Quantum metrology in interacting and open systems (QUMINOS)

Registrants Book

Table of contents

Paolo Abiuso 1
Clarice Aiello 2
Francesco Albarelli 3
Nicholas Anto-Sztrikacs 4
George Bakewell-Smith 5
Jessica Bavaresco 6
Gianmichele Blasi 7
Julia Boeyens 8
Jonatan Bohr Brask 9
Albert Cabot 10
John Calsamiglia 11
Angelo Carollo 12
Farhan T. Chowdhury 13
Matthias Christandl 14
Luis Correa 15
Rafal Demkowicz-Dobrzanski 16
Giovanni Di Fresco 17
Alicja Dutkiewicz 18
Philippe Faist 19
Simone Felicetti 20
Irénée Frérot 21
Louis Garbe 22
Manuel Gessner 23
Karol Gietka 24
Wojciech Gorecki 25
Madalin Guta 26
Géraldine Haack 27
Arne Hamann 28

Stanisław Kurdziałek 29
Patryk Lipka-Bartosik 30
Mohammad Mehboudi 31
Florian Meier 32
George Mihailescu 33
Devendra Kumar Mishra 34
Andrew Mitchell 35
Mark Mitchison 36
GUILLEM MÜLLER-RIGAT 37
Alberto Muñoz de las Heras 38
Tobias Nadolny 39
Stefan Nimmrichter 40
Matheus Eiji Ohno Bezerra 41
Marti Perarnau Llobet 42
Ricard Puig i Valls 43
Marco Radaelli 44
Ricard Ravell Rodríguez 45
Alberto Rolandi 46
Jesús Rubio Jiménez 47
Pavel Sekatski 48
Alice Sinatra 49
Michalis Skotiniotis 50
Anubhav Kumar Srivastava 51
Alejandro Vivas-Viaña 52

Paolo Abiuso #18

Personal Data

Affiliation: IQOQI - Vienna

Contribution

Title: Quantum metrology at equilibrium

Abstract: We consider parameter estimation on generic systems at thermal equilibrium, assuming total or partial control on their finite-dimensional Hamiltonian. First, we study the problem of temperature estimation, given a physically-sound class of control Hamiltonians constrained only by the locality of interactions between constituents. We prove that even with classical, two-body, and short-ranged interactions, it is possible to approximate the fundamental limits of thermometry in finite-dimensional systems. Secondly, we study the estimation of parameters encoded in generic perturbations of the control Hamiltonian. We prove that, with no constraints on the control, no fundamental advantage is offered by quantum mechanics in terms of the maximum attainable Fisher information, which can be achieved with classical interactions and whose optimal scaling is typically quadratic in the number of constituents of the system. A quantum advantage is recovered when assuming additional constraints on the control Hamiltonian, such as a minimum energy gap between the ground state and the first excited level.

Clarice Aiello #53

Personal Data

Affiliation: QuBitLab

Contribution

Title: “Quantum Biology”: how nature harnesses quantum processes to function optimally, and how might we control such quantum processes to therapeutic and tech advantage

Abstract: Imagine driving cell activities to treat injuries and disease simply by using tailored magnetic fields. Many relevant physiological processes, such as: the regulation of oxidative stress, proliferation, and respiration rates in cells; wound healing; ion channel functioning; and DNA repair were all demonstrated to be controlled by weak magnetic fields (with a strength on the order of that produced by your cell phone). Such macroscopic physiological responses to magnetic fields are consistent with being driven by chemical reactions that depend on the electron quantum property of spin. In the long-term, the electromagnetic fine-tuning of endogenous “quantum knobs” existing in nature could enable the development of drugs and therapeutic devices that could heal the human body — in a way that is non-invasive, remotely actuated, and easily accessible by anyone with a mobile phone. However, whereas spin-dependent chemical reactions have been unambiguously established for test-tube chemistry (bearing uncanny similarities with what physicists call “spin quantum sensing”), current research has not been able to deterministically link spin states to physiological outcomes in vivo and in real time. With novel quantum instrumentation, we are learning to control spin states within cells and tissues, having as a goal to write the “codebook” on how to deterministically alter physiology with weak magnetic fields to therapeutic and technological advantage. Bio Dr. Clarice D. Aiello is a quantum engineer interested in how quantum physics informs biology at the nanoscale. She is an expert on nanosensors harnessing room-temperature quantum effects in noisy environments. Clarice received her B.S. in Physics from the Ecole Polytechnique; her M.Phil. in Physics from the University of Cambridge, Trinity College; and her Ph.D. from MIT in Electrical Engineering. She also held postdoctoral appointments in Bioengineering at Stanford, and in Chemistry at Berkeley. Two months before the pandemic, she joined UCLA, where she led the Quantum Biology Tech (QuBiT) Lab. Since Nov 2023, she is the CEO of a startup unsurprisingly named Quantum Biology Tech (QuBiT) Lab, and is writing the first-ever textbook about Quantum Biology.

