# QI 7: Quantum Information: Applications

Time: Wednesday 10:45–12:30 Location: H4

QI 7.1 Wed 10:45 H4

**qopt: An experiment-oriented Qubit Simulation and Quantum Optimal Control Package** — •Julian Teske and Hendrik Bluhm — JARA-FIT Institute for Quantum Information, Forschungszentrum Jülich GmbH and RWTH Aachen University, 52074 Aachen, Germany

Realistic modelling of qubit systems including noise and constraints imposed by control hardware is required for performance prediction and control optimization of quantum processors. We introduce qopt, a software framework for simulating qubit dynamics and robust quantum optimal control considering common experimental situations. To this end, we model open and closed qubit systems with a focus on the simulation of realistic noise characteristics and experimental constraints. Specifically, the influence of noise can be calculated using Monte Carlo methods, effective master equations or with the efficient filter function formalism, which enables the investigation and mitigation of auto-correlated noise. In addition, limitations of control electronics including finite bandwidth effects can be considered. The calculation of gradients based on analytic results is implemented to facilitate the efficient optimization of control pulses. The software is published under an open source license, well-tested and features a detailed documentation.

QI 7.2 Wed 11:00 H4

**Cyclic cooling of quantum systems at the saturation limit** — •Durga Dasari[1], Sadegh Raeisi[2], and Joerg Wrachtrup[1] — [1]3. Physics Institute, University of Stuttgart, Stuttgart, GERMANY — [2]Department of Physics, Sharif University of Technology, Tehran, IRAN

The achievable bounds of cooling quantum systems, and the possibility to violate them is not well-explored experimentally. For example, among the common methods to enhance spin polarization (cooling), one utilizes the low temperature and high-magnetic field condition or employs a resonant exchange with highly polarized spins. The achievable polarization, in such cases, is bounded either by Boltzmann distribution or by energy conservation. Heat-bath algorithmic cooling schemes (HBAC), on the other hand, have shown the possibility to surpass the physical limit set by the energy conservation and achieve a higher saturation limit in spin cooling. Despite, the huge theoretical progress, and few principle demonstrations, neither the existence of the limit nor its application in cooling quantum systems towards the maximum achievable limit have been experimentally verified. Here, we show the experimental saturation of the HBAC limit for single nuclear spins, beyond any available polarization in solid-state spin system, the Nitrogen-Vacancy centers in diamond. We benchmark the performance of our experiment over a range of variable reset polarizations (bath temperatures), and discuss the role of quantum coherence in HBAC.

QI 7.3 Wed 11:15 H4

**Superradiant many-qubit absorption refrigerator** — Michal Kloc[1], Kurt Meier[1], Kimon Hadjikyriakos[2], and •Gernot Schaller[3] — [1]Department of Physics, University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland — [2]Institut für Theoretische Physik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany — [3]Helmholtz-Zentrum Dresden-Rossendorf, Bautzner Landstraße 400, 01328, Dresden, Germany

We show that the lower levels of a large-spin network with a collective anti-ferromagnetic interaction and collective couplings to three reservoirs may function as a quantum absorption refrigerator. In appropriate regimes, the steady-state cooling current of this refrigerator scales quadratically with the size of the working medium, i.e., the number of spins. The same scaling is observed for the noise and the entropy production rate.

[1] arXiv:2106.04164

QI 7.4 Wed 11:30 H4

**The Dicke Model as an Associative Quantum Neural Network** — •Lukas Bödeker[1], Eliana Fiorelli[1,2], and Markus Müller[1,2] — [1]Institute for Quantum Information, RWTH Aachen University, D-52056 Aachen, Germany — [2]Peter Gruenberg Institute, Theoretical Nanoelectronics, Forschungszentrum Juelich, D-52425 Juelich, Germany

Nowadays Classical Artificial Neural Networks (NNs) show their great power and versatility in information processing tasks. Early instances of NNs are given by Associative NNs, that have the ability to retrieve a stored state, starting from a compromised initial one. Such dynamics can be engineered via a stochastic evolution, where stored configurations are minima of an energy landscape. One of the first examples of associative NNs is the Hopfield NN, which is an Ising-type system featuring all-to-all interactions. Motivated by the fast progress in controlling quantum systems, as well as in quantum computation, a question that is currently explored is whether a Hopfield-type associative memory could be hosted in quantum systems. The goal is to understand whether quantum effects can be advantageous to store information. To this end, we consider the multi-mode Dicke model, in which a bosonic bath mediates an effective all-to-all spin interaction. The latter can be exploited to store information associatively, by setting the spin boson couplings accordingly. We analyse the storage properties of this system and further aim at investigating the maximum capacity i.e. the maximum number of stored states given a certain system size, generalising the classical approach introduced by Gardner.

