QI 9: Quantum Metrology

Time: Thursday 10:45–12:45 Location: H4

Invited Talk QI 9.1 Thu 10:45 H4

The true Heisenberg limit in optical interferometry — •Rafal Demkowicz-Dobrzanski — University of Warsaw, Poland

The concept of the Heisenberg limit represents the ultimate bound on estimation precision in quantum enhanced optical interferometry and in quantum metrology in general. In the context of optical interferometry it refers to the inverse-proportionality scaling of the phase estimation precision as a function of the number of photons used in the experiment—a quadratic improvement over the shot noise scaling. Even though at a first glance there should be no ambiguity as to the actual form of the limit, it comes in different variants depending on whether: (i) definite or indefinite photon number states are considered, (ii) reference beam is explicitly taken into account or not, (iii) multiple-repetition or single-shot scenarios are considered. This results in Heisenberg limits that differ by constant factors and a reasonable question to ask is: ‘which one is the actual operationally meaningful one?’.

This issue has an even more dramatic turn in case of multiple-arm interferometry where multiple relative phases are to be estimated simultaneously. In this case the actual scaling of the Heisenberg limit, in terms of the number of phases being estimated, may differ depending on the approach.

Invited Talk QI 9.2 Thu 11:15 H4

On the quantum limits of field sensing — •Morgan Mitchell — ICFO - The Institute of Photonic Sciences, Barcelona, Spain

We discuss the nature and status of “energy resolution” limits in magnetic field sensing. Unlike better-known quantum limits, energy resolution limits constrain directly the sensitivity, with no reference to particle number or any other resource. Today’s best-developed magnetometer technologies are known to be limited to an energy resolution per bandwidth of about $\hbar$. We discuss the possibility that this is a universal sensing limit, and describe proposed sensing methods that could surpass the $\hbar$ level.

Reference: Mitchell, Morgan W. and Palacios Alvarez, Silvana, “Colloquium: Quantum limits to the energy resolution of magnetic field sensors,” Rev. Mod. Phys. **92**, 021001 (2020). `https://doi.org/10.1103/RevModPhys.92.021001`

QI 9.3 Thu 11:45 H4

Activating hidden metrological usefulness — •Géza Tóth[1,2,3,4], Tamás Vértesi[5], Paweł Horodecki[6,7], and Ryszard Horodecki[6,8] — [1]Theoretical Physics, University of the Basque Country UPV/EHU, E-48080 Bilbao, Spain — [2]Donostia International Physics Center (DIPC), E-20080 San Sebastián, Spain — [3]IKERBASQUE, Basque Foundation for Science, E-48011 Bilbao, Spain — [4]Wigner Research Centre for Physics, H-1525 Budapest, Hungary — [5]Institute for Nuclear Research, Hungarian Academy of Sciences, H-4001 Debrecen, Hungary — [6]International Centre for Theory of Quantum Technologies, University of Gdańsk, PL-80308 Gdańsk, Poland — [7]Faculty of Applied Physics and Mathematics, National Quantum Information Centre, Gdańsk University of Technology, PL-80233 Gdańsk, Poland — [8]Institute of Theoretical Physics and Astrophysics, National Quantum Information Centre, Faculty of Mathematics, Physics and Informatics, University of Gdańsk, PL-80308 Gdańsk, Poland

We consider entangled states that cannot outperform separable states in any linear interferometer. Then, we show that these states can still be more useful metrologically than separable states if several copies of the state are provided or an ancilla is added to the quantum system. We present a general method to find the local Hamiltonian for which a given quantum state performs the best compared to separable states.