Francesco Albarelli #38

Personal Data

Affiliation: Scuola Normale Superiore

Contribution

Title:
Abstract:

Nicholas Anto-Sztrikacs #43

Personal Data

Affiliation: University of Toronto

Contribution

Title: Bypassing thermalization timescales in temperature estimation using prethermal probes

Abstract: We introduce prethermal temperature probes for sensitive, fast and robust temperature estimation. While equilibrium thermal probes with a manifold of quasidegenerate excited states have been previously recognized for their maximal sensitivity, they suffer from long thermalization timescales. When considering time as a critical resource in thermometry, it becomes evident that these equilibrium probes fall short of ideal performance. Here, we propose a different paradigm for thermometry, where setups originally suggested for optimal equilibrium thermometry should instead be employed as prethermal probes, by making use of their long-lived quasiequilibrium state. For a class of physically-motivated initial conditions, we find that energy measurements of the prethermal state exhibit a similar sensitivity as the equilibrium state. However, they offer the distinct benefit of orders of magnitude reduction in the time required for the estimation protocol, opening avenues for rapid thermometry by harnessing the long-lived prethermal states. Upon introducing a figure-of-merit that accounts for the estimation protocol time, prethermal probes surpass the corresponding equilibrium probes in terms of effective thermal sensitivity, opening avenues for rapid thermometry by harnessing the long-lived prethermal states.

George Bakewell-Smith #20

Personal Data

Affiliation: University of Nottingham

Contribution

Title: Upper Bounds on Fluctuations of First Passage Times for Classical and Quantum Markov Processes

Abstract: First passage times (FPTs) denote the time taken for a process to reach a specific threshold value, such as the arrival of a molecule at a reaction site, or the crossing of a financial stock beyond a critical value. In the realm of quantum systems, FPTs can capture the time taken for specific computations. Much work has been done on lower bounding fluctuations about some average of dynamical quantities, notably in the form of the celebrated thermodynamic uncertainty relations (TURs), a class of lower bounds on the uncertainty of observables of the process. The TURs have also been extended to the FPTs themselves. In previous works [1], we derived complementary upper bounds on such fluctuations of observables in the form of a concentration inequality, from which one can not only determine an upper limit on the size of the uncertainty, but also on the tails of the distribution. We now extend this work and derive a concentration inequality for first passage times. This allows us, for a given time, to upper bound the probability of the process having reached this condition. We derive these bounds using perturbative techniques. Our bounds are valid for “counting” observables, representing the number of configuration changes in the system. In a quantum system, these counts represent the number of photons emitted for a particular duration. We present bounds applicable to both classical and quantum Markov processes. Classical applications could be determining the likelihood of a company descending into insolvency within a timeframe, or the concentration of a chemical. In quantum metrology, these bounds can be used to obtain confidence intervals for dynamical parameters of the system [2]. I will discuss these results and their interesting applications. This talk is based on joint work with Madalin Guta, Federico Girotti and Juan P. Garrahan. [1] G. Bakewell-Smith, F. Girotti, M. Gut¸˘a, J. P. Garrahan, Phys. Rev. Lett. 131, 197101 (2023) [2] F. Girotti, J. P. Garrahan, M. Gutta, Annales Henri Poincare, pp. 1–34 (2023)

Jessica Bavaresco #51

Personal Data

Affiliation: University of Geneva

Contribution

Title: Unitary channel discrimination beyond group structures: Advantages of sequential and indefinite-causal-order strategies

Abstract: The formalism of higher-order operations can be used to efficiently find the optimal strategies for a channel discrimination task. Such strategies may be subjected to different causal constraints, such as being parallel (non-adaptive) or sequential (adaptive). Furthermore, a different class of strategies, those involving indefinite causal order, naturally arise when considering tasks of channel discrimination. Focusing on the discrimination of unitary channels, we show that sequential strategies may outperform parallel ones, and that, in turn, general strategies with indefinite causal order may outperform sequential ones. This hierarchy of discrimination is only possible when at least one of two things are true: either the prior distribution of the unitary channels is not uniform, or the unitaries being discriminated do not form a group. When the hypothesis that the prior is uniform and the unitaries form a group holds, we show that parallel strategies are optimal even when compared to indefinite-causal-order strategies. Finally, we present an ultimate upper bound for the probability of successfully discriminating a set of unitary channels and study the application of strategies based on the quantum switch for this task.

Gianmichele Blasi #9

Personal Data

Affiliation: University of Geneva

Contribution

Title:

Abstract:

Julia Boeyens #41

Personal Data

Affiliation: University of Siegen

Contribution

Title: Global quantum thermometry and the role of information geometry

Abstract: Abstract: Quantum metrology facilitates the design of precise protocols for quantum thermometry. The application of Bayesian principles to open system metrology, in particular, has received considerable attention in recent years. When the data and the prior information are limited, Bayesian estimates perform more reliably than standard maximum likelihood estimation would suggest. But to use the Bayesian framework, one is required to choose a deviation function quantifying the accuracy of the scheme, as well as a to specify of the amount of prior information about the unknown parameter. In the interest of designing a protocol that is globally applicable, one should start with a prior distribution that is as uninformative as possible, but this choice needs to be based on the physical properties of the type of quantity to be estimated. On the one hand, invariance under repametrisations of the likelihood model has been suggested as a way to derive uninformative priors in thermometry. This naturally leads to specifying the deviation of the scheme via information geometry. On the other hand, temperature defines an energy scale, suggesting that scale invariance is in fact the relevant symmetry. But scale invariance induces a different deviation function and uninformed prior. In this work we investigate under which conditions each of these seemingly competing assumptions ought to be employed, establishing practical guidelines depending on how much data is available.