QI 7.5 Wed 11:45 H4

**Hyperfine Structure of Transition Metal Defects in SiC** — •Benedikt Tissot and Guido Burkard — Universtität Konstanz

Transition metal (TM) defects in silicon carbide (SiC) are a promising platform in quantum technology, especially because some TM defects emit in the telecom band. We develop a theory for the interaction of an active electron in the $D$-shell of a TM defect in SiC with the TM nuclear spin and derive the effective hyperfine tensor within the Kramers doublets formed by the spin-orbit coupling. Based on our theory we discuss the possibility to exchange the nuclear and electron states with potential applications for nuclear spin manipulation and long-lived nunclear-spin based quantum memories.

QI 7.6 Wed 12:00 H4

**Quantum polyspectra for modeling and evaluating quantum measurements: A unifying approach to the strong and weak measurement regime** — •Markus Sifft[1], Annika Kurzmann[2], Jens Kerski[2], Rüdiger Schott[3], Arne Ludwig[3], Andreas D. Wieck[3], Axel Lorke[2], Martin Geller[2], and Daniel Hägele[1] — [1]Ruhr University Bochum, Faculty of Physics and Astronomy, Experimental Physics VI (AG), Germany — [2]Faculty of Physics and CENIDE, University of Duisburg-Essen, Lotharstraße 1, 47057 Duisburg, Germany — [3]Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, Universitätsstraße 150, D-44780 Bochum, Germany

Quantum polyspectra of up to fourth order are introduced for modeling and evaluating quantum measurements. As an example, experimental time-traces of the occupation dynamics of a single quantum dot are evaluated via simultaneously fitting their 2nd-, 3rd-, and 4th-order spectra. Moreover, the evaluation of time-traces via quantum polyspectra is demonstrated to be feasible also in the weak measurement regime even when quantum jumps can no longer be identified from time-traces and methods related to the full counting statistics cease to be applicable. Quantum polyspectra thus constitute a unifying approach to the strong and weak regime of quantum mea- surements in general with possible applications in diverse fields as nano-electronic, circuit quantum electrodynamics, spin noise spectroscopy, or quantum optics.

QI 7.7 Wed 12:15 H4

**Towards satellite-suited noise-free quantum memories** — •Luisa Esguerra[1,2], Leon Messner[1,2], Elizabeth Robertson[1,2], Mustafa Gündoğan[1,3], and Janik Wolters[1,2] — [1]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institute of Optical Sensor Systems, Rutherfordstr. 2, 12489 Berlin, Germany. — [2]TU Berlin, Institut für Optik und Atomare Physik, Hardenbergstr. 36, 10623 Berlin, Germany. — [3]Institut für Physik, Humboldt-Universität zu Berlin, Newtonstr. 15, Berlin 12489, Germany.

The use of memory-assisted quantum repeaters on satellites as transmission links between the nodes of a quantum network could push the current distance limit for quantum key distribution QKD [1]. We have

realised a technologically simple, satellite-suited quantum memory in Caesium vapour, based on electromagnetically induced transparency (EIT) on the D1 line, similar to [2]. We have achieved light storage at the single-photon level with end-to-end efficiencies up to 11%, which correspond to internal memory efficiencies of up to 44%. We also achieve a maximal signal-to-noise level of unity for input signal pulses containing $\bar{\mu}_1 = 0.029$ photons. Furthermore, we have determined the limiting noise source at this level to be spontaneous Raman scattering processes in the Lambda-system.

[1] M. Gündoğan et al., arXiv:2006.10636 (2020)
[2] J. Wolters, et al., PRL 119, 060502 (2017)