# QI 36: Quantum Metrology (joint session QI/Q)

Time: Friday 11:00–13:00 Location: F428

QI 36.1 Fri 11:00 F428

**Super-Resolution Imaging with Multiparameter Quantum Metrology in Passive Remote Sensing** — •Emre Köse and Daniel Braun — Institut für Theoretische Physik, Eberhard Karls Universität Tübingen, 72076 Tübingen, Germany

We study super-resolution imaging theoretically using a distant n-mode interferometer in the microwave regime for passive remote sensing, used e.g., for satellites like the "soil moisture and ocean salinity (SMOS)" mission to observe the surface of the Earth. We give a complete quantum mechanical analysis of multiparameter estimation of the temperatures on the source plane. We find the optimal detection modes by combining incoming modes with an optimized unitary that enables the most informative measurement based on photon counting in the detection modes and saturates the quantum Cramér-Rao bound from the symmetric logarithmic derivative for the parameter set of temperatures. In our numerical analysis, we achieved a quantum-enhanced super-resolution by reconstructing an image using the maximum likelihood estimator with a pixel size of 3 (km), which is ten times smaller than the spatial resolution of SMOS with comparable parameters. Further, we find the optimized unitary for uniform temperature distribution on the source plane, with the temperatures corresponding to the average temperatures of the image. Even though the corresponding unitary was not optimized for the specific image, it still gives a super-resolution compared to local measurement scenarios for the theoretically possible maximum number of measurements.

QI 36.2 Fri 11:15 F428

**Activation of metrologically useful genuine multipartite entanglement** — •Róbert Trényi[1,2,3], Árpád Lukács[1,4,3], Paweł Horodecki[5,6], Ryszard Horodecki[5], Tamás Vértesi[7], and Géza Tóth[1,2,8,3] — [1]Dept. of Theoretical Physics, U. of the Basque Country UPV/EHU, Bilbao, Spain — [2]DIPC, San Sebastián, Spain — [3]Wigner Research Centre for Physics, Budapest, Hungary — [4]Dept. of Mathematical Sciences, Durham University, United Kingdom — [5]International Centre for Theory of Quantum Technologies, University of Gdansk, Gdansk, Poland — [6]Faculty of Applied Physics and Mathematics, National Quantum Information Centre, Gdansk University of Technology, Gdansk, Poland — [7]Institute for Nuclear Research, Debrecen, Hungary — [8]IKERBASQUE, Bilbao, Spain

In quantum metrology, the usefulness of a quantum state is determined by how much it outperforms separable states. For the maximal metrological usefulness genuine multipartite entanglement (GME) is required. In order to improve the usefulness of a quantum state we consider a scheme of having several of its copies. With this scheme, it is possible to find a large class of practically important entangled states that can achieve maximal metrological performance in the limit of many copies, whereas in the single copy case these states can even be non-useful. Thus, we essentially activate quantum metrologically useful GME. Moreover, this maximal usefulness is attained exponentially fast with the number of copies and it can be achieved by measurements of simple correlation observables. We also give examples of improving the usefulness outside of the above mentioned class.

QI 36.3 Fri 11:30 F428

**Quantum metrology with ultracold chemical reactions** — Seong-Ho Shinn[1], Uwe R. Fischer[1], and •Daniel Braun[2] — [1]Seoul National University — [2]Eberhard Karls University Tübingen

Classical chemical reactions are routinely used for extremely sensitive detection schemes in chemical, biological, and medical analysis, and have even been employed in the search for dark matter. Now we show that coherent, ultracold chemical reactions harbor great potential for quantum metrology [1]: In an atom-molecule Bose-Einstein condensate (BEC), a weak external perturbation can generate elementary excitations, "reactons", of a reaction field. In an appropriate atom-dominant parameter regime this translates to the coherent creation of molecules which can be selectively detected with modern spectroscopic techniques. This promises to improve the viability of previously proposed BEC-based sensors for gravitational waves and other physical quantities, for which so far no practical read-out scheme could be demonstrated.

[1] Seong-Ho Shinn, Uwe R. Fischer, and Daniel Braun, arXiv:2208.06380

QI 36.4 Fri 11:45 F428

**Quantum metrology from randomized measurements** — •Satoya Imai[1], Otfried Gühne[1], and Géza Tóth[2,3,4,5] — [1]Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Walter-Flex-Str. 3, 57068 Siegen, Germany — [2]Department of Theoretical Physics, University of the Basque Country UPV/EHU, P.O. Box 644, E-48080 Bilbao, Spain — [3]Donostia International Physics Center (DIPC), ES-20080 San Sebastian, Spain — [4]IKERBASQUE, Basque Foundation for Science, E-48013 Bilbao, Spain — [5]Wigner Research Centre for Physics, Hungarian Academy of Sciences, P.O. Box 49, H-1525 Budapest, Hungary

A central task in quantum metrology is to consider a parameter encoding on a quantum system and to improve schemes to reach optimal precision. To reach higher precision, precise control of state preparation and favorable measurements may be necessary. In practice, however, unavoidable noise effects, such as magnetic field fluctuations, may affect the estimation accuracy. A key idea to address this situation is to perform a random measurement on the quantum system and access local unitary invariants. This procedure motivates the study of quantum metrology without a common reference frame between several parties. In this talk, we present a systematic method to investigate the estimation sensitivity in the dynamics based on nonlinear interaction Hamiltonians. We show that the well-known Heisenberg scaling is achievable and even better scaling is attainable.