Jonatan Bohr Brask #54

Personal Data

Affiliation: Technical University of Denmark

Contribution

Title: TBA
Abstract: -

Albert Cabot #47

Personal Data

Affiliation: Universität Tübingen

Contribution

Title: Continuous sensing and parameter estimation with the boundary time crystal

Abstract: A boundary time crystal is a quantum many-body system whose dynamics is governed by the competition between coherent driving and collective dissipation. It is composed of N two-level systems and features a transition between a stationary phase and an oscillatory one. The fact that the system is open allows to continuously monitor its quantum trajectories and to analyze their dependence on parameter changes. This enables the realization of a sensing device whose performance we investigate as a function of the monitoring time T and of the system size N. We find that the best achievable sensitivity is proportional to $\sqrt{T} N$, i.e., it follows the standard quantum limit in time and Heisenberg scaling in the particle number. This theoretical scaling can be achieved in the oscillatory time-crystal phase and it is rooted in emergent quantum correlations. The main challenge is, however, to tap this capability in a measurement protocol that is experimentally feasible. We demonstrate that the standard quantum limit can be surpassed by cascading two time-crystals, where the quantum trajectories of one time-crystal are used as input for the other one.

John Calsamiglia #56

Personal Data

Affiliation: Universitat Autònoma de Barcelona

Contribution

Title: Quantum Sequential Analysis

Abstract: The standard paradigm in quantum statistical inference protocols is to optimize the accuracy of the estimates given a fixed sample size of quantum data. That is, the data (or stream of data) has a finite fixed horizon. Sequential analysis is the branch of statistics that goes beyond this finite horizon setting by considering inference problems in which the decision whether or not to stop at any stage depends on the observations previously made. I will present the ultimate quantum limits for two paradigmatic sequential analysis problems. The first one is sequential quantum hypothesis testing, where the goal is to discriminate between two arbitrary quantum states, with a prescribed error threshold and with the minimal average number copies used. I will show that sequential strategies outperform the currently established ultimate limits based on fixed number of copies. The second problem is that of the quickest change point detection. Here, a source emits quantum particles in a default state, until a certain moment when it undergoes an abrubpt change and starts producing a different state. The task is to detect the change point as quick as possible given a prescribed false alarm rate. In both problems, the quantity characterizing their performance will be shown to be quantum relative entropy.

Angelo Carollo #46

Personal Data

Affiliation: University of Palermo

Contribution

Title: Quantum-enhanced sensing from non-Hermitian topology

Abstract: Non-Hermitian physics predicts open quantum system dynamics with unique topological features such as exceptional points and the non-Hermitian skin effect. We show that this new paradigm of topological systems can serve as probes for bulk Hamiltonian parameters with quantum-enhanced sensitivity reaching Heisenberg scaling. Such enhancement occurs close to a spectral topological phase transition, where the entire spectrum undergoes a delocalization transition. We provide an explanation for this enhanced sensitivity based on the closing of point gap, which is a genuinely non-Hermitian energy gap with no Hermitian counterpart. This extends the role of energy-gap closing as the main factor for quantum enhancement to the non-Hermitian realm. Our findings are demonstrated through several paradigmatic non-Hermitian topological models in various dimensions and potential experimental implementations.

Farhan T. Chowdhury #40

Personal Data

Affiliation: University of Exeter

Contribution

Title: Quantum Control of Radical Pair Dynamics beyond Time-Local Optimisation

Abstract: We realise arbitrary waveform-based control of spin-selective radical pair recombination reactions in the low magnetic field regime. To this end, we extended the Gradient Ascent Pulse Engineering (GRAPE) paradigm to allow for optimising time-integral reaction yields. This overcomes drawbacks of previously suggested time-local optimisation approaches for the reaction control of radical pairs, which were limited in their applicability to spin systems in high biasing fields. We demonstrate how efficient time-global optimisation of recombination yields can be achieved by gradient based methods augmented by time-blocking, sparse sampling of the yield, and evaluation of the central single-timestep propagators and their Frechet derivatives using iterated Trotter-Suzuki splittings. Results are demonstrated in simulations for both a toy model, previously used to demonstrate coherent control of radical pair reactions in the simpler high-field scenario, and furthermore for a realistic exciplex-forming donor-acceptor system comprising 16 nuclear spins. This raises prospects for the spin-control of actual radical pair systems in ambient magnetic fields, by suppressing or boosting radical reaction yields using purpose-specific radio-frequency waveforms, paving the way for reaction-yield-dependent quantum magnetometry and potentially applications of quantum control to biochemical radical pair reactions.

