# DY 40: Many-body Quantum Dynamics I (joint session DY/TT)

Time: Thursday 9:30–13:00 Location: A 151

DY 40.1 Thu 9:30 A 151

**Topological synchronization of fractionalized spins** — •Christopher Wächtler[1] and Joel Moore[1,2] — [1]University of California, Berkeley, USA — [2]Lawrence Berkeley National Laboratory, Berkeley, USA

The gapped symmetric phase of the Affleck-Kennedy-Lieb-Tasaki (AKLT) model exhibits fractionalized spins at the ends of an open chain. We show that breaking SU(2) symmetry and applying a global spin-lowering dissipator achieves synchronization of these fractionalized spins. Additional local dissipators ensure convergence to the ground state manifold. In order to understand which aspects of this synchronization are robust within the entire Haldane-gap phase, we reduce the biquadratic term which eliminates the need for an external field but destabilizes synchronization. Within the ground state subspace, stability is regained using only the global lowering dissipator. These results demonstrate that fractionalized degrees of freedom can be synchronized in extended systems with a significant degree of robustness arising from topological protection.

DY 40.2 Thu 9:45 A 151

**Understanding NMR signals by cluster dynamic mean-field theory** — •Timo Gräßer[1], Thomas Hahn[2], and Götz S. Uhrig[1] — [1]Condensed Matter Theory, TU Dortmund University, Otto-Hahn Straße 4, 44221 Dortmund, Germany — [2]School of Physics and Astronomy, The University of Manchester, Manchester M13 9PL, United Kingdom

A recently developed dynamic mean-field theory for spins at infinite temperature (spinDMFT)[1] is used to understand NMR signals quantitatively. The underlying idea is to couple a spin to a dynamic Gaussian mean-field with second moments that are self-consistently linked to the spin's autocorrelations. We improve the approach by considering clusters of spins quantum-mechanically (CspinDMFT)[2]. The extended model is more accurate and it allows for computing multi-spin correlations. We show that generic NMR signals comprise contributions of such multi-spin correlations. The applicability and validity of this approach is shown by describing NMR data for calcium fluoride (Ca F2) and adamantane (C10 H16).

[1] T. Gräßer et al., Phys. Rev. Research 3, 043168 (2021).
[2] T. Gräßer et al., arXiv:2307.14188 (2023).

DY 40.3 Thu 10:00 A 151

**Domain wall dynamics of a two dimensional quantum Ising model using tree tensor networks** — •Wladislaw Krinitsin[1], Niklas Tausendpfund[1,2], Matteo Rizzi[1,2], and Markus Schmitt[1,3] — [1]Forschungszentrum, Jülich, Deutschland — [2]Institut für Theoretische Physik, Köln, Deutschland — [3]Fakultät für Informatik und Data Science, Regensburg, Deutschland

Many body systems out of equilibrium are notoriously difficult to solve due to the rapid growth of entanglement with time. In particular the expanding possibilities to address two-dimensional systems in quantum simulations turn a spotlight on the lack of reliable numerical methods in this regime. We explore an approach to solve the time evolution of two-dimensional quantum systems by applying the time-dependent variational principle to Tree Tensor Networks. As an application, we consider the relaxation of domain wall initial conditions in a quantum Ising model, where pre-thermal behavior leads to a slow relaxation of domain wall initial conditions.

