# DY 9: Quantum Dynamics, Decoherence and Quantum Information

Time: Monday 14:00–17:15 Location: MOL 213

DY 9.1 Mon 14:00 MOL 213

**From Dual Unitarity to Generic Quantum Operator Spreading** — •Michael A. Rampp, Roderich Moessner, and Pieter W. Claeys — Max Planck Institute for the Physics of Complex Systems, 01187 Dresden, Germany

Dual-unitary circuits are paradigmatic examples of exactly solvable yet chaotic quantum many- body systems, but solvability naturally goes along with a degree of non-generic behaviour. By investigating the effect of weakly broken dual-unitarity on the spreading of local operators we study whether, and how, small deviations from dual-unitarity recover fully generic many-body dynamics. We present a discrete path-integral formula for the out-of-time-order correlator and use it to recover a butterfly velocity smaller than the light-cone velocity, $v_B < v_{LC}$ , and a diffusively broadening operator front, two generic features of ergodic quantum spin chains absent in dual-unitary circuit dynamics. We find that the butterfly velocity and diffusion constant are determined by a small set of microscopic quantities and that the operator entanglement of the gates plays a crucial role.

DY 9.2 Mon 14:15 MOL 213

**Harnessing the exponential Hilbert space dimension of quantum systems for reservoir computing** — •Niclas Götting[1,2], Frederik Lohof[1,2], and Christopher Gies[1,2] — [1]Institute for Theoretical Physics, University of Bremen, Bremen — [2]Bremen Center for Computational Material Science, University of Bremen, Bremen

With the ever growing prevalence of machine learning in science and industry, the machine learning paradigm of reservoir computing has gained new attention. While classical reservoir computers have proven to be able to solve various prediction tasks by exploiting the complex dynamics of classical systems, their quantum counterparts are yet to be fully explored.

Coherent quantum systems exhibit properties like superposition and quantum entanglement, which in principle lead to an exponential scaling of the reservoir phase space dimension with respect to the number of quantum particles. The question arises if these quantum reservoir computers (QRCs) can energy and space efficiently outperform their classical analogues in complex prediction tasks.

As a first step we investigate the transverse-field Ising model as a QRC to find the link between the properties of the quantum network, the phase space dimension, and the performance of the QRC.

DY 9.3 Mon 14:30 MOL 213

**Giant Residual Current from Ultrafast AC Driving of Bloch Electrons** — •Adrian Seith, Jan Wilhelm, and Ferdinand Evers — Institut für Theoretische Physik, Universität Regensburg

In recent experiments, residual currents were seen to survive long after the laser illumination has died out[1]. Motivated by a vision of a "light-wave electronics", the effect has been utilized to design a petahertz logical gate[2].

In this work, we theoretically study residual currents of Bloch electrons and demonstrate that residual currents can be as large as the maximum current during illumination.

Based on a perturbative expansion of the semiconductor-Bloch equations, we derive an analytical formula; it explains the strong dependence of residual currents on the model parameters and the laser pulse shape. In particular, our formula allows to optimize pulse shapes for maximizing the residual currents' magnitude reaching values order of magnitudes larger than observed in recent experiments.

[1] Higuchi et. al., Nature 550, 224 (2017)
[2] Boolakee et. al., Nature 605, 251 (2022)

DY 9.4 Mon 14:45 MOL 213

**Time-local generator of non-Markovian quantum dynamics by iterating its memory kernel** — Maarten Wegewijs[1], Jan Vanberg[2], and •Konstantin Nestmann[2] — [1]Peter Grünberg Institute, Forschungszentrum Jülich, Germany — [2]Institute for Theory of Statistical Physics, RWTH Aachen University

The time-convolutionless generator (TCL) $\mathcal{G}$ of a quantum master equation (QME) has been found to be the fixed point $\mathcal{G} = \hat{\mathcal{K}}[\mathcal{G}]$ of the Nakajima-Zwanzig memory kernel $\mathcal{K}$ of the equivalent QME with time-convolution[a]. Here we investigate the calculation of $\mathcal{G}$ by iterating $\mathcal{K}$ directly in the stationary limit starting from any initial guess to construct approximations to the dynamics. We show that the local stability of the iteration is connected to the long-time dynamics using an extended but still tractable version of the dissipative Jaynes-Cummings model. The iteration automatically selects the asymptotically most relevant decay and oscillation frequency, providing a non-perturbative Markovian semigroup approximation. Linearization about the fixed point allows to extract the amplitude of this approximation in the full dynamics, providing a non-perturbative initial-slip correction. Around the strongly non-Markovian regime (non-CP divisibility) the iteration stability can be either lost, or, remarkably, enhanced, yielding an additional fixed point. The global iteration stability is counter-intuitive: convergence to the main locally stable fixed point is guaranteed by starting from an initial guess "far away" with frequencies in the "wrong", *non*-physical half-plane. [a]Phys. Rev. X 11, 021041 (2021), Phys. Rev. B 104, 155407 (2021) [b]SciPost Phys. 11, 053 (2021)