Matthias Christandl #45

Personal Data

Affiliation: University of Copenhagen

Contribution

Title: Lindblad Tomography of a Superconducting Quantum Processor

Abstract: As progress is made towards the first generation of error-corrected quantum computers, robust characterization and validation protocols are required to assess the noise environments of physical quantum processors. While standard coherence metrics and characterization protocols such as T1 and T2, process tomography, and randomized benchmarking are now ubiquitous, these techniques provide only partial information about the dynamic multi-qubit loss channels responsible for processor errors, which can be described more fully by a Lindblad operator in the master equation formalism. Here, we introduce and experimentally demonstrate Lindblad tomography, a hardware-agnostic characterization protocol for tomographically reconstructing the Hamiltonian and Lindblad operators of a quantum noise environment from an ensemble of time-domain measurements. Performing Lindblad tomography on a small superconducting quantum processor, we show that this technique characterizes and accounts for state-preparation and measurement (SPAM) errors and allows one to place bounds on the fit to a Markovian model. Comparing the results of single- and two-qubit measurements on a superconducting quantum processor, we demonstrate that Lindblad tomography can also be used to identify and quantify sources of crosstalk on quantum processors, such as the presence of always-on qubit-qubit interactions.

Luis Correa #50

Personal Data

Affiliation: Universidad de La Laguna

Contribution

Title: Optimal cold atom thermometry using adaptive bayesian strategies

Abstract: Precise temperature measurements on systems of few ultracold atoms is of paramount importance in quantum technologies, but can be very resource intensive. Here, we put forward an adaptive Bayesian framework that substantially boosts the performance of cold atom temperature estimation. Specifically, we process data from real and simulated release–recapture thermometry experiments on few potassium atoms cooled down to the microkelvin range in an optical tweezer. From simulations, we demonstrate that adaptively choosing the release–recapture times to maximize information gain does substantially reduce the number of measurements needed for the estimate to converge to a final reading. Unlike conventional methods, our proposal systematically avoids capturing and processing uninformative data. We also find that a simpler nonadaptive method exploiting all the a priori information can yield competitive results, and we put it to the test on real experimental data. Furthermore, we are able to produce much more reliable estimates, especially when the measured data are scarce and noisy, and they converge faster to the real temperature in the asymptotic limit. Importantly, the underlying Bayesian framework is not platform specific and can be adapted to enhance precision in other setups, thus opening new avenues in quantum thermometry.

Rafal Demkowicz-Dobrzanski #16

Personal Data

Affiliation: Faculty of Physics, University of Warsaw

Contribution

Title: Quantum Metrological Toolbox - all you need to know to find the optimal metrological protocols in presence of noise

Abstract: Identifying the optimal quantum metrological protocols in presence of realistic noise may be challenging. Brute force methods usually do not allow to study models in the regimes interesting from practical point of view. In this talk I will present the state-of-the-art (and even a bit beyond..) tools that allow for an efficient search of the optimal protocols even in asymptotic regime of infinite available resources (particles, time, etc..) as well as methods to derive fundamental bounds that can certify their optimality.

Giovanni Di Fresco #30

Personal Data

Affiliation: Palermo university, Italy.

Contribution

Title: Metrological Aspects of Measurement-Induced Quantum Phase Transitions

Abstract: Recently, it has been shown that the interaction between deterministic quantum evolution and a sequence of measurement processes can give rise to sudden alterations in the entanglement characteristics of a system, leading to a phenomenon known as a measurement-induced phase transition (MIPT). In various contexts, Quantum Fisher Information (QFI) is employed to assess a quantum system's sensitivity to slight parameter variations and is commonly utilized to detect quantum phase transitions. It is natural to inquire whether phase transitions induced by measurement processes can also be identified through the QFI. In this work, we use two different approaches to assess whether the QFI can detect MIPT in fermionic/spin system. With the first approach, we aim to observe the entanglement of the system. Indeed, one of the defining sig- natures of an MIPT is the abrupt changes in the entanglement properties of the system, typically discerned through entanglement entropy. However, when adopting an appropriate metrological approach, the QFI not only detects entanglement but also provides more comprehensive insights than entanglement entropy, revealing the presence of valuable metrological entanglement and multipartite entanglement. Our findings demonstrate that the QFI can discriminate between distinct phases within an MIPT scenario. In the second approach, we establish a scheme where the QFI is directly related to the fidelity susceptibility, and our analysis demonstrates that, for this specific class of phase transition, the QFI exhibits a non-analytic behavior at the transition point.