DY 40.4 Thu 10:15 A 151

**Edge modes of the random-field Floquet quantum Ising model** — •Harald Schmid[1], Alexander-Georg Penner[1], Kang Yang[1], Leonid Glazman[2], and Felix von Oppen[1] — [1]Dahlem Center for Complex Quantum, Freie Universität Berlin, 14195 Berlin, Germany — [2]Department of Physics, Yale University, New Haven, Connecticut 06520, USA

Motivated by a recent experiment on a superconducting quantum processor [Mi et al., Science 378, 785 (2022)], we study edge modes in the random-field Floquet quantum Ising model. The edge modes induce pairings in the many-body Floquet spectrum with splittings exponentially close to zero or $\pi$. We find that random transverse fields induce a log-normal distribution for both types of splittings. In contrast, random longitudinal fields affect the zero and $\pi$ splittings in drastically different ways. While zero pairings are rapidly lifted, the $\pi$ pairings are remarkably robust, or even strengthen, up to vastly larger disorder strengths. We explain our result within a self-consistent Floquet perturbation theory and study implications for boundary spin-spin correlations. The robustness of $\pi$ pairings against longitudinal disorder may be useful for quantum information processing.

DY 40.5 Thu 10:30 A 151

**A metronome spin stabilizes time-crystalline dynamics** — •Niklas Euler[1,2], Adrian Braemer[2], and Martin Gärttner[1,2] — [1]Institute of Condensed Matter Theory and Optics, Friedrich-Schiller-University Jena, Max-Wien-Platz 1, 07743 Jena, Germany — [2]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

We investigate a disorder-free quantum Ising chain subject to a time-periodic drive that rotates each spin by an angle $\pi(1-\epsilon_i)$. In case all spins experience the same deviation $\epsilon$ and the system starts from a fully magnetized state, the dynamics is known to be time crystalline: The magnetization exhibits stable, period-doubled oscillations for timescales that grow exponentially with system size. In this work, we study the effect of $\epsilon$ differing between the spins. We find that reducing $\epsilon$ for a single spin drastically enhances the lifetime of spatial-temporal order, suggesting the name "metronome" spin. Employing perturbative arguments, we explain this observation for initial states with macroscopic bulk magnetization. Furthermore, in the case of random bitstring initial states, we report enhancement of the lifetime of a topological edge mode. Here, we relate the presence of the metronome spin to the suppression of resonant processes. Finally, we discuss an altered geometry in which the metronome spin is not directly part of the chain, making the two described mechanisms clearly distinguishable. Our results illuminate the rich nature of spatially-varying Floquet driving, establishing it as a promising technique for fields like Floquet engineering.

DY 40.6 Thu 10:45 A 151

**Non-equilibrium dynamics of bosons with dipole symmetry: Emergence of new symmetry broken steady states** — •Md Mursalin Islam[1,3], Krishnendu Sengupta[2], and Rajdeep Sensarma[3] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [2]Indian Association for the Cultivation of Science, Kolkata, India — [3]Tata Institute of Fundamental Research, Mumbai, India

We study equilibrium and dynamical phase diagrams of an interacting system of N-component charged bosons with dipole symmetry. In the large N limit, the equilibrium phase diagram of these bosons shows a first-order transition between two phases. The first one is a localized normal phase where both the global U(N) and the dipole symmetries are conserved and the second one is a delocalized condensed phase where both the symmetries are broken. In contrast, the steady state after an instantaneous quantum quench from the condensed phase shows an additional, delocalized normal phase, where the global U(N) symmetry is conserved but the dipole symmetry is broken, for a range of the quench parameters. A study of the ramp dynamics of the model shows that the above-mentioned steady state exists only above a critical ramp rate.

DY 40.7 Thu 11:00 A 151

**Symmetries as Ground States of Local Operators** — •Sanjay Moudgalya[1,2] and Olexei Motrunich[3] — [1]Technical University of Munich, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), 80799 Munich, Germany — [3]Department of Physics, California Institute of Technology, Pasadena, California 91125, USA