DY 9.5 Mon 15:00 MOL 213

**Performance of quantum registers in diamond in the presence of spin impurities** — •Dominik Maile and Joachim Ankerhold — Institut for Complex Quantum Systems, Ulm University

The Nitrogen Vacancy Center in diamond coupled to addressable surrounding nuclear spins forms a versatile building block for future quantum technologies. While previous activities focused on sensing with only a single or very few spins in operation, recently multi-qubit registers have been successfully implemented for quantum information processing. Further progress requires a detailed understanding of the performance of quantum protocols for consecutive gate operations and thus, beyond established treatments for relaxation and dephasing. In this talk (see also [1]), we provide such an analysis for a small spin registers with up to four spins built out of NV and environmental constituents in presence of ensembles of interacting impurity spins. Adapting a cluster correlation expansion, we predict coherence properties as well as fidelities for GHZ- and Bell-gate operations. The influence of the volume density and the geometry of the spin-bath consisting of substitutional nitrogen atoms are also taken into account.

[1] D. Maile and J. Ankerhold, arXiv:2211.06234

DY 9.6 Mon 15:15 MOL 213

**Quantum Zeno manipulation of quantum dots** — Naser Ahmadiniaz[1], Martin Paul Geller[2], Jürgen König[2], Peter Kratzer[2], Axel Lorke[2], •Gernot Schaller[1], and Ralf Schützhold[1,3] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Bautzner Landstraße 400, 01328 Dresden, Germany — [2]Fakultät für Physik and CENIDE, Universität Duisburg-Essen, Lotharstraße 1, 47057 Duisburg, Germany — [3]Institut für Theoretische Physik, Technische Universität Dresden, 01062 Dresden, Germany

We investigate whether and how the quantum Zeno effect, i.e., the inhibition of quantum evolution by frequent measurements, can be employed to isolate a quantum dot from its surrounding electron reservoir. In contrast to the often studied case of tunneling between discrete levels, we consider the tunneling of an electron from a continuum reservoir to a discrete level in the dot. Realizing the quantum Zeno effect in this scenario can be much harder because the measurements should be repeated before the wave packet of the hole left behind in the reservoir moves away from the vicinity of the dot. Thus the required repetition rate could be lowered by having a flat band (with a slow group velocity) in resonance with the dot or a sufficiently small Fermi velocity or a strong external magnetic field. We also consider the anti-Zeno effect, i.e., how measurements can accelerate or enable quantum evolution.

[1] N. Ahmadiniaz *et al.*, Phys. Rev. Res. **4**, L032045 (2022).

**15 min. break**

DY 9.7 Mon 15:45 MOL 213

**Winding Number Statistics for Parametric Chiral Random Matrices** — •Nico Hahn[1], Mario Kieburg[2], Omri Gat[3], and Thomas Guhr[1] — [1]University of Duisburg-Essen — [2]University of Melbourne — [3]The Hebrew University of Jerusalem

The winding number is a concept in complex analysis which has, in the presence of chiral symmetry, a physics interpretation as the topologi-

cal invariant belonging to gapped phases of Fermions. We analytically study the statistical properties of this topological quantity. To this end, we set up a random matrix model for a chiral system with a parametric dependence. We address two chiral symmetry classes, the chiral unitary class without any further symmetries and the chiral symplectic class with additional time reversal symmetry. These classes are referred to as AIII and CII in the tenfold way of topological insulators and superconductors.

DY 9.8 Mon 16:00 MOL 213

**Simulating Non-Markovian Qubit Dynamics on a Quantum Processor** — •Mirko Rossini, Dominik Maile, Joachim Ankerhold, and Brecht Donvil — Institute for Complex Quantum Systems and IQST

We propose a novel scheme to simulate the open system dynamics of a qubit. We go beyond the completely positive framework and consider linear, trace and Hermicity-preserving but not necessarily positivity-preserving evolution maps. We call these maps general dynamical maps. These maps naturally arise as the solution of general time-local master equations and for finite-dimensional systems they can always be decomposed as the difference between two completely positivity maps. We bring this difference into a form suitable for quantum simulation.

We illustrate our scheme by implementing two examples on IBMQ quantum processors: in the first example, we simulate the evolution of a general time local master equation both from an initial time when the evolution map is guaranteed to be completely positive and from an intermediate time when it is not. With our second example, we show that the simulation of non-completely positive maps gives the ability to recover the initial state of Lindbladian evolution.