Alicja Dutkiewicz #26

Personal Data

Affiliation: Leiden University

Contribution

Title: The advantage of quantum control in many-body Hamiltonian learning

Abstract: We study the problem of learning the Hamiltonian of a many-body quantum system from experimental data. We show that the rate of learning depends on the amount of control available during the experiment. We consider three control models: one where time evolution can be augmented with instantaneous quantum operations, one where the Hamiltonian itself can be augmented by adding constant terms, and one where the experimentalist has no control over the system's time evolution. With continuous quantum control, we provide an adaptive algorithm for learning a many-body Hamiltonian at the Heisenberg limit: T = O(1/ϵ), where T is the total amount of time evolution across all experiments and ϵ is the target precision. This requires only preparation of product states, time-evolution, and measurement in a product basis. In the absence of quantum control, we prove that learning is standard quantum limited, T = Ω(1/ϵ^2), for large classes of many-body Hamiltonians, including any Hamiltonian that thermalizes via the eigenstate thermalization hypothesis. These results establish a quadratic advantage in experimental runtime for learning with quantum control.

Philippe Faist #31

Personal Data

Affiliation: Freie Univ. Berlin

Contribution

Title: Quantum metrology in the finite-sample regime

Abstract: In quantum metrology, one of the major applications of quantum technologies, the ultimate precision of estimating an unknown parameter is often stated in terms of the Cramér-Rao bound. Yet, the latter is no longer guaranteed to carry an operational meaning in the regime where few measurement samples are obtained, which we illustrate through a simple example. We instead derive an inherently finite-size analysis of a quantum metrology protocol inspired by single-shot quantum information theory. This approach ensures operational significance in the finite-sample regime. The accuracy guarantees hold for any value of the unknown parameter, unlike the Cramér-Rao bound which assumes it is approximately known. We establish stronger connections to multi-hypothesis testing with quantum states, we obtain an analogue of the Cramér-Rao bound which contains explicit corrections relevant to the finite-sample regime, and apply our framework to the example task of phase estimation with an ensemble of spin-1/2 particles. Overall, our operational approach allows the study of quantum metrology in the finite-sample regime and opens up a plethora of new avenues for research at the interface of quantum information theory and quantum metrology.

Simone Felicetti #57

Personal Data

Affiliation: Institute for Complex Systems, National Research Council (ISC-CNR) and Physics Department, Sapienza University

Contribution

Title: Critical Parametric Quantum Sensing

Abstract: Finite-component phase transitions (FCPT) are critical phenomena that take place in driven-dissipative quantum systems with a finite number of components, where the thermodynamical limit is replaced by a rescaling of the system physical parameters. The framework of FCPT represents a compelling approach to explore quantum critical phenomena using few-body quantum optical models, greatly simplifying both theoretical analyses and experimental implementations. In turn, designing critical quantum sensing (CQS) protocols based on FCPT has a two-fold advantage: On the one hand, FCPT allows us to investigate fundamental bounds of the estimation precision achievable with CQS protocols using analytical or semi-analytical methods. On the other hand, FCPT provide a feasible approach to implement optimal critical quantum sensors using small-scale, controllable devices. In this contribution, we will first review recent theoretical efforts on the design of quantum sensing protocols. Then, we will present the results of an experimental observation of a FCPT in a superconducting parametric quantum resonator.

Irénée Frérot #19

Personal Data

Affiliation: Laboratoire Kastler Brossel, Sorbonne Université, CNRS, ENS-PSL Research University, Collège de France, 4 Place Jussieu, 75005 Paris, France

Contribution

Title:

Abstract:

Louis Garbe #55

Personal Data

Affiliation: TU München

Contribution

Title: Critical sensing in finite-size bosonic systems

Abstract: Systems close to a critical point become extremely sensitive to small external perturbations, a property that could be leveraged for sensing applications. In this talk, I will discuss how these effects can be implemented even in "finite-size" systems, ie systems involving a finite number of components (such as the Rabi model, driven Kerr oscillator, or a pair of interacting bosonic modes). These systems could allow to implement critical sensing protocols with greater simplicity and controllability.

Manuel Gessner #52

Personal Data

Affiliation: Departament de Física Teòrica, IFIC, Universitat de València

Contribution

Title: Quantum metrology with finite samples: Generalizing the quantum Cramér-Rao bound

Abstract: The cornerstone of modern quantum metrology is the quantum Cramér-Rao bound and the quantum Fisher information. Under generic conditions, this bound can be saturated by an optimal estimator and measurement, provided that a large amount of repeated measurements on the system are performed. However, in the presence of smaller data sets it typically largely underestimates the error that can actually be achieved. In this talk, we present a family of generalized bounds on the variance of unbiased estimators that are larger than the quantum Cramér-Rao bound when the sample is small and thereby provide a more realistic limit on the achievable precision of a finite-sample quantum measurement. In the large-data limit, the hierarchy of bounds collapses back onto the quantum Cramér-Rao bound.

Karol Gietka #6

Personal Data

Affiliation: University of Innsbruck

Contribution

Title: Temperature-enhanced Critical Quantum Metrology

Abstract: We show that the performance of critical quantum metrology protocols, counter-intuitively, can be enhanced by finite temperature. We consider a toy-model squeezing Hamiltonian, the Lipkin-Meshkov-Glick model and the paradigmatic Ising model. We show that the temperature enhancement of the quantum Fisher information can be achieved by adiabatic preparation of the critical state and by preparing it directly in the proximity of the critical point. We also find a relatively simple, however, non-optimal measurement capable of harnessing finite temperature to increase the parameter estimation sensitivity. Therefore, we argue that temperature can be considered as a resource in critical quantum metrology.