Symmetry algebras of quantum many-body systems with locality can be understood using commutant algebras, which are defined as algebras of operators that commute with a given set of local operators. In this work, we show that these symmetry algebras can be expressed as frustration-free ground states of a local superoperator, which we refer to as a "super-Hamiltonian". We demonstrate that for conventional on-site unitary symmetries, the symmetry algebras map to various kinds of ferromagnetic ground states. We obtain a physical interpretation of this super-Hamiltonian as the superoperator that governs the operator relaxation in noisy symmetric Brownian circuits, which relates its low-energy excitations to approximate symmetries that determine slowly relaxing modes in symmetric systems. We find examples of gapped/gapless super-Hamiltonians indicating the absence/presence of slow-modes, which happens in the presence of discrete/continuous symmetries. In the gapless cases, we recover slow-modes such as diffusion in the presence of U(1) symmetry. We also demonstrate this framework for unconventional symmetries that lead to Hilbert space fragmentation and quantum many-body scars, which lead to novel kinds of slow-modes such as tracer diffusion and asymptotic quantum scars.

**15 min. break**

DY 40.8 Thu 11:30 A 151

**Active quantum flocks** — •Reyhaneh Khasseh[1], Sascha Wald[2], Roderich Moessner[3], Christoph A. Weber[1], and Markus Heyl[1] — [1]Theoretical Physics III, Center for Electronic Correlations and Magnetism, Institute of Physics, University of Augsburg, D-86135 Augsburg, Germany — [2]Statistical Physics Group, Centre for Fluid and Complex Systems, Coventry University, Coventry, England — [3]Max-Planck-Institut fur Physik komplexer Systeme, 01187 Dresden, Germany

In the captivating overlap of quantum physics and biophysics, our research seeks to reveal how characteristics intrinsic to living systems can manifest within quantum matter. Flocks of animals in the macroscopic classical world are iconic representations of collective behavior, where constituents move in harmony as though a singular entity. The intriguing intersection between quantum physics and biophysics prompts the exploration of whether such flocks can manifest in the microscopic quantum realm. Introducing the concept of active quantum matter through a series of models on a one-dimensional lattice, we present analytical and numerical evidence pointing to the emergence of quantum flocks.

DY 40.9 Thu 11:45 A 151

**Quantum motility-induced phase separation** — •Laurin Brunner[1], Reyhaneh Khasseh[1], Federico Carollo[2], Igor Lesanovsky[2], Juan Garrahan[3], and Markus Heyl[1] — [1]University of Augsburg, Augsburg, Germany — [2]Universität Tübingen, Tübingen, Germany — [3]University of Nottingham, Nottingham, United Kingdom

Active matter is a central concept in biophysics explaining key mechanisms of living organisms. Very recently, a quantum analogue in open quantum systems has been introduced for the first time. Here, we study a theoretical model showing evidence of a quantum counterpart of motility-induced phase separation. We solve the dynamics by means of neural quantum states and we furthermore discuss the quantum features of our model.

DY 40.10 Thu 12:00 A 151

**Fluctuations Approach to Quantum Many-Body Systems and its Application to Density Correlations and the Dynamic Structure Factor** — •Erik Schroedter, Jan-Philip Joost, and Michael Bonitz — CAU Kiel, Germany

The dynamics of quantum many-body systems following external excitation are of great interest in many areas, such as correlated solids or dense plasmas. Standard approaches used for the description of the dynamics of such systems include the formalisms of reduced density matrices (RDM) and nonequilibrium Green functions (NEGF). However, both approaches are limited in their applicability due to the numerical scaling of simulations with respect to the system size or propagation time. Here, an alternative approach to the dynamics of quantum systems is presented, which is based on fluctuations and their correlation functions [1]. While this new approach is closely related to NEGF and RDM theory [2], it has interesting complementary features, such as the capability to simulate many-body effects using stochastic methods [3,4], which reduce the computational complexity and additionally increase numerical stability for stronger coupling. Moreover, this approach provides direct access to spectral two-particle quantities, such as the density response function or dynamic structure factor, for systems in and far from equilibrium.