QI 36.5 Fri 12:00 F428

**Closed-loop Quantum Optimal Control for Electronic Spins** — •Thomas Reisser[1,2], Marco Rossignolo[3,4], Matthias M. Müller[1], Felix Motzoi[1], Fedor Jelezko[3], Simone Montangero[4,5], and Tommaso Calarco[1,2] — [1]Forschungszentrum Jülich GmbH — [2]University of Cologne — [3]Ulm University — [4]Università degli Studi di Padova — [5]INFN, Sezione di Padova

To unlock the full potential of many quantum technologies, quantum optimal control (QOC) algorithms and strategies are used to enhance and enable operations on a quantum system. While some methods depend on simulations and good models of the system, it can be helpful to close the loop with an experiment in order to tweak the given controls for a specific setup. The Quantum Optimal Control Suite (QuOCS) is designed to perform black-box optimization in connection with an arbitrary experiment or simulation. Due to its interface with the experiment control software Qudi [1] is has been used successfully for the optimization of pulses for color centers in diamond and also two-qubit gates with Rydberg Atoms [2]. We show the main features of the QuOCS software package and report on recent developments and applications of QOC on electron spins in crystals with a focus on quantum sensing.

References:

[1] J. M. Binder et al., Qudi: A modular python suite for experiment control and data processing, SoftwareX (2017)

[2] A. Pagano et al., Error budgeting for a controlled-phase gate with strontium-88 rydberg atoms, PRR (2022)

QI 36.6 Fri 12:15 F428

**Quantum Wasserstein distance based on an optimization over separable states** — •Géza Tóth[1,2,3,4] and József Pitrik[4,5,6] — [1]Theoretical Physics and EHU Quantum Center, University of the Basque Country UPV/EHU, ES-48080 Bilbao, Spain — [2]Donostia International Physics Center (DIPC), ES-20080 San Sebastián, Spain — [3]IKERBASQUE, Basque Foundation for Science, ES-48011 Bilbao, Spain — [4]Wigner Research Centre for Physics, HU-1525 Budapest, Hungary — [5]Alfréd Rényi Institute of Mathematics, HU-1053 Budapest, Hungary — [6]Department of Analysis, Institute of Mathematics, Budapest University of Technology and Economics, HU-1111 Budapest, Hungary

We define the quantum Wasserstein distance such that the optimization is carried out over bipartite separable states rather than bipartite quantum states in general, and examine its properties. Surprisingly, we find that its self-distance is related to the quantum Fisher information. We discuss how the quantum Wasserstein distance introduced is connected to criteria detecting quantum entanglement. We define variance-like quantities that can be obtained from the quantum Wasserstein distance by replacing the minimization over quantum states by a maximization. We extend our results to a family of generalized quantum Fisher information.

[1] G. Tóth and J. Pitrik, arXiv:2209.09925.

QI 36.7 Fri 12:30 F428

**Infrared laser absorption magnetometry with Ensembles of Nitrogen-Vacancy centres** — •Felipe Perona[1,2], Julian Bopp[2], Jonas Wollenberg[2], and Tim Schröder[1,2] — [1]Ferdinand-Braun-Institut (FBH), Berlin, Germany — [2]Humboldt-Universität zu Berlin, Department of Physics, Berlin, Germany

Magnetometers based on ensembles of Nitrogen-Vacancy (NV) centres have shown sub-nanotesla sensitivities [1]. The applied measurement concept relies on the detection and analysis of the intensity of the NV's red fluorescence, which, under the proper conditions, encodes the value of a magnetic field at the defect location. A less explored approach is using the infrared absorption of the NV centre at 1042 nm as a medium to read its local magnetic environment [2]. This strategy avoids the necessity of implementing high photon collection efficiencies, improves the read-out contrast, and simplifies the sensing setup, allowing a higher degree of integration. In this work, we implement infrared laser absorption magnetometry and demonstrate that such magnetometer can reach high sensitivities. To maximize this sensitivity, we engineer the NV density of our diamonds and optimize it for this task. We integrate the concept into a compact device towards enabling miniaturized, portable magnetometers.

[1] H. Clevenson et al., "Broadband magnetometry and temperature sensing with a light-trapping diamond waveguide", Nat. Phys., 11:5, 2015 [2] V. Acosta et al., "Broadband magnetometry by infrared-absorption detection of nitrogen-vacancy ensembles in diamond", Appl. Phys. Lett., 97:17, 2010

QI 36.8 Fri 12:45 F428

**Gradient Magnetometry with Atomic Ensembles** — •Iagoba Apellaniz[1], Iñigo Urizar-Lanz[1], Zoltán Zimborás[1,2,3], Philipp Hyllus[1], and Géza Tóth[1,3,4] — [1]Department of Physics, University of the Basque Country UPV/EHU, P. O. Box 644, E-48080 Bilbao, Spain — [2]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany — [3]Wigner Research Centre for Physics, Hungarian Academy of Sciences, P.O. Box 49, H-1525 Budapest, Hungary — [4]IKERBASQUE, Basque Foundation for Science, E-48013 Bilbao, Spain

We calculate precision bounds for estimating the gradient of the magnetic field based on the quantum Fisher information for various types of ensembles, such as for example, a single atomic ensemble with an arbitrary density profile, where the atoms cannot be addressed individually and which is a very relevant case for experiments.

We present a method to find spin states for gradient magnetometry with two spatially separated atomic ensembles based on states for sensing a global phase shift, such as the GHZ state or the Dicke state.

[1] I. Apellaniz et al., Phys. Rev. A, 97 053603 (2018)
[2] G. Vitagliano et al., arXiv:2104.05663 (2021)