a cross-shaped chain [3], showing how the method can be generalized to arbitrary N particles and L edges.

1

1. E. Compagno, L. Banchi, C. Gross, and S. Bose, Noon states via a quantum walk of bound particles, Physical Review A, vol. 95, no. 1, p. 012307, 2017;
2. A. M. Marques and R. G. Dias, Analytical solution of open crystalline linear 1D tight- binding models, *submitted*;
3. J. Pino, J. D. Gouveia, A. M. Marques, and R. G. Dias, Topological radial states in systems with rotation symmetry, *to be submitted.*

TRACKING TOPOLOGICAL PHASE TRANSITIONS

Syed Tahir Amin[1,2,3]

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2 CeFEMA, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001 Lisboa, Portugal
3 Instituto de Telecomunicações, 1049-001 Lisbon, Portugal

We study the behavior of the fidelity and the Uhlmann connection in one and two- dimensional systems of free fermions with short range [1] as well as long range [2] amplitudes that exhibit non-trivial topological behavior. In particular, we use the fidelity and a quantity closely related to the Uhlmann factor in order to detect phase transitions at zero and finite temperature for topological insulators and superconductors. We show that at zero temperature both quantities predict quantum phase transitions: a sudden drop of fidelity indicates an abrupt change of the spectrum of the state, while the behavior of the Uhlmann connection signals equally rapid change in its eigenbasis. At finite temperature, the topological features are gradually smeared out, indicating the absence of finite-temperature phase transitions, which we further confirm by performing a detailed analysis of the edge states. Moreover, we performed both analytical and numerical analysis of the fidelity susceptibility in the thermodynamic limit, providing an explicit quantitative criterion for the existence of phase transitions. The critical behavior at zero temperature is further analysed through the numerical computation of critical exponents.

PS-I 2

[1]. S. T. Amin, B. Mera, C. Vlachou, N. Paunkovic, and V. R. Vieira, Fidelity and Uhlmann connection analysis of topological phase transitions in two dimensions. Phys. Rev. B, 98:245141, Dec 2018.
[2]. S. T. Amin, B. Mera, N. Paunkovic, and V. Rocha Vieira, Information geometric analysis of long range topological superconductors. Journal of Physics: Condensed Matter, Accepted (2019).

BOUND-STATE SPECTRUM OF AN IMPURITY IN A QUANTUM VORTEX

J. E H. Braz[1], H. Terças[2]

1 CeFEMA, Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal
2 IPFN, Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal

PS-I 3

We consider the problem of finding the bound-state spectrum of an impurity immersed in a weakly interacting two-dimensional Bose-Einstein condensate supporting a single vortex. We obtain approximate expressions for the energy levels and show that, due to the finite size of the condensate, the impurity can access only a finite number of physical bound states. By virtue of the topological quantisation of the vorticity and of the emergence of the Tkachenko lattice, this system is promising as a robust and scalable platform for the realisation of qubits. Moreover, it provides a potentially new paradigm for polaron physics in Bose-Einstein condensates and a glimpse towards the study of quantum turbulence in low-dimensionality systems.

EXCITATION OF GRAPHENE PLASMONS BY LIGHT DIFFRACTION IN METALLIC STRUCTURES

B. S. C. Alexandre[1,2]

1 International Iberian Nanotechnology Laboratory, Braga, Portugal
2 Center of Physics of the University of Minho and the University of Porto, Portugal

We show that is possible to excite graphene surface plasmon polaritons either with the fundamental mode of a waveguide [1] or with the diffraction of a wavepacket by a metallic slit [2]. In both cases we see that the momenta allowed for SPP's are $\frac{n\pi}{2a}$ ($n \neq 0$ and even), which are the same as the evanescent modes of the cavity, β_n, and the energy of this plasmons only depends on the Fermi energy of dopped graphene.

PS-I
4

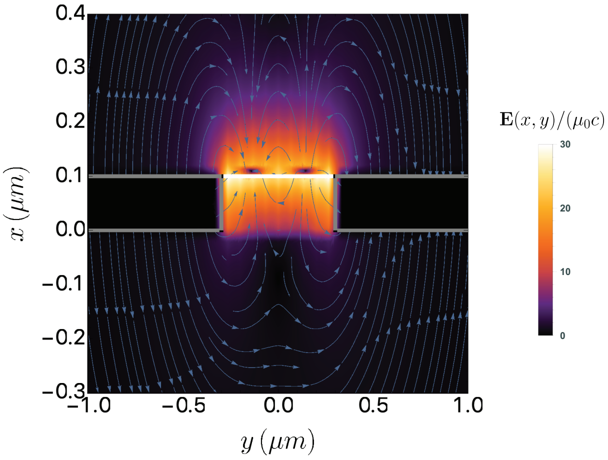

Fig. 1: Stream density plot of the electric fields resulting from the diffraction of a wavepacket by a metallic slit covered with a graphene sheet.

