DY 42: Focus: Many-Body Quantum Chaos

The inter-relation between the complex time evolution of interacting many-body quantum systems and the corresponding often classically chaotic, high-dimensional dynamics of their classical counterparts has received increasing interest in various fields in the recent past, ranging from quantum statistical mechanics and quantum chaos via atomic and condensed quantum matter to high energy physics. This Focus Session will comprise recent developments and different perspectives in this emerging research area.

Andreas Buchleitner, Thomas Guhr, Klaus Richter

Time: Thursday 9:30–13:00 Location: H20

Invited Talk DY 42.1 Thu 9:30 H20

Quantum dynamics in strongly correlated one-dimensional Bose gases — •Hanns-Christoph Nägerl — Institut für Experimentalphysik, Universität Innsbruck, A-6020 Innsbruck

We have experimentally studied the dynamics of strongly correlated bosonic quantum gases confined to a one-dimensional (1D) geometry, with focus on two different model systems. We have realized 1D Hubbard chains and have studied correlated tunneling dynamics when the many-body system is suddenly exposed to a strong force. This has allowed us to observe how interacting quantum particles prepared in the Mott-insulating phase tunnel through multiple wells of the lattice potential in a situation where a single particle cannot move at all [1]. Our studies further comprise the coherent evolution of an interacting superfluid that exhibits Bloch-oscillations modulated by interaction-driven collapse and revival dynamics [2]. In a certain parameter regime, the transition to quantum chaotic behavior can be observed. The second system of interest constitutes a uniform Luttinger liquid with highly tunable interactions. We have probed the dynamics of a strongly coupled impurity atom injected into the liquid and have found an intriguing Bloch-oscillation type motion induced in the correlated system in the absence of an imprinted lattice structure [3].

[1] F. Meinert et al., Science 344, 1259 (2014). [2] F. Meinert et al., Phys. Rev. Lett. 112, 193003 (2014). [3] F. Meinert et al., Science 356, 945 (2017).

Invited Talk DY 42.2 Thu 10:00 H20

Extreme Decoherence and Quantum Chaos — Zhenyu Xu[1,2], Aurélia Chenu[3,4], Luis Pedro García-Pintos[2], Javier Molina-Vilaplana[5], and •Adolfo Del Campo[3,4] — [1]School of Physical Science and Technology, Soochow University, Suzhou 215006, China — [2]Department of Physics, University of Massachusetts, Boston, MA 02125, USA — [3]Donostia International Physics Center, E-20018 San Sebastián, Spain — [4]IKERBASQUE, Basque Foundation for Science, E-48013 Bilbao, Spain — [5]Technical University of Cartagena, UPCT, 30202, Cartagena, Spain

We study the ultimate limits to the decoherence rate associated with dephasing processes. Fluctuating chaotic quantum systems are shown to exhibit extreme decoherence, with a rate that scales exponentially with the particle number, thus exceeding the polynomial dependence of systems with fluctuating k-body interactions. Our findings suggest the use of quantum chaotic systems as a natural test-bed for spontaneous wave function collapse models. We further discuss the implications on the decoherence of AdS/CFT black holes resulting from the unitarity loss associated with energy dephasing [1]. To conclude, we shall elucidate the connection between quantum work statistics, Loschmidt echo dynamics and information scrambling in chaotic quantum systems [2].

Bibliography:

[1] Zhenyu Xu, Luis Pedro García-Pintos, Aurélia Chenu, Adolfo del Campo, Phys. Rev. Lett. 122, 014103 (2019).

[2] Aurélia Chenu, Javier Molina-Vilaplana, Adolfo del Campo, arXiv:1804.09188 (2018).

