Q 33: Quantum Information (Concepts and Methods) IV

Time: Wednesday 14:00–16:00 Location: e001

Group Report Q 33.1 Wed 14:00 e001

Quantum simulations in a linear Paul trap and a 2D array — •Deviprasath Palani, Florian Hasse, Matthias Wittemer, Frederick Hakelberg, Philip Kiefer, Jan-Philipp Schröder, Ulrich Warring, and Tobias Schaetz — Physikalisches Institut, University of Freiburg

Trapped ions present a promising platform for quantum simulations [1]. In our linear Paul trap, we switch the trapping potential sufficiently fast to induce a non-adiabatic change of the ions' motional mode frequencies. Thereby, we prepare the ions in a squeezed state of motion. This process is accompanied by the formation of entanglement in the ions' motional degree of freedom and can be interpreted as an experimental analogue to the particle pair creation during cosmic inflation in the early universe [2].

In our basic triangular array of individually trapped ions with 40 μm inter-site distance, we realize the coupling between ions at different sites via their Coulomb interactions. We demonstrate its tuning in real-time and show interference of coherent states of currently large amplitudes [3]. In addition, we employ the individual control for local modulation of the trapping potential to realize Floquet-engineered coupling of adjacent sites [4].

[1] T. Schaetz *et al.*, New J. Phys. **15**, 085009 (2013).
[2] M. Wittemer *et al.*, Phys. Rev. Lett. **123**, 180502 (2019).
[3] F. Hakelberg *et al.*, Phys. Rev. Lett. **123**, 100504 (2019).
[4] P. Kiefer *et al.*, Phys. Rev. Lett. **123**, 213605 (2019).

Q 33.2 Wed 14:30 e001

Dynamical decoupling of anisotropic interacting spin ensembles — •Pablo Cova Fariña[1], Benjamin Merkel[1], Penghong Yu[1], Natalia Herrera Valencia[1], and Andreas Reiserer[1,2] — [1]Max Planck Institute of Quantum Optics, Hans-Kopfermann-Straße 1, 85748 Garching bei München, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Ludwig-Maximilians-Universität München, 80799 München, Germany

Rare-earth doped crystals are explored for quantum memory and quantum sensing applications because they can exhibit long coherence times of both spin and optical transitions. Among the rare earths, Erbium stands out for two reasons. First, its optical transition is at a telecom wavelength. Second, the large magnetic moment of its electronic spin, with effective g factors up to 16, renders it a possible candidate for quantum magnetometers with high sensitivity. Unfortunately, this large and anisotropic effective g factor comes at the prize of strong spin-spin interactions that often limit the achievable coherence time. In this work, we explore how to overcome this challenge in Er:YSO crystals using dynamical decoupling (DD). With a simple spin echo, we observe an increase of the coherence time by an order of magnitude. However, using standard DD sequences, such as XY-8, does not bring a much larger improvement, as the coherence in our 10 ppm doped crystal is limited by instantaneous diffusion. We therefore analyze the effect of novel DD sequences, both from an experimental and a theoretical point of view, and show that they can outperform standard DD sequences for anisotropic and strongly interacting spin ensembles.

Q 33.3 Wed 14:45 e001

Neural Network Heuristics for Adaptive Bayesian Quantum Estimation — Lukas J. Fiderer[1], Jonas Schuff[1,2], and •Daniel Braun[1] — [1]Institute for Theoretical Physics, University of Tübingen, Tübingen, Germany — [2]Department of Materials, University of Oxford, Oxford, United Kingdom

Adaptive experiment design is crucial in order to exploit the benefits of Bayesian quantum estimation. We propose and demonstrate a general method for creating fast and strong experiment design heuristics based on neural networks. Training of the neural networks relies on a combination of imitation and reinforcement learning. Based on the well-studied example of frequency estimation with a qubit which suffers from T_2 relaxation, we demonstrate that neural networks trained with reinforcement learning are tailored to the properties of the estimation problem and take into account the availability of resources such as time or the number of measurements. The simultaneous estimation of the frequency and the relaxation rate is considered as well. We find that the neural network heuristics are able to outperform well-established heuristics in all examples.