1. D. C. Pedrelli, B. S. C. Alexandre and N. M. R. Peres, *Excitation of SPPs in graphene by a waveguide mode*, EPL Europhysics Letter **126**, (2019)
2. Yu. V. Bludov, N. M. R. Peres, and M. I. Vasilevskiy, *Excitation of localized graphene plasmons by a metallic slit*, (2019).

ISING IN A TRANSVERSE FIELD WITH ADDED TRANSVERSE DZYALOSHINSKII-MORIYA INTERACTION

F. Khastehdel Fumani [1], M. R. Soltani [2], S. Mahdavifar[1]

1 Department of Physics, University of Guilan, 41335-1914 Rasht, Iran,

2 Department of Physics, Azad University of Shahre-rey Branch, Tehran, Iran

A one-dimensional spin-1/2 Ising model in a transverse magnetic field (ITF) with added the transverse Dzyaloshinskii-Moriya (DM) interaction is considered. The Hamiltonian of the model is written as

$$H = J\sum_n S_n^x S_{n+1}^x + \sum_n \overrightarrow{D}\cdot\left(\overrightarrow{S}_n \times \overrightarrow{S}_{n+1}\right) - h\sum_n S_n^z,$$

where $\overrightarrow{S}_n$ is the spin-1/2 operator on the n-th site, h is the transverse magnetic field and $J > 0$ denotes antiferromagnetic coupling constant. The Hamiltonian is exactly diagonalized using the fermionization approach. The energy spectrum, the magnetization and the chiral order parameter are calculated in the thermodynamic limit of the system.

PS-I 5

Analyzing the response functions, the quantum critical points are found. In the absence of the transverse magnetic field, a second order quantum phase transition into the chiral ordered phase is happened. In the presence of the transverse magnetic field, the quantum critical point is changed. Based on obtained results, three phases named chiral, Neel and ferromagnetic are distinguished and the ground state phase diagram has been plotted.

In addition to the response functions, the entanglement [1] and the quantum discord (QD) [2,3] between nearest (NN) and next to nearest neighbor (NNN) pair of spins are also investigated. Regarding the quantum correlations, the existence of different ground state phases has been confirmed. Results have showed where the ground state is in the Neel phase, the entanglement and the QD between NN spins increase by increasing the transverse field. Although the concurrence between NN spins will be maximum close to the critical field, the maximum of the QD placed exactly at the critical point. In the chiral phase, the QD exists between NN spin pairs while no entanglement found between them. In addition, NNN pair spins are not entangled in both Neel and chiral phases. The QD between NNN pair of spins can also separate chiral and ferromagnetic phases at $h = D$ critical points.

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TOPOLOGICAL RADIAL STATES IN SYSTEMS WITH ROTATIONAL SYMMETRY

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Topological phases and edge state topological protection are explicitly related by the bulk-edge correspondence which assumes the existence a real space boundary in 1D, 2D or 3D systems. Extensions of this picture to systems where the boundary is present in the domain of generalized coordinates may generate unusual topological behavior in real space. In this paper, we discuss topological radial states in molecules with rotational symmetry with staggered hopping amplitudes in the radial direction and the dependence of the topological features on the central site orbital. Lower dimensional boundary states ("corner" states) in sliced molecules are also discussed.

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EXCITON-POLARITONS OF A 2D SEMICONDUCTOR LAYER IN A CYLINDRICAL MICROCAVITY

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We describe exciton-polariton modes formed by the interaction between excitons in a nearly twodimensional (2D) layer of a transition metal dichalcogenide (TMD) embedded in a cylindrical microcavity and the microcavity photons. For this, an expression for the excitonic susceptibility of a 2D semiconductor disk placed in the symmetry plane perpendicular to the axis of the microcavity is derived using the second order perturbation theory. Using it, classical electrodynamics provides dispersion relations for the polariton modes, while the quantum-mechanical treatment of a simplified model yields the Hopfield coefficients[1] that measure the degree of exciton-photon mixing in the coupled modes. The density of states (DOS) and its projection onto the photonic subspace are calculated taking monolayer MoS2 embedded in a silica cylinder as an example. The calculated results demonstrate enhancement of the local DOS (Purcell effect[2]) for some values of angular momentum (μ), caused by the presence of the 2D layer. The effect is stronger than in a planar cavity that has been considered before[3].