Wojciech Gorecki #8

Personal Data

Affiliation: INFN Sez. Pavia, University of Pavia

Contribution

Title: Critical quantum metrology in a finite time framework

Abstract: Critical metrology provides a framework to find states that are extremely sensitive to a change in a system parameter. However, achieving such states in practice (adiabatically or by thermalization) may require a proportionately long time. Therefore, for a fair comparison with other metrology protocols, both the state's energy N and evolution time T should be treated as a resource. It then becomes legitimate to ask: what advantage can critical metrology manifest over other quantum protocols, assuming that both use the same total amount of resources understood as the product of energy and time $N \cdot T$? In this work, we analyze the issue of estimating the frequency of a resonant cavity interacting with a thermal bath. It was shown in that when a nonlinearity is added to the system via a parametric Kerr resonator, the stationary state of the system becomes extremely sensitive to changes in frequency. In our work, we address the time evolution of this system, both zero and non-zero temperatures. We show that the analyzed protocol is close to saturating the fundamental bounds formulated in terms of $N \cdot T$. Moreover, it presents a substantial advantage over simpler passive protocols when finite measurement time is taken into account.

Madalin Guta #23

Personal Data

Affiliation: University of Nottingham

Contribution

Title: Optimal estimation of quantum Markov chains

Abstract: In this talk I will discuss the problem of estimating dynamical parameters of a quantum Markov chain. The key tool will be the use of a coherent quantum absorber which transforms the problem into a simpler one pertaining to a system with a pure stationary state at a reference parameter value. I will then define certain translationally invariant modes of the output and show that the output state reduces to a coherent state of these modes. This provides a concrete representation of the local asymptotic normality phenomenon for Markov dynamics. I will then discuss how to optimally estimate unknown dynamical parameters by using a recently developed technique of displaced-null measurements.

Géraldine Haack #49

Personal Data

Affiliation: University of Geneva

Contribution

Title:
Abstract:

Arne Hamann

#5

Personal Data

Affiliation: Universität Innsbruck

Contribution

Title:
Abstract:

Stanisław Kurdziałek #7

Personal Data

Affiliation: University of Warsaw

Contribution

Title: Optimal adaptive quantum metrological protocols via tensor network formalism

Abstract: We present an efficient algorithm for determining optimal adaptive quantum channel estimation protocols with arbitrary quantum control operations between subsequent channel uses. Our method optimizes quantum Fisher information across all adaptive (quantum active feedback) strategies, utilizing an effective iterative procedure where each step is a semidefinite program. The procedure can be applied for all types of correlated and uncorrelated noise. We introduce a tensor network representation of an estimation strategy, which drastically reduces the time and memory consumption of an algorithm—we demonstrate optimal protocols for $N = 50$ qubit channel uses, whereas the state-of-the-art methods only work for $N < 5$. Additionally, in our approach, it is possible to control the size of the ancillary system used. Results are presented for key noise models, including amplitude damping and dephasing, with a particular focus on the role of noise correlations in dephasing scenarios.

Patryk Lipka-Bartosik #1

Personal Data

Affiliation: University of Geneva

Contribution

Title: Organizer
Abstract: No abstract

Mohammad Mehboudi #36

Personal Data

Affiliation: TU Wien

Contribution

Title: Optimal protocols for single-shot Bayesian quantum metrology

Abstract: Using quantum systems as sensors or probes has been shown to greatly improve the precision of parameter estimation by exploiting unique quantum features such as entanglement. A major task in quantum sensing is to design the optimal protocol, i.e., the most precise one. It has been solved for some specific instances of the problem, but in general even numerical methods are not known. Here, we focus on the single-shot Bayesian setting, where the goal is to find the optimal initial state of the probe (which can be entangled with an auxiliary system), the optimal measurement, and the optimal estimator function. We leverage the formalism of higher-order operations to develop a method based on semidefinite programming that finds a protocol that is close to the optimal one with arbitrary precision. This method is not restricted to any specific quantum evolution, cost function or prior distribution, and thus can be applied to any estimation problem. Moreover, it can be applied to both single or multiparameter estimation tasks. We demonstrate our method with three examples, consisting of unitary phase estimation, thermometry in a bosonic bath, and multiparameter estimation of an SU(2) transformation. Exploiting our methods, we extend several results from the literature. For example, in the thermometry case, we find the optimal protocol at any finite time and quantify the usefulness of entanglement.