[1] E. Schroedter, *et al.*, Cond. Matt. Phys. **25**, 23401 (2022)
[2] E. Schroedter, and M. Bonitz, phys. stat. sol. (b) (2024)
[3] D. Lacroix, *et al.*, Phys. Rev. B **90**, 125112 (2014)
[4] E. Schroedter, *et al.*, Phys. Rev. B **108**, 205109 (2023)

DY 40.11 Thu 12:15 A 151

**Conserved Superoperators and Non-Universality in Unitary Circuits** — •Marco Lastres[1,2], Frank Pollmann[1,2], and Sanjay Moudgalya[1,2] — [1]Technical University of Munich, TUM School of Natural Sciences, Physics Department, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, 80799 München, Germany

An important result in the theory of quantum control is the “universality” of 2-local unitary gates, i.e. the fact that any global unitary evolution of a system of $L$ qudits can be implemented by composition of 2-local unitary gates. Surprisingly, recent results show that universality can break down in the presence of symmetries: in general, not all globally symmetric unitaries can be constructed using $k$-local symmetric unitary gates. This also restricts the dynamics that can be implemented by symmetric local Hamiltonians.

In this study, we show that these obstructions to universality can in general be understood in terms of unconventional superoperator symmetries associated with unitary evolution by $k$-local gates. We demonstrate this explicitly in several examples by systematically deriving the superoperator symmetries using the framework of commutant algebras, which has recently been applied to derive the unconventional symmetries responsible for weak ergodicity breaking phenomena, such as quantum many body scars and Hilbert space fragmentation. In all, our work establishes a new comprehensive approach to explore the universality of unitary circuits and derive physical consequences of its absence.

DY 40.12 Thu 12:30 A 151

**Exploring Quantum Dynamics of hard disks on a lattice** — •Vighnesh Dattatraya Naik, Fabian Ballar Trigueros, and Markus Heyl — Theoretical Physics III, Center for Electronic Correlations and Magnetism, Institute of Physics, University of Augsburg, 86135 Augsburg, Germany

Recent strides in quantum simulators have propelled the investigation of quantum matter with local constraints to the forefront of research. This study delves into the hard-disk problem, a paradigmatic class of constrained matter, by introducing its quantum version on lattices, which exhibits a natural realization in Rydberg atom arrays due to the Rydberg blockade mechanism. While static properties align with classical cases, dynamical properties are fundamentally different. In one dimension, we identify genuine quantum features in the melting process of a finite-size crystal displaying ballistic behavior, whereas the classical scenario exhibits sub-diffusion governed by the Kardar-Parisi-Zhang universality class. On two-dimensional square lattices, we show that in the quantum domain, crystals remain intact against most defects, whereas classically the initial crystal structure is washed out completely. We link this peculiar quantum behavior to the presence of quantum many-body scars, breaking conventional expectations of ergodicity. Our study highlights the potential of constrained two-dimensional quantum matter to display unique dynamical behaviors.

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**Non-ergodic dynamical phenomena in lattice gauge theories** — •Nilotpal Chakraborty[1], Markus Heyl[2], and Roderich Moessner[1] — [1]Max Planck Institute for physics of complex systems, Dresden — [2]University of Augsburg

Lattice gauge theories are paradigmatic examples of constrained many-body interacting systems. Such theories, while ubiquitous in nature, emerge in condensed matter settings as effective low-energy theories for certain classes of topological magnets. More recently such theories have also been at the forefront of a large quantum simulation effort using ultra cold atoms. With the advent of such simulation efforts and novel dynamical methods for solid state systems, the dynamics of such constrained interacting theories becomes an important theoretical question with physical relevance. In this talk I shall present lattice gauge theories as an ideal testbed for exploring a plethora of non-ergodic dynamical phenomena - ranging from fragmentation to scars as well as many-body localization. In particular, I shall focus on the occurrence of an interference induced many-body localization transition in two dimensional U(1) lattice gauge theories. Such a transition occurs for the problem of a single matter field hopping on a disordered background of interacting gauge fields. I will explore the problem both at the classical and quantum level and highlight interesting dynamical phenomena for both - such as sub-diffusion for the classical and many-body localization for the quantum problem.