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MAGNETIZATION AND ENTANGLEMENT AFTER A GEOMETRIC QUENCH IN THE XXZ CHAIN

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We consider the XXZ spin chain in the gapless regime and study magnetization and entropy profiles after a geometric quench. This quench is realized by preparing the ground states with zero and maximum magnetizations on the two halves of a chain and letting it evolve subsequently. The magnetization profiles during time evolution are studied numerically by tDMRG and compared to the predictions obtained from generalized hydrodynamics (GHD). We find that the GHD description of the dynamics provides a very good agreement with the numerical data. Furthermore, entanglement entropy profiles are also studied, finding a closed form expression in the non-interacting XX case. For the general interacting case, the propagation velocities of the entropy fronts are studied both before and after the reflection from the boundaries. Finally, we also study the relationship between magnetization fluctuations and entanglement entropy. PS-I 8

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IMPACT OF STRONG CORRELATIONS ON A BAND TOPOLOGICAL INSULATOR ON THE LIEB LATTICE

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The Lieb lattice possesses three bands and with intrinsic spin orbit coupling λ, supports topologically non-trivial band insulating phases. At half filling the lower band is fully filled, while the upper band is empty. The chemical potential lies in the flat band (FB) located at the middle of the spectrum, thereby stabilizing a flat band insulator. At this filling, we introduce on-site Hubbard interaction U on all sites. Within a slave rotor mean field theory we show that, in spite of the singular effect of interaction on the FB, the three bands remain stable up to a fairly large critical correlation strength (U_{crit}), creating a correlated flat band insulator. Beyond U_{crit}, there is a sudden transition to a Mott insulating state, where the FB is destroyed due to complete transfer of spectral weight from the FB to the upper and lower bands. We show that all the correlation driven insulating phases host edge modes with linearly dispersing bands along with a FB passing through the Dirac point, exhibiting that the topological nature of the bulk band structure remains intact in presence of strong correlation. Furthermore, in the limiting case of U introduced only on one sublattice where $\lambda = 0$, we show that the Lieb lattice can support mixed edge modes containing contributions from both spinons and electrons, in contrast to purely spinon edge modes arising in the topological Mott insulator.

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COMPACT EDGE STATES IN GEOMETRICALLY FRUSTRATED WEAK TOPOLOGICAL INSULATORS

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Topologically non-trivial phases are linked to the appearance of localized modes in the boundaries of an open insulator. On the other hand, the existence of geometric frustration gives rise to degenerate localized bulk states. The interplay of these two phenomena may, in principle, result in an enhanced protection/localization of edge states. In this paper, we study a two-dimensional Lieb-based topological insulator with staggered hopping parameters and diagonal open boundary conditions. This system belongs to the C_{2v} class and sustains 1D boundary modes except at the topological transition point, where the C_{4v} symmetry allows for the existence of localized (0D) corner states. Our analysis reveals that, while a large set of boundary states have a common well defined topological phase transition, other edge states reflect a topological non-trivial phase for any finite value of the hopping parameters, are completely localized (compact) due to destructive interference and evolve into corner states when reaching the higher symmetry point. We consider the robustness of these compact edge states with respect to time-dependent perturbations and indicate ways that these states could be prepared and measured in experiments with ultracold atoms.

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ANALYTICAL SOLUTION OF OPEN CRYSTALLINE LINEAR 1D TIGHT-BINDING MODELS

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A method for finding the exact analytical solutions for the bulk and edge energy levels and corresponding eigenstates for all commensurate Aubry-André/Harper single-particle models under open boundary conditions is presented here, both for integer and non-integer number of unit cells [1]. The derivation follows from the properties of the Hamiltonians of these models, all of which can be written as Hermitian block-tridiagonal Toeplitz matrices [2]. The concept of energy spectrum is generalized to incorporate both bulk and edge bands. The method is then extended to solve the case where one of these chains is coupled at one end to an arbitrary cluster/impurity.

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INVESTIGATING A DISORDERED CHERN INSULATOR

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Robustness against disorder is a defining property of topological phases. In a topological insulator (TI) , the edge states are immune to backscattering under weak disorder and are topologically protected. However, for sufficiently strong disorder the band gap closes and the system becomes topologically trivial in accordance with the theory of Anderson localisation. We use a framework of Transfer matrices to investigate the QWZ model [1] of a two dimensional Chern Insulator, a TI that shows Quantum Anamolous Hall Effect and falls in the Unitary symmetry class 'A', in the presence of 'onsite' disorder. A global phase diagram for the system is established numerically and employing scaling analysis of the localisation length [2], the critical exponent of the insulator-TI transition is calculated. We find that the location of the phase boundaries is renormalised by disorder and a Topological Anderson Insulator (TAI) phase emerges in the system. The emergence of a TAI phase indicates that protected edge states can be induced, rather than inhibited, by the addition of sufficient disorder to a topologically trivial insulator. Hence, it exemplifies the complex relationship between topology and disorder.