DY 42.3 Thu 10:30 H20

Many-Body Quantum Interference and the Saturation of Out-of-Time-Order Correlators — •Josef Rammensee, Juan Diego Urbina, and Klaus Richter — Institut für Theoretische Physik, Universität Regensburg, Germany

Out-of-time-ordered correlators $\langle[\hat{V},\hat{W}(t)]^\dagger[\hat{V},\hat{W}(t)]\rangle$ have been found to be highly suitable tools to identify the onset of chaos in many-body quantum systems[1]. Contrary to already known indicators, the unusual time ordering of the operators is able to directly capture the local hyperbolic nature of the classical counterpart as one expects an exponential increase at short times with a rate related to classical Lyapunov exponents. Numerical studies in chaotic systems[2] further indicate a saturation after the time scale for the classical-to-quantum-crossover, known as Ehrenfest or scrambling time. We provide insight into the physical origin of the exponential growth and the saturation by using semiclassical methods based on the Van-Vleck-propagator for single- and many-body systems[3]. We show[4] that the notion of interfering classical trajectories is well suited to provide a quantitative picture and we explicitly discuss the emergence of the Lyapunov exponent, and the relevant time scales.

[1] Maldacena, Shenker, and Stanford, JHEP 2016:106 (2016)
[2] Rozenbaum, Ganeshan, Galitski, PRL **118**, 086801 (2017)
[3] Engl, Dujardin, Argüelles, Schlagheck, Richter, J. D. Urbina, PRL **112**, 140403 (2014)
[4] Rammensee, Urbina, Richter, PRL **121**, 124101 (2018)

DY 42.4 Thu 10:45 H20

Many-body Multifractality in Fock space for Interacting Bosons — Jakob Lindinger, Andreas Buchleitner, and •Alberto Rodríguez — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany

We analyse the many-body multifractality of the Bose-Hubbard Hamiltonian's eigenstates in Fock space, for arbitrary values of the interparticle interaction. For the ground state, generalized fractal dimensions unambiguously signal, even for small system sizes, the emergence of a Mott insulator. We show that the scaling of the derivative of any generalised fractal dimension with respect to the interaction strength encodes the critical point of the superfluid to Mott insulator transition, and we establish that the transition can be quantitatively characterized by one single wavefunction amplitude from the exponentially large Fock space [1]. Furthermore, multifractality of the excited eigenstates is investigated and the possible existence of localization in Fock space is thoroughly studied.

[1] J. Lindinger, A. Buchleitner, A. Rodríguez, arXiv:1810.06369

DY 42.5 Thu 11:00 H20

Particle-Evolution Operator in Spin Chains with Spin 1/2 — •Daniel Waltner[1], Maram Akila[1], Boris Gutkin[2], and Thomas Guhr[1] — [1]Fakultät für Physik, Universität Duisburg-Essen, Lotharstr. 1, 47048 Duisburg — [2]Department of Applied Mathematics, Holon Institute of Technology, 58102 Holon, Israel

A major difficulty in describing interacting many-body systems is the enormous size of the Hilbert space: usually it grows exponentially with the number of particles. In order to overcome this difficulty I will introduce in my talk an evolution in *particle* instead of *time* direction. The dimension of the particle-evolution operator grows exponentially with *time* making it especially appropriate to describe the short-time dynamics of the system. I will consider a chain of spin 1/2 particles with nearest neighbor Ising interaction and on-site magnetic field. I will discuss the properties of this particle-evolution operator and the spectral form factor that is used to analyze the correlation properties of the eigenvalues of the underlying quantum system.

DY 42.6 Thu 11:15 H20

Scrambling and quantum butterfly effect in critical systems: instability vs. chaos — •Benjamin Geiger, Quirin Hummel, Juan Diego Urbina, and Klaus Richter — Universität Regensburg

The investigation of scrambling of information in interacting quantum systems has recently attracted a lot of attention as a manifestation of many-body quantum chaos. However, it has been demonstrated that certain integrable systems that are subject to quantum phase transitions allow for fast information scrambling if they are tuned close to their critical point [1]. To investigate the origin of this quasi-chaotic behavior we studied a momentum-truncated model of an attractive one-dimensional Bose gas using established semiclassical methods. We find that the quantum critical behavior has its origin in the appearance of a separatrix in the classcial phase space that renders the classical dynamics locally unstable. This leads to quasichaotic features the underlying quantum system, i.e., a fast growth of multiparticle entanglement and exponential growth of certain out-of-time ordered correlators, in counter-intuitive coexistence with asymptotic periodicity of the respective quantities.