QI 9.4 Thu 12:00 H4

Time-energy uncertainty relation for noisy quantum metrology — •Philippe Faist[1], Mischa P. Woods[2], Victor V. Albert[4], Joseph M Renes[2], Jens Eisert[1], and John Preskill[3,5] — [1]Freie Universität Berlin — [2]ETH Zurich, Switzerland — [3]Caltech, Pasadena, USA — [4]JCQCI, NIST and University of Maryland, USA — [5]AWS Center for Quantum Computing, USA

Quantum metrology has many applications to science and technology, including the detection of very weak forces and precise measurement of time. To sense time, one prepares an initial state of a clock system, allows the system to evolve as governed by a Hamiltonian H, and then performs a measurement to estimate the time elapsed. Here, we introduce and study a fundamental trade-off which relates the amount by which the application of a noise channel reduces the accuracy of a quantum clock to the amount of information about the energy of the clock that leaks to the environment. We prove that Bob’s loss of quantum Fisher information about the elapsed time is equal to Eve’s gain of quantum Fisher information about a complementary energy parameter. We also prove a similar, but more general, trade-off that applies when Bob and Eve wish to estimate the values of parameters associated with two non-commuting observables. We derive the necessary and sufficient conditions for the accuracy of the clock to be unaffected by the noise, which are weaker than the Knill-Laflamme error-correction conditions. We discuss applications of the trade-off relation to sensing using a quantum many-body probe subject to erasure or amplitude-damping noise.

QI 9.5 Thu 12:15 H4

Metrological complementarity reveals the Einstein-Podolsky-Rosen paradox — •Benjamin Yadin[1,2], Matteo Fadel[3], and Manuel Gessner[4] — [1]School of Mathematical Sciences, University of Nottingham, Nottingham, UK — [2]Wolfson College, University of Oxford, Oxford, UK — [3]Department of Physics, University of Basel, Basel, Switzerland — [4]Laboratoire Kastler Brossel, ENS-Université PSL, CNRS, Sorbonne Université, Collège de France, Paris, France

The Einstein-Podolsky-Rosen (EPR) paradox plays a fundamental role in our understanding of quantum mechanics, and is associated with the possibility of predicting the results of non-commuting measurements with a precision that seems to violate the uncertainty principle. This apparent contradiction to complementarity is made possible by nonclassical correlations stronger than entanglement, called steering. Quantum information recognises steering as an essential resource for a number of tasks but, contrary to entanglement, its role for metrology has so far remained unclear. Here, we formulate the EPR paradox in the framework of quantum metrology, showing that it enables the precise estimation of a local phase shift and of its generating observable. Employing a stricter formulation of quantum complementarity, we derive a criterion based on the quantum Fisher information that detects steering in a larger class of states than well-known uncertainty-based criteria. Our result identifies useful steering for quantum-enhanced precision measurements and allows one to uncover steering of non-Gaussian states in state-of-the-art experiments.

QI 9.6 Thu 12:30 H4

Bayesian Quantum Thermometry — •Julia Boeyens[1], Stefan Nimmrichter[1], and Stella Seah[2] — [1]University of Siegen, Siegen 57068, Germany — [2]University of Geneva, 1211 Geneva, Switzerland

Most theoretical treatments of temperature estimation in quantum systems have focused on systems in thermal equilibrium in the asymptotic limit of many measurements. In this limit, the thermal Cramér-Rao bound applies, and the optimal measurement strategy can be found by maximizing the Fisher information, either locally for each possible temperature or over a desired temperature range [1]. It has also been shown that driving systems out of thermal equilibrium by means of repeated finite-time collisions with non-thermal probes can boost temperature sensitivity beyond the Cramér-Rao bound in the limit of many repetitions [2]. However, in practical implementations, only scarce data may be available and the Bayesian method of parameter estimation is more appropriate [3]. Here, we study non-informative Bayesian thermometry with a minimal restriction on the allowed temperature range and with a limited number of qubit probes in and out of thermal equilibrium. We compare different estimates for the temperature and the associated error and work out the most faithful estimation strategy. We demonstrate how non-equilibrium thermometry improves measurement precision at high temperatures already for a few hundred qubit probes.

[1] M. Mehboudi, A. Sanpera, L.A. Correa; J. Phys. A 52, 303001 (2019) [2] S. Seah et al; Phys. Rev. Lett. 123, 180602 (2019) [3] J. Rubio, J. Anders, L.A. Correa; arXiv:2011.13018