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THERMALIZATION/RELAXATION IN INTEGRABLE AND FREE FIELD THEORIES: AN OPERATOR THERMALIZATION HYPOTHESIS

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Free or integrable theories are often considered to be too constrained to thermalize. For example, the retarded two-point function of a free field, even in a thermal state, does not decay to zero at long times. On the other hand, the magnetic susceptibility of the critical transverse field Ising is known to thermalize, even though that theory can be mapped by a Jordan-Wigner transformation to that of free fermions. We reconcile these two statements by clarifying under which conditions conserved charges can prevent relaxation
PS-I at the level of linear response and how such obstruction can be overcome. In particular, we give a necessary
13 condition for the decay of retarded Greenâs functions. We give explicit examples of composite operators in free theories that nevertheless satisfy that condition and therefore do thermalize. We call this phenomenon the Operator Thermalization Hypothesis ("OTH") [1]. Using exact diagonalization for the Ising chain (in both integrable and non-integrable regimes), we can compare OTH to the usual eigenstate thermalization hypothesis and highlight some similarities as well as differences [2].

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TOPOLOGICAL INSULATORS: FROM CONVENTIONAL TO HIGHER-ORDER

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Here we will give an overview of topological insulators (TI), ranging from conventional to higher-order. Conventional TIs are d-dimensional models that exhibit $d-1$ edge states under open boundary conditions (OBC) [1]. These can be further subdivided in two categories, strong and weak TIs, where the topological invariant able to predict the existence of these states is d- and $(d-1)$-dimensional for strong and weak TIs, respectively. On the other hand, higher-order TIs are a recently discovered class of TIs that exhibit $(d-n)$ dimensional edge states under OBC, with $n \geq 2$ [2]. For strong TIs we will study the 1D SSH model and the 2D Haldane model [3]. For weak TIs we will study the 2D SSH model and show how, by introducing magnetic flux, this model becomes a higher-order TI [4]. The relevant topological invariant for each case is presented, and its quantified change across a critical gap closing point is related to the topological transition between trivial and non-trivial phases.

PS-I 14

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MANY-BODY COMPACT LOCALIZED STATES IN INTERACTING GEOMETRICALLY FRUSTRATED SYSTEMS

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Many-body localized states are shown to exist in geometrically frustrated lattices if the interacting Hamiltonian generates a network of transition matrix elements between many-body Wannier states with bubble-like structures. We show that such structures occur in the $U/t = \infty$ Hubbard model on the Lieb lattice and hole localized eigenstates of these models are standing waves in these bubbles. These bubble-like standing waves constitute an interesting many-body generalization of the concept of most compact localized state. The full set of hole localized states of the $U/t = \infty$ Hubbard model on the Lieb lattice is constructed and the general expression of the number of one-hole localized states with one flipped spin is given for clusters with arbitrary shape. We also show how to construct interacting many-body Hamiltonians, starting from the non-interacting tight-binding Hamiltonians, that preserve or even expand susbspaces of localized states. The methods involve modifications in the one-body network representation of the many-body Hamiltonians which generate new interacting terms in these Hamiltonians. Furthermore, we present numerical methods for the determination of many-body localized states that allows one to address larger clusters and larger number of particles than those accessible by full diagonalization of the interacting Hamiltonian.

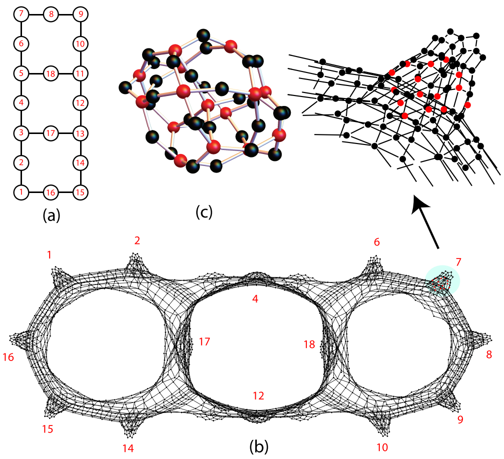

Fig. 1: Lieb-1×3 cluster with indexed sites. (b) Network corresponding to the Hamiltonian for the Lieb-1×3 cluster with two holes and one flipped spin (in a ferromagnetic background). The localized states in the network are standing waves in bubbles, like the one shown in (c), which is a set of interlocked rings (single-particle standing waves) in the network. The small bubbles in (b) generate localized states with a fixed flipped spin at the site indicated by the number next to the bubble, according to the labellings shown in (a).

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A SCANNING MICROSCOPY STUDY ON THE ORIGIN OF ANOMALOUS TRANSPORT IN CORRUGATED GRAPHENE NANORIBBONS

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Graphene nanoribbons are a class of the many fundamental structures constructed out of graphene. Their electronic properties are mostly dominated by edge states and confinement effects. In the past, 40 nm wide sidewall graphene nanoribbons have been shown to facilitate low resistance electron transport, which furthermore is independent of probe spacing up to distances of 10μ m. Although this resembles ballistic transport, ballistic transport typically happens in very narrow ribbons. Topology measurements with STM however show that the ribbons are corrugated across their width, creating small strips of graphene, the coupling between which depends on the curvature of the corrugation. Quasi one-dimensional systems provide a platform for non Fermi-liquid physics. Scanning tunneling microscopy and spectroscopy are used to investigate the local density of states in order to determine whether the corrugation results in decoupled quasi one-dimensional systems or if the ribbon has the character of bulk graphene. Ultimately the goal is to find the origin of the anomalous transport properties of these wide graphene nanoribbons.

PS-I 16

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THE ANTIFERROMAGNETIC PHASE OF THE FLOQUET-DRIVEN HUBBARD MODEL

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We present a saddle point plus fluctuations analysis of the periodically driven half-filled two-dimensional Hubbard model. For drive frequencies below the equilibrium gap, we find discontinuous transitions to time-dependent solutions. A highly excited, generically non-thermal distribution of magnons occurs even for drive frequencies far above the gap. Above a critical drive amplitude, the low-energy magnon distribution diverges as the frequency tends to zero and antiferromagnetism is destroyed, revealing the generic importance of collective mode excitations arising from a non-equilibrium drive.

Poster session II

POSTER SESSION II **84**
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HYBRID MAGNON-PLASMON MODES IN ANTIFERROMAGNET HETEROSTRUCTURES

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We consider a hybrid structure [1] formed by graphene and an insulating antiferromagnet, separated by a dielectric of thickness up to $d \simeq 500\,nm$. When uncoupled, both graphene and the antiferromagneic surface host their own polariton modes coupling the electromagnetic field with plasmons in the case of graphene, and with magnons in the case of the antiferromagnet. We show that the hybrid structure can host two new types of hybrid polariton modes. First, a surface magnon-plasmon polariton whose dispersion is radically changed by the carrier density of the graphene layer, including a change of sign in the group velocity. Second, a surface plasmon-magnon polariton formed as a linear superposition of graphene surface plasmon and the antiferromagnetic bare magnon. This polariton has a dispersion with two branches, formed by the anticrossing between the dispersive surface plasmon and the magnon. We discuss the potential these new modes have for combining photons, magnons, and plasmons to reach new functionalities.

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DIMENSIONAL CROSSOVER IN QUASI-1D SYSTEMS

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Dimensional crossover in interacting electronic systems is a complex phenomenon which can directly impact the competition between superconducting and insulating phases in unconventional superconductors (USCs). It is usually difficult to study dimensional crossover quantitatively due to the fermionic nature of the problem. Working our way towards a quantitative description of the case of spinful electrons, here we consider an 2D array of one-dimensional hard-core bosons (HCBs) with repulsive nearest-neighbour interactions. It is a simplest-case analysis where the HCBs model the electron-pairs in e.g. a quasi-1D USC such as the Bechgaard and Fabre salts, which will serve as a paradigm for more complex models.

Static Mean-Field (SMF) theory is combined with Density Matrix Renormalization Group (DMRG) to reduce the full 3D to a self-consistently treated 1D one, enabling calculation of ground and thermal equilibrium states. This approach is motivated by the low cost of such an implementation. Using DMRG also allows the simulation real-time/frequency dynamics. PS-II 2

We find this model exhibiting the paradigmatic phase transition from a 3-dimensional superfluid (SF) to a 1-dimensional Mott insulator (MI) that forms the basis of the more complex behavior in the USCs. Interestingly, the order parameters indicating the different phases suggest a mix between first- and second-order transitions.

Our goal with this work is to quantitatively compute the critical temperature for models of this type as a function of the microscopic parameters. Such theory will find application in work with e.g. ultra-cold atomic and dipolar gases and weakly coupled Tomonaga-Luttinger liquids (TLL)

DETERMINATION OF UNIVERSAL CRITICAL EXPONENTS USING LEE-YANG THEORY

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Lee-Yang zeros are points in the complex plane of an external control parameter at which the partition function vanishes for a many-body system of finite size. In the thermodynamic limit, the Lee-Yang zeros approach the critical value on the real-axis, where a phase transition occurs. Partition function zeros have for many years been considered a purely theoretical concept, however, the situation is changing now as Lee-Yang zeros have been determined in several recent experiments. Motivated by these developments, we here devise a direct pathway from measurements of partition function zeros to the determination of critical points and universal critical exponents of continuous phase transitions. To illustrate the feasibility of our approach, we extract the critical exponents of the Ising model in two and three dimensions from the fluctuations of the total energy and the magnetization in lattices of finite size. Importantly, the
PS-II critical exponents can be determined even if the system is away from the phase transition. Moreover, in
3 contrast to standard methods based on Binder cumulants, it is not necessary to drive the system across the phase transition. As such, our method provides an intriguing perspective for investigations of phase transitions that may be hard to reach experimentally, for instance at very low temperatures or at very high pressures. Our method can not only be applied to equilibrium phase transitions but also non-equilibrium situations such as space-time phase transitions in glass formers and dynamical phase transitions in quantum many-body systems after a quench. The method may also provide a novel pathway towards the detection of quantum phase transitions in quantum computers and simulators.

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FORMATION OF BOUND STATES IN A 1D TOMONAGA-LUTTINGER LIQUID WITH ATTRACTIVE INTERACTIONS

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We study the formation of bound states in a one-dimensional, single-component Fermi chain with attractive interactions. The phase diagram, computed from DMRG (density matrix renormalization group), shows not only a superfluid of paired fermions (pair phase) and a liquid of three-fermion bound states (trion phase), but also a phase with two gapless modes. We show that the latter phase is described by a 2-component Tomonaga-Luttinger liquid (TLL) theory, consisting of one charged and one neutral mode. We argue based on our numerical data, that the single, pair, and trion phases are descendants of the 2-component TLL theory. In one sentence, we demonstrate the emergence of a neutral field as a mechanism of bound-states formation.

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DISCRETE AND GENERALIZED PHASE SPACE TECHNIQUES IN CRITICAL QUANTUM SPIN CHAINS

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We apply the Wigner function formalism from quantum optics via two approaches, Wootters' discrete Wigner function and the generalized Wigner function, to detect quantum phase transitions in critical spin-$\frac{1}{2}$ systems. We develop a general formula relating the phase space techniques and the thermodynamical quantities of spin models, which we apply to single, bipartite and multi-partite systems governed by the XY and the XXZ models. Our approach allows us to introduce a novel way to represent, detect, and distinguish first-, second- and infinite-order quantum phase transitions. Furthermore, we show that the factorization phenomena of the XY model is only directly detectable by quantities based on the square root of the bipartite reduced density matrix. We establish that phase space techniques provide a simple, experimentally promising tool in the study of many-body systems and we discuss their relation with measures of quantum correlations and quantum coherence.

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MACROSCOPIC AND MICROSCOPIC FUNCTIONS OF THE GROUND STATE IN SPIN-1/2 TRANSVERSE ANNNI CHAINS

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We focuse on the ground state phase diagram of a one-dimensional spin-1/2 quantum Ising model with competing first and second nearest neighbour interactions known as the ANNNI model in the presence of a transverse magnetic field. Due to contradictory results obtained by different approaches, there is no clear picture of its phase diagram at zero temperature. Here, using numerical and analytical approaches, some important evidence is provided which is helpful to clarify the identification of the ground state phase diagram. According to numerical Lancsoz results, the critical lines and the order of phase transitions are determined by the study of some proper ground state functions and quantum correlations of the system. All studied quantities identify the two ferromagnetic-paramagnetic and antiphase-floating boundary lines. Quantum correlations play a crucial role in the detecting of two other phase transitions. The Peschel-Emery one-dimensional line can be identified by the quantum discord and its derivative. The entanglement of formation is also the only quantity able to magnificently reveal the fourth boundary line regarding the floating-paramagnetic phase transition. Our results obtained using the Jordan-Wigner transformation confirm the accuracy of the numerical ones.

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TRANSPORT THROUGH PERIODICALLY DRIVEN SYSTEMS

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Periodic drives have been receiving renewed attention as the building blocks of new phases of matter such as topological non-trivial states and time crystals. The dynamics of these new non-equilibrium phases is quite different from their equilibrium counterparts. When isolated, the evolution is strongly dependent on its initial condition. Yet, it is hard to imagine that such a regime can be experimentally probed in electronic systems, due to their short decay-times. In practice, it is expected that the state created after a long period of driving will be determined by the systemâs environment. We will consider electronic systems whose main thermalization mechanism is due to the contact with metallic leads. We will use this setup to probe transport through periodically driven systems in particular when the Floquet band structure acquires a non-trivial topology.

NUCLEAR MAGNETIC RESONANCE IN WEYL SEMIMETALS

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We focus on the hyperfine coupling and the NMR spin-lattice relaxation time, T_1 in Weyl semimetals. In these systems, the density of states varies with the square of the energy around the Weyl node. The naive power counting suggests a $1/T_1T \sim E^4$ scaling with E the maximum of temperature (T) and chemical potential. By carefully investigating the hyperfine interaction between nuclear spins and Weyl fermions, we PS-II find that its spin part behaves conventionally, while its orbital part diverges unusually with the inverse of 8 energy around the Weyl node. Consequently, the nuclear spin relaxation rate scales as $1/T_1T \sim E^2 \ln(E/\omega_L)$ with ω_L the nuclear Larmor frequency. We also analyze the experimental data on the spin-lattice relaxation rate of TaP crystal. The non-monotonic temperature dependence is explained by taking into account the temperature dependence of chemical potential. The anomalous behavior of T_1 allows us to introduce an effective hyperfine coupling constant, which is tunable by gating or doping.

INTERACTING FERMIONS IN ONE DIMENSIONAL LATTICES WITH HIGHLY DEGENERATE ENERGY LEVELS

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PS-II 9

We discuss the single-particle and many-particle physics of interacting spinless fermions in presence of disorder in one dimensional lattices with high degeneracy in the single-particle spectrum in absence of disorder. The single particle spectrum shows the presence of two distinct localized phases in the low and high disorder regimes, which are characterized by different localization strength. Turning on interaction introduces three phases in the many-body system based on the interaction strength, which shows a mixed phase and a localized phase separated by a delocalized phase. Especially, the small disorder regime shows interesting behavior for such systems. The effect of degeneracy of the clean system on the many body localization brings forth interesting properties. All the single-particle and many-particle results are assisted by the non-equilibrium dynamics of entanglement entropy and experimentally more relevant quantities such as revival probability and imbalance parameter. We further analyze the change in the mentioned phase diagram as function of the interaction, number of fermions and system size. We then comment on the thermodynamic limit.

1. J. Vidal *et al.*, Phys. Rev Lett. **85**, 18 (2004).
2. D. Leykam *et al.*, Eur. Phys. J. B **90**, 1 (2017).
3. P. Shukla, Phys. Rev. B **98**, 054206 (2018).

NON-LOCAL EMERGENT HYDRODYNAMICS IN A LONG-RANGE QUANTUM SPIN SYSTEM

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Generic short-range interacting quantum systems with a conserved quantity exhibit universal diffusive transport at late times. We show how this universality is replaced by a more general transport process in the presence of long-range couplings that decay algebraically with distance as $r^{-\alpha}$ [1]. While diffusion is recovered for large exponents $\alpha > 1.5$, longer-ranged couplings with $0.5 < \alpha \leq 1.5$ give rise to effective classical Lévy flights; a random walk with step sizes following a distribution which falls off algebraically at large distances. We investigate this phenomenon in a long-range interacting XY spin chain, conserving the total magnetization, at infinite temperature by employing non-equilibrium quantum field theory and semi-classical phase-space simulations. We find that the space-time dependent spin density profiles are self-similar, with scaling functions given by the stable symmetric distributions. As a consequence, autocorrelations show hydrodynamic tails decaying in time as $t^{-1/(2\alpha-1)}$ when $0.5 < \alpha \leq 1.5$. We also extract the associated generalized diffusion constant, and demonstrate that it follows the prediction of classical Lévy flights; quantum many-body effects manifest themselves in an overall time scale depending only weakly on α. Our findings can be readily verified with current trapped ion experiments. PS-II 10

1. Alexander Schuckert, Izabella Lovas, Michael Knap, arXiv: 1909.01351.

TEMPERATURE DRIVEN MULTIPLE PHASE TRANSITIONS AND QUADRUPOLAR ORDER IN β-TEVO$_4$

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We present a microscopic understanding of the magnetic phase diagram of β-TeVO$_4$ in terms of a minimal anisotropic Heisenberg model. Using cluster mean field approach to capture quantum correlations we find, upon reducing temperature in the absence of applied field, (i) a partially ordered state, (ii) a collinear antiferromagnetic phase, and (iii) an elliptical spiral state characterized by finite vector chirality. The sequence of occurrence of these phases and the orders of the corresponding phase transitions are in excellent agreement with experiments[1,2]. For finite fields, we find metamagnetic response close to saturation magnetization as reported in the experiments. We show via explicit calculations that the quadrupolar order parameter is finite in the metamagnetic regime.