[1] Dvali et al. Phys. Rev. D **88**, 124041 (2013)

15min. break

DY 42.7 Thu 11:45 H20

Hamiltonian Matrix Elements of the Stadium Billiard — •Jaewon Kim[1,2], Martina Hentschel[1], and Chil-Min Kim[2] — [1]Institute for Physics, Theoretical Physics II/Computational Physics Group, Technische Universität Ilmenau, Weimarer Straße 25, 98693 Ilmenau, Germany — [2]Department of Emerging Materials Science, DGIST,

We study the Hamiltonian matrix elements of the stadium billiard using a method of coordinate transformation. We apply special coordinate transformation which gives a remarkable simple form of the Hamiltonian. The spectrum from the Hamiltonian matrix shows good agreement with the fully numerical result from the BEM. Also, the simple Hamiltonian implies theoretically interesting points. With proper extensions, the Hamiltonian matrix elements calculated from the first principle provide a new way of studying quantum billiard system, especially for chirality and exceptional points.

DY 42.8 Thu 12:00 H20

Spin Diffusion Triggered by the Onset of Quantum Chaos in Surrounding Spin Bath — •Walter Hahn and Viatcheslav Dobrovitski — QuTech, Delft University of Technology, The Netherlands

We theoretically investigate spin diffusion driven by a finite quantum spin bath for a realistic solid-state NMR experiment. The total system consists of a disordered spin system which is acted upon by a surrounding spin bath via dipolar coupling. The bath consists of strongly coupled groups which are weakly interacting among each other. By means of numerical simulations, we show that the common expectation that only bath spins contributing to local noise are relevant is violated. In fact, nearby and farther bath spins can be equally important. While nearby bath spins govern the driving noise, the farther bath spins provide ergodicity within the bath by breaking integrability and, thereby, drastically change the spin diffusion dynamics. Specifically, we consider polycrystalline L-alanine in a realistic solid-state NMR setting including all experimental details. Spin diffusion occurs within the disordered carbon-spin subsystem and the spin bath is given by the surrounding proton spins. To modify the properties of the bath, we also consider deuterated alanine with protons replaced by deuterons having a smaller nuclear magnetic dipole moment. For deuterated L-alanine, we show that the driving noise is insufficient to allow for spin diffusion. Instead, spin diffusion is governed by the spin-lattice relaxation of deuteron spins on much larger time scales.

DY 42.9 Thu 12:15 H20

Spectral structure of systems of partially distinguishable bosons — •Gabriel Dufour[1,2], Tobias Brünner[1], Alberto Rodríguez[1], and Andreas Buchleitner[1] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg — [2]Freiburg Institute for Advanced Studies, Albert-Ludwigs-Universität Freiburg

We consider bosons whose single-particle "external" Hilbert space is augmented by an "internal" degree of freedom, which allows to tune their mutual distinguishability and switch many-particle interference effects on or off. The resulting many-particle Hilbert space decomposes as a direct sum of irreducible representations of the external unitary group. Hamiltonians which do not act on the internal degree of freedom can be accordingly block-diagonalised. We discuss the consequences for the spectra of non-interacting and interacting systems as the distinguishability of the particles is varied [1]. In particular, we show how the transition between regular and chaotic spectra is affected by the distinguishability of the bosons.

[1] T. Brünner, Signatures of partial distinguishability in the dynamics of interacting bosons, PhD thesis, Albert-Ludwigs-Universität Freiburg (2018)

Invited Talk DY 42.10 Thu 12:30 H20

Semiclassical approach in Bose-Hubbard models: from universal spectral statistics to far-out-of-equilibrium dynamics — •Remy Dubertrand — Institut für Theoretische Physik Universität Regensburg Universitätsstraße 31 D-93053 Regensburg

Semiclassical techniques from quantum chaos have been recently generalised to describe many-body interacting bosonic systems written as second quantised models. To understand the emergence of new phenomena due to many-body coherent effects I will first motivate how to build a quantum/classical correspondence, and how to follow the semiclassical program from there. This will be used first to state when universal spectral and eigenstate statistics appear in Bose-Hubbard models. This involves more precisely the connection with Random Matrix Theory and Berry's ansatz of random superpositions of Fock states respectively. A second, more recent application aims at studying the far-out-of-equilibrium dynamics of interacting cold atom systems, where the semiclassical perspective enables one to identify a dramatic change of the dynamical regime using both classical probes (well beyond the truncated Wigner range of validity) and quantum signatures.