DY 9.9 Mon 16:15 MOL 213

**Quantum Non-Markovianity made simple through extended states** — Meng Xu[1], Yaming Yan[2], Qiang Shi[2], Joachim Ankerhold[1], and •Jürgen T. Stockburger[1] — [1]Institute for Complex Quantum Systems and IQST, Ulm University — [2]Beijing National Laboratory for Molecular Sciences, Chinese Academy of Sciences

We present a recent computational treatment of non-Markovianity [1] in open-system quantum dynamics. Focusing more on intrinsic timescales than on properties of a quantum channel and its generator, we extend the Hierarchical Equations of Motion (HEOM) approach through a highly efficient decomposition of environmental correlation functions into complex exponentials. Complex dynamics at ultralow temperatures and long reservoir timescales becomes tractable by this approach. We demonstrate that our version of the HEOM approach is closely related to an entire family of extended-state approaches, with our new approach being favored through a comparably low number of auxiliary dimensions. The accurate reproduction of long-time algebraic tails in an open-system correlation function provides a benchmark result.

[1] M. Xu *et al.*, Phys. Rev. Lett. **129**, 230601 (2022).

DY 9.10 Mon 16:30 MOL 213

**The Influence of Dynamical Phases on a Quantum Processor based Reservoir Computer** — •Brecht Donvil, Mirko Rossini, Dominik Maile, and Joachim Ankerhold — ICQ and IQST, University of Ulm, Ulm, Germany

Reservoir computing is subbranch of machine learning where a physical system, the reservoir, is used to perform computational tasks instead of a large neural network which has to be trained. In the last years, quantum systems systems are being explored as potential reservoirs[1,2,3]. While most of the research has focussed on Ising spin systems, recently it was shown that also quantum processors can serve as reservoirs. The authors of [3] illustrated this fact by successfully implementing reservoir computing on an IMBQ quantum processor.

The dynamical phase of the reservoir can influence its performance on certain information processing tasks. For example, the authors of [2] found that the transverse-field Ising model performs best on examples of memory related tasks on the edge of the ergodic phase. The work I present here concerns quantum processor based reservoir computing as proposed in [3]. I consider simple circuit layout which is know to exhibit a dynamical phase transition between a localised and ergodic phase. I show the influence of the dynamical phase of the circuit on its information processing capacity and its performance as a readout device.

[1] K. Fujii and K. Nakajimna, Phys. Rev. Applied **8**, 024030 (2017)
[2] R. Martínez-Peña et al., Phys. Rev. Lett. **127**, 100502 (2021)
[3] J. Chen et al., Phys. Rev. Applied **14**, 024065 (2020)

DY 9.11 Mon 16:45 MOL 213

**String order in measurement-induced symmetry-protected topological phases** — •Raúl Morral[1], Frank Pollmann[1,3], and Izabella Lovas[1,2] — [1]Department of Physics, TFK, Technische Universität München, James-Franck-Straße 1, D-85748 Garching, Germany — [2]Kavli Institute for Theoretical Physics, University of California, Santa Barbara, CA 93106, USA — [3]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, 80799 München, Germany

We study measurement-induced symmetry protected topological (SPT) order in a wide class of quantum random circuit models, by combining calculations within the stabilizer formalism with tensor network simulations. We construct a family of quantum random circuits, generating the out-of-equilibrium version of all generalized cluster models, and derive a set of non-local string order parameters to distinguish symmetry protected topological phases. We apply this framework to study the random circuit realization of the XZX cluster model, and use the string order parameter to demonstrate that the phase diagram is strikingly stable against extending the class of unitary gates in the circuit, from Clifford gates to Haar unitaries. We then turn to the XZZX generalized cluster model, and demonstrate the coexistence of SPT order and spontaneous symmetry breaking, by relying on string order parameters and a connected correlation function. Our results pave the way to study the properties of a wide range SPT phases in quantum random circuit models with efficient tensor network methods.

DY 9.12 Mon 17:00 MOL 213

**Quasiclassical and exact approaches to dissipative nonadiabatic quantum dynamics** — •Graziano Amati[1], Johan Runeson[2], and Jerem Richardson[3] — [1]Albert Ludwigs Universitaet Freiburg, Hermann Herder Str. 3, 79104 Freiburg, Germany — [2]Physical and Theoretical Chemistry Laboratory, Oxford University, South Parks Road, Oxford, OX1 3QZ, UK — [3]Laboratory of Physical Chemistry, ETH Zuerich, 8093 Zuerich, Switzerland

The study of many relevant processes in nature from photosynthesis, to radiation damage, to vision, depends on an accurate description of the electronic nonadiabatic dynamics. The brute-force simulation of nonadiabatic systems happens to be a computationally intensive task, given that the complexity of dynamic simulations scales exponentially with time and with the size of the system. Recently developed of 'spin mapping' approaches allow to recast a wide class of quantum nonadiabatic models onto quasiclassical systems of spins, whose dynamics exhibit a favorable linear or polynomial scaling in complexity. In my contribution I will firstly compare the accuracy in the long-time relaxation of several quasiclassical methods, borrowing ideas from classical ergodic theory. I will then discuss how to further improve the reliability of the long-time predictions of spin mapping techniques, by coupling these methods to the formalism of the non-Markovian generalized quantum master equation. I will then introduce the recent 'ellipsoid mapping' approach, a detailed-balance-preserving extension of spin mapping suited to study systems in thermal equilibrium.