Florian Meier #48

Personal Data

Affiliation: Atominstitut, Technische Universität Wien

Contribution

Title: Fundamental accuracy-resolution trade-off in timekeeping devices

Abstract: In a world intricately connected by time, clocks synchronize global communication networks, ensure GPS precision, and they allow the Swiss people to live up to their punctuality stereotype. While classical physics has long held a firm grasp on the workings of clocks and their continuous refinement, our journey into the quantum realm reveals new frontiers in precision timekeeping. In this talk, we delve into the fundamental physics of clocks, uncovering their role in quantum metrology. The key insight is that autonomous clocks which tick periodically without an external agent controlling them require out of equilibrium resources to run. By understanding this deep connection between thermodynamics and timekeeping we find out how oscillatory (quantum) systems are essential in enhancing clock accuracy by temporally modulating the thermodynamic flux toward equilibrium. These ideas reveal two fundamental limitations impacting clock performance. Firstly, the frequency of oscillatory systems inside the clock inevitably experiences drift over time, and secondly, the thermodynamic processes driving the clock are inherently stochastic and thus not perfectly predictable. The first issue is conventionally addressed by finding stable atomic or nuclear transitions as a frequency reference, contributing to the remarkable precision achieved by modern clocks. In this talk, we focus on the second limitation by presenting a universal trade-off relation applicable to all clocks whose ticking events are generated by a memoryless stochastic process. The trade-off establishes that the accuracy of a clock is bounded by its resolution: higher resolution results in lower accuracy, and vice versa. This bound complements ongoing research on quantifying the thermodynamic resources required for accurate timekeeping. Furthermore, by unveiling the boundaries of what can be achieved within the laws of physics, the bound also offers crucial insights into overcoming the challenges that stand in the way of realizing accurate high-resolution clocks.

George Mihailescu #21

Personal Data

Affiliation: University College Dublin

Contribution

Title: Multiparameter critical quantum metrology with impurity probes

Abstract: Quantum systems can be used as probes in the context of metrology for enhanced parameter estimation. In particular, the delicacy of critical systems to perturbations can make them ideal sensors. Arguably the simplest realistic probe system is a spin-1/2 impurity, which can be manipulated and measured in-situ when embedded in a fermionic environment. Although entanglement between a single impurity probe and its environment produces nontrivial many-body effects, criticality cannot be leveraged for sensing. Here we introduce instead the two-impurity Kondo (2IK) model as a novel paradigm for critical quantum metrology, and examine the multiparameter estimation scenario at finite temperature. We explore the full metrological phase diagram numerically and obtain exact analytic results near criticality. Enhanced sensitivity to the inter-impurity coupling driving a second-order phase transition is evidenced by diverging quantum Fisher information (QFI) and quantum signal-to-noise ratio (QSNR). However, with uncertainty in both coupling strength and temperature, the multiparameter QFI matrix becomes singular -- even though the parameters to be estimated are independent -- resulting in vanishing QSNRs. We demonstrate that by applying a known control field, the singularity can be removed and measurement sensitivity restored. For general systems, we show that the degradation in the QSNR due to uncertainties in another parameter is controlled by the degree of correlation between the unknown parameters.

Devendra Kumar Mishra #13

Personal Data

Affiliation: Department of Physics, Institute of Science, Banaras Hindu University, Varanasi-221005, India

Contribution

Title: Quantum-enhanced sensitivity of Mach-Zehnder interferometer using squeezed Kerr state

Abstract: For precision measurement of certain parameters, which are not measurable directly via conventional techniques, phase estimation via optical interferometers, like Mach-Zehnder interferometer (MZI), plays an important role. The proposal of using the squeezed vacuum on the unused input port of the MZI by C. M. Caves in 1981 started a new era in the field ofquantum metrology. In order to improve the phase sensitivity of aMZI several nonclassical states and approaches have come. Here, theoretically, we are investigating the phase super-sensitivity of the MZI by using the squeezed Kerr state (SKS) and coherent states as inputs of the interferometer. A squeezed Kerr state can be generated by squeezing the coherent state followed by the Kerr medium. Employing single intensity detection, intensity difference detection, and homodyne detection schemes, we demonstrate that, in some conditions, our approach achieves enhanced sensitivity under both lossless and lossy conditions when compared to established input combinations such as coherent plus vacuum, coherent plus squeezed vacuum and double coherent states. The feasibility of generating the SKS using existing quantum optical techniques adds a layer of practicality to our findings. We expect that SKS could emerge as a valuable nonclassical resource, propelling the advancement of phase super-sensitivity within MZIs under real-world conditions. In essence, our exploration opens the door to a more precise and practical era in optical interferometry. The work has been reported in arXiv: 2309.04731 [quant-ph].