Q 33.4 Wed 15:00 e001

Spin-Sensitive Readout of Two-Dimensional Wigner Crystals in Transition-Metal Dichalcogenides — Johannes Knörzer[1,2], Martin J. A. Schuetz[3], •Géza Giedke[4,5], Richard Schmidt[1,2], Dominik S. Wild[3], Kristiaan De Greve[3], Mikhail D. Lukin[3], and J. Ignacio Cirac[1,2] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), 80799 München, Germany — [3]Physics Department, Harvard University, Cambridge, MA 02318, USA — [4]Donostia International Physics Center, 20018 San Sebastián, Spain — [5]Ikerbasque Foundation for Science, 48013 Bilbao, Spain

Wigner crystals are prime candidates for the realization of regular electron lattices with minimal requirements on external control and a potential basis for quantum registers or simulators. However, technical challenges have prevented their detailed experimental investigation to date. Here, we investigate two-dimensional electron lattices based on self-assembled Wigner crystals in transition-metal dichalcogenides (TMDs), which provide favorable conditions for the formation of Wigner crystals. We show that they allow for minimally invasive, all-optical detection schemes of charge ordering and total spin. For suitably chosen incident light, we predict a strong dependence of the transmitted and reflected signals on the underlying lattice periodicity, thus revealing the charge order inherent in Wigner crystals. At the same time, the selection rules in TMDs provide direct access to the spin degree of freedom via Faraday rotation measurements. Prospects for the quantum simulation of spin-systems are discussed.

Q 33.5 Wed 15:15 e001

Simulation of topological phases and edge states via quantum walks with step-dependent coins — •Shahram Panahiyan and Stephan Fritzsche — Helmholtz-Institut Jena, Jena, Germany

We investigate simulations of topological phenomena in condense matter through two types of quantum walk (simple-step and split-step) with step-dependent coins. Here, we address two issues for simulation of topological phases and edge states via quantum walk. First, we show that quantum walk with step dependent coin simulates all types of topological phases and edge states. This also indicates the simulation of all types of topological phase transitions. Second, we show that step-dependent coins provide the step number as a controlling factor over the simulations. In fact, with tuning the step number, we can determine the occurrences of edge states/topological phases, the type of edge state/topological phases and where they should be located.

Q 33.6 Wed 15:30 e001

Topological order in perturbed toric code models — •Amit Jamadagni Gangapuram and Hendrik Weimer — Institut für Theoretische Physik, Leibniz Universität Hannover, Hannover, Germany.

We present a few signatures to detect topological order using concepts from quantum information. Based on the toric code model, we construct various closed and open quantum systems that encode a possible topological phase transition. We compare various approaches to topological order by their ability to successfully detect topological phase transitions within these models.

Q 33.7 Wed 15:45 e001

Unsupervised phase discovery with deep anomaly detection — •Korbinian Kottmann[1], Patrick Hümbeli[1], Maciej Lewenstein[1,2], and Antonio Acín[1,2] — [1]ICFO, Avinguda Carl Friedrich Gauss, 3, 08860 Castelldefels — [2]ICREA, Passeig de Lluís Companys, 23, 08010 Barcelona

We present a novel method for automated and unsupervised discovery of new and unknown phases in quantum many-body scenarios. Instead of supervised learning, where data is classified using labeled data, we perform anomaly detection, where the task is to differentiate a normal data set, composed of one or several classes, from anomalous data. We propose a scheme, employing deep neural networks, to map out the whole phase diagram. The method can be used completely unsupervised and automated to explore the entire phase diagram. As a paradigmatic example, we explore the phase diagram of the extended Bose Hubbard model in one dimension at integer filling. We compute the ground states using tensor networks and exemplarily use both unprocessed data like the central tensor and processed data like entan-

glement spectra that suffice to reproduce the phase diagram. The formulation of the method is independent of the nature of the data and could as well be used with physical observables, i.e. experimental data.