1. M. Pregelj et al., Nat. Commun. 6, 7255 (2015).
2. F. Weickert et al., Phys. Rev. B 94, 064403 (2016).

SINGLE-PARTICLE EXCITATION CONTENT AS A MEASURE OF ELECTRONIC CORRELATION AND ITS RELATION TO EIGENSTATE THERMALIZATION

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Quantum simulation of small physically realizable systems (e.g. chains of precision-placed dopant atoms in silicon or atoms on surfaces, STM-created dangling bonds, or cold atoms in optical lattices) provides an opportunity to learn about many-body physics at larger scales. The exact study of small systems can guide us toward relevant measures for extracting information about many-body physics as we move to larger and more complex systems capable of quantum information processing or quantum analog simulation. We use exact diagonalization to study many electrons in short 1-D atom chains represented by long-range extended Hubbard-like models. We introduce a novel measure, the Single-Particle Excitation Content (SPEC) of an eigenstate and show that the dependence of SPEC on energy reveals the nature of the ground state (ordered phases), and the onset and saturation of correlation between the electrons as Coulomb interaction strength increases. We use this SPEC behavior to identify five regimes: a non-interacting single-particle limit, a regime of perturbative Coulomb interaction in which the SPEC is a nearly universal function of energy, the onset and saturation of correlation, a regime of fully correlated states in which hopping is a perturbation and SPEC is a different universal function of energy, and the limit of no hopping. While SPEC is a quantity that can be calculated for small exactly diagonalizable systems, it guides our intuition for larger systems, suggesting the nature of excitations and their distribution in the spectrum.

For a broad range of Coulomb interaction strengths (in the regimes of perturbative Coulomb interaction and onset of correlation) the SPEC as a function of energy takes the form of a Fermi function. This suggests a relation to the Eigenstate Thermalization Hypothesis (ETH). To investigate this relationship, we compare the behavior of SPEC to various markers of thermalization (thermal behavior of entanglement entropy, energy level statistics, local measurement outcomes). The regime of thermalization is arguably narrower than the regime of the universal function and the SPEC of a single eigenstate is not the same as the SPEC of the relevant thermal mixture. However the most thermal regime of the parameter space corresponds to the best fit of SPEC to a Fermi function, as shown in the figure. It remains an open question whether ETH is the source of the Fermi function behavior of SPEC.

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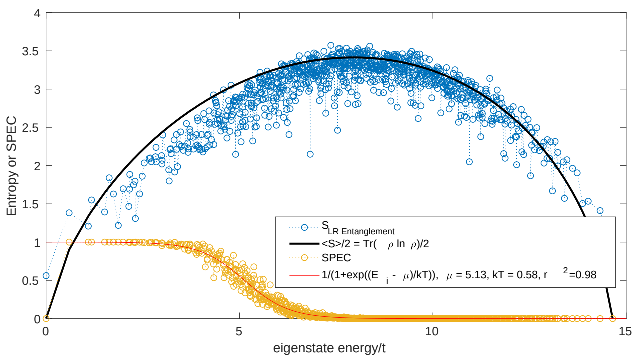

Fig. 1: Single Particle Excitation Content (SPEC), Entanglement Entropy ($S_{LREntanglement}$) and Thermal Entropy ($< S > /2$) vs. Eigenstate Energy divided by hopping (E/t) for the thermal regime of a long-range extended Hubbard model. The correspondence of thermal and entanglement entropies coincides with Fermi-like behavior of SPEC.

QUANTUM MANY-BODY SCARS FROM A SINGLE PARTICLE PERSPECTIVE

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We study the emergence and physical consequences of so called quantum many-body scars which are special eigenstates in the spectrum of quantum many-body Hamiltonians. Such states are believed to be associated with special properties such as low entanglement entropy and have been identified in certain quantum non-integrable models, most prominently the so-called PXP model[1] recently realized in quantum simulators using optical tweezer arrays and Rydberg atoms[2]. We have developed a systematic and intuitive approach for constructing these eigenstates by drawing an analogy between the quantum scars of single particles in real space and that of the state evolution on a graph representing the many-body Hilbert space. The quantum many-body scars are then defined as sparse eigenstates extended in this Hilbert space. This allows us to identify suitable initial states for quench experiments probing the physics, such as the lack of thermalization, associated with the many-body scar states. In order to demonstrate the universality of the developed framework, we apply it to a number of examples in particular constrained spin models, which are realized in quantum simulators with Rydberg atoms.

1. C. J. Turner et al, Nat. Phys., **14**, 745-749 (2018).
2. H. Bernien et al, Nature, **551**, 579-584 (2017)

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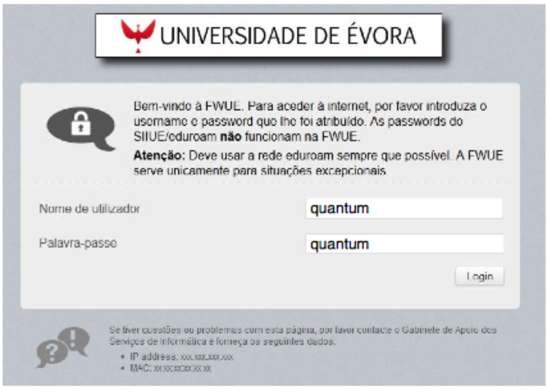

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