Andrew Mitchell #39

Personal Data

Affiliation: University College Dublin

Contribution

Title: Measuring entropy in a quantum nanoelectronics device

Abstract: Quantum nanoelectronics devices are strongly correlated many-body systems involving a few localized interacting quantum degrees of freedom, coupled to metallic leads comprising a continuum of conduction electrons in the thermodynamic limit. Experimental platforms such as semiconductor quantum dots or single-molecule transistors exhibit a wide range of nontrivial physics, from Coulomb blockade and Kondo effect, to non-Fermi liquid behavior at quantum critical points and fractionalization. Signatures of this physics show up clearly in the theoretically-predicted entropy of the device, but measuring this entropy experimentally in a mesoscopic system has been a long-standing open question. Here I discuss recent theoretical and experimental results for measuring the entropy of an interacting open quantum system, by exploiting local Maxwell relations that connect the measured *charge* on the device to changes in entropy for a given process. I also explore the role of the charge sensor in existing experiments in terms of measurement backaction. PRL 129, 227702 (2022); PRL 128, 146803 (2022)

Mark Mitchison #4

Personal Data

Affiliation: Trinity College Dublin

Contribution

Title: Thermometry by correlated dephasing of impurities in a 1D Fermi gas

Abstract: We theoretically investigate the pure dephasing dynamics of two static impurity qubits embedded within a common environment of ultracold fermionic atoms, which are confined to one spatial dimension. Our goal is to understand how bath-mediated interactions between impurities affect their performance as nonequilibrium quantum thermometers. By solving the dynamics exactly using a functional determinant approach, we show that the impurities become correlated via retarded interactions of the Ruderman-Kittel-Kasuya-Yosida type. Moreover, we demonstrate that these correlations can provide a metrological advantage, enhancing the sensitivity of the two-qubit thermometer beyond that of two independent impurities. This enhancement is most prominent in the limit of low temperature and weak collisional coupling between the impurities and the gas. We show that this precision advantage can be exploited using standard Ramsey interferometry, with no need to prepare correlated initial states nor to individually manipulate or measure the impurities. We also quantitatively assess the impact of ignoring these correlations when constructing a temperature estimate, finding that acceptable precision can still be achieved from a simplified model of independent impurities. Our results demonstrate the rich nonequilibrium physics of impurities dephasing in a common Fermi gas, and may help to provide better temperature estimates at ultralow temperatures.

GUILLEM MÜLLER-RIGAT #22

Personal Data

Affiliation: ICFO

Contribution

Title: Certifying the quantum Fisher information from a given set of mean values: a semidefinite programming approach

Abstract: We introduce a semidefinite programming algorithm to find the minimal quantum Fisher information compatible with an arbitrary dataset of mean values. This certification task allows one to quantify the resource content of a quantum system for metrology applications without complete knowledge of the quantum state. We implement the algorithm to study quantum spin ensembles. We first focus on Dicke states, where our findings challenge and complement previous results in the literature. We then investigate states generated during the one-axis twisting dynamics, where in particular we find that the metrological power of the so-called multi-headed cat states can be certified using simple collective spin observables, such as fourth-order moments for small systems, and parity measurements for arbitrary system sizes. Quantum 7, 1152 (2023).

Alberto Muñoz de las Heras #15

Personal Data

Affiliation: Institute of Fundamental Physics IFF-CSIC

Contribution

Title: Photonic quantum metrology with variational quantum optical non-linearities

Abstract: Photonic quantum metrology harnesses complex quantum states of light, such as Fock or NOON states, to measure unknown parameters beyond classical precision limits. Currently, its main bottleneck is the efficient generation of metrologically-relevant states with large photon numbers because state-of-the-art methods are either probabilistic with a decreasing success probability with the photon number [1] or deterministic ones with poor fidelities due to the large number of operations required [2]. In this contribution I will show how to deterministically generate metrologically-relevant states with large photon numbers exploiting tunable quantum optical non-linearities in a variational quantum algorithm [3]. The key idea of such hybrid algorithm is to use a classical optimizer to find the set of parameters of a parametrized quantum circuit implemented on the hardware such that it generates states maximizing the quantum Fisher information. In a second step of the algorithm, by maximizing the classical Fisher information we also find optimal measurements for the protocol. We benchmark our method with two different classes of non-linearities: the one coming from the coupling of light to a two-level emitter and a Kerr-type one. We show that our method can reach metrologically-relevant states with a low number of operations independently of the photon-number, and study its resilience against noise [4]. Type of contribution: oral
References: [1] C. Sayrin, I. Dotsenko, X. Zhou, et al., Nature 477, 73–77 (2011). [2] M. Hofheinz, H. Wang, M. Ansmann, et al., Nature 459, 546–549 (2009). [3] M. Cerezo, A. Arrasmith, R. Babbush, et al., Nature Reviews Physics 3, 625–644 (2021). [4] AMH, C. Tabares, J. T. Schneider, et al., arXiv:2309.09841 (2023).

Tobias Nadolny #25

Personal Data

Affiliation: University of Basel

Contribution

Title: Synchronization of quantum oscillators

Abstract: Synchronization is a widespread phenomenon in which limit-cycle oscillators adjust their frequencies and exhibit coherence even in the presence of noise and disorder in their natural frequencies. This poster presents synchronization of quantum oscillators. After discussing relations between quantum and classical synchronization, we focus on quantum effects in the synchronization of large ensembles of quantum oscillators [PRL 131, 190402 (2023)]. We demonstrate how quantum features of the individual oscillators shape the collective synchronization dynamics. Since quantum synchronization is related to the presence of entanglement and robust coherence, we aim to explore its connections to quantum metrology in the future.

Stefan Nimmrichter #33

Personal Data

Affiliation: University of Siegