# Q 41: Quantum Effects: Entanglement and Decoherence II

Time: Wednesday 14:30–16:30 Location: f442

**Group Report** Q 41.1 Wed 14:30 f442

**A quantum random walk of a Bose-Einstein condensate in momentum space** — •Sandro Wimberger[1,2,3] and Gil Summy[4] — [1]DiFeST, Università degli Studi di Parma, Via G. P. Usberti 7/a, 43124 Parma, Italy — [2]INFN, Sezione di Milano Bicocca, Gruppo Collegato di Parma, 43124 Parma, Italy — [3]ITP, Heidelberg University, Philosophenweg 12, 69120 Heidelberg, Germany — [4]Department of Physics, Oklahoma State University, Stillwater, Oklahoma 74078-3072, USA

Each step in a quantum random walk is typically understood to have two basic components; a "coin-toss" which produces a random superposition of two states, and a displacement which moves each component of the superposition by different amounts. Here we suggest the realization of a walk in momentum space with a spinor Bose-Einstein condensate subject to a quantum ratchet realized with a pulsed, off-resonant optical lattice. By an appropriate choice of the lattice detuning, we show how the atomic momentum can be entangled with the internal spin states of the atoms. For the coin-toss, we propose to use a microwave pulse to mix these internal states. We present the first experimental results showing a new type of ratchet, and through a series of simulations, demonstrate how our proposal can allow for extraordinary control of the quantum walk. This should allow for the investigation of possible biases, and classical-to-quantum dynamics in the presence of natural and engineered noise.

Q 41.2 Wed 15:00 f442

**Random Unitary Evolution Model of Dissipation, Dephasing and Quantum Darwinism** — •Nenad Balaneskovic[1], Gernot Alber[1], and Jaroslav Novotny[2] — [1]Institut für Angewandte Physik, Technische Universität Darmstadt, D-64289 Darmstadt, Germany — [2]Department of Physics, FNSPE, Czech Technical University in Prague, 11519 Praha 1 - Stare Mesto, Czech Republic

We discuss characteristic properties of Quantum Darwinism (QD) when pure decoherence is disturbed by dissipation and dephasing. Based on digraph interaction models of open qubit systems interacting with their respective environment by iterated and randomly applied (Controlled-NOT-type) unitary operations, we introduce a unitary two-qubit dissipative-dephased operator. We investigate the QD-appearance of Classicality from the analytically determined asymptotic dynamics of the resulting quantum Markov chain. In addition, we concentrate on interaction digraphs which comprise environmental qubits that do not interact among themselves by unitary quantum operations and are thus suitable to describe physically objective quantum measurements performed on an open system by autonomous observers (environmental qubits). In particular, we investigate whether it is possible to achieve the most efficient storage of classical information about a system into its environment by altering the strength parameters of the dissipative-dephased operator. Furthermore, we discuss the structure of the corresponding dissipative-dephased attractor spaces of our extended qubit-model of QD.

Q 41.3 Wed 15:15 f442

**A master equation for high-precision spectroscopy** — •Andreas Alexander Buchheit and Giovanna Morigi — Universität des Saarlandes, 66123 Saarbrücken, Germany

The progress in high-precision spectroscopy requires one to check the accuracy of theoretical models such as the master equation describing spontaneous emission of atoms. For this purpose, we systematically derive a master equation of an atom interacting with the modes of the electromagnetic field which naturally includes interference in the decay channels and fulfills the requirements of the Lindblad theorem without the need of phenomenological assumptions. We apply our model to the 2S-4P transition in atomic Hydrogen and show that interference effects in the dissipative dynamics can alter the lineshape of the spectroscopic line, leading to frequency shifts ranging from few to tens of kHz, depending on the collection angle of the photodetection setup. These results can contribute in understanding spectroscopic measurements in atomic Hydrogen performed in recent experiments for testing the validity of quantum electrodynamics.

Q 41.4 Wed 15:30 f442

**Controllable Markovian to Non-Markovian Transition in Open Quantum Systems Implemented with Cold Rydberg Atoms** — Michael Genkin, David Schönleber, •Alexander Eisfeld, and Sebastian Wüster — MPI für Physik komplexer Systeme, Dresden

We propose a setup of an open quantum system in which the system-environment-interaction can be switched from Markovian to non-Markovian in a controlled fashion. The scheme is implemented with cold Rydberg atoms, utilizing their strong long-range interactions. It helps to assess the applicability of Rydberg aggregates as quantum simulators of molecular systems, and presents a possible new test bench for fundamental studies of the classification of system-environment-interactions in open systems.

Q 41.5 Wed 15:45 f442

**Master equation for collective spontaneous emission including quantization of the atomic motion** — •François Damanet[1], Daniel Braun[2], and John Martin[1] — [1]Institut de Physique Nucléaire, Atomique et de Spectroscopie, Université de Liège, Bât B15, 4000 Liège, Belgium. — [2]Institut für theoritische Physik, Universität Tübingen, 72076 Tübingen, Germany.

We derive a markovian master equation for the internal dynamics of an ensemble of two-level atoms including the quantization of their motion. Our equation provides a unifying picture of the effects of recoil and indistinguishability of atoms beyond the Lamb-Dicke regime on both their dissipative and conservative dynamics. We give general expressions for the decay rates and the dipole-dipole shifts for any motional states, generalizing those in Ref. [1]. We find closed-form formulas for a number of relevant states (gaussian states, Fock states and thermal states). In particular, we show that dipole-dipole interactions and cooperative photon emission [2] can be modulated through the external state of motion. As an application of our general formalism, we study the spatial Pauli blocking of two fermionic atoms beyond the Lamb-Dicke regime [3].

[1] G. S. Agarwal, Springer Tracts In Modern Physics **70**, 1 (1974).
[2] R. H. Dicke, Phys. Rev. **93**, 99 (1954).
[3] R. M. Sandner, M. Müller, A. J. Daley & P. Zoller, Phys. Rev. A **84**, 043825 (2011).

Q 41.6 Wed 16:00 f442

**Time-resolved observation of thermalization in an isolated quantum system** — •Govinda Clos[1], Diego Porras[2], Ulrich Warring[1], and Tobias Schaetz[1] — [1]Physikalisches Institut, Albert-Ludwigs-Universität, Hermann-Herder-Straße 3, 79104 Freiburg, Germany — [2]Department of Physics and Astronomy, University of Sussex, Brighton BN1 9QH, United Kingdom

How can thermalization occur in an isolated quantum system? Unitary time evolution does not permit the total system to reach a thermal state. However, for a strongly interacting system with many degrees of freedom, expectation values of local observables can come to agreement with microcanonical predictions. This behaviour is described within a conjecture called Eigenstate Thermalization Hypothesis [1].

Using a near-perfectly isolated trapped-ion system, we experimentally study the evolution of a single spin in a Hilbert space of dimension up to $2^{22}$ by controlling its coupling to a discrete bosonic environment [2]. Varying the effective size of the system, we measure the dynamics of spin observables and determine its time average and fluctuations to study the onset of thermalization [3].

[1] Eisert *et al.*, *Nature Physics* **11**, 124 (2015).
[2] Porras *et al.*, *Physical Review A* **78**, 010101 (2008).
[3] Clos *et al.*, *arXiv:1509.07712* (2015).

Q 41.7 Wed 16:15 f442

**Intrinsic limit to electron spin coherence in InGaAs quantum dots** — Robert Stockill, Claire Le Gall, Clemens Matthiesen, •Lukas Huthmacher, and Mete Atatüre — Cavendish Laboratory, University of Cambridge, JJ Thomson Avenue, Cambridge CB3 0HE, UK

Single electron spins in self-assembled InGaAs quantum dots show outstanding photonic properties, allowing for ultrafast all-optical control [1] and therefore are a promising candidate for spin qubits. However, the fluctuations of the nuclear spin bath in the surrounding semiconductor limit the electron-spin dephasing to a few nanoseconds

[2]. The exact mechanism leading to this limitation is masked by the measurement-induced dynamic polarisation of the nuclear bath, often revealed in the dragging of resonance frequencies, and hence remains unclear [3]. Here, we introduce an all-optical method allowing us to access the electron-spin without influencing the nuclear bath. By combining this method with a spin-echo decoupling scheme we are able to reach the intrinsic limit to electron-spin coherence, which, for our samples, amounts to a few microseconds, depending on the external magnetic fields. Taking into account the quadrupolar and Zeeman Hamiltonians we show that this bound is set by the quadrupolar interaction of the nuclear bath with inhomogeneous electric field gradients; a result of the naturally occurring strain in these systems. [1] Press, D. et al., Nature 456, 218-221 (2008) [2] Greilich, A. et al., Science 313, 341-345 (2006) [3] Latta, C. et al., Nature Phys. 5, 758-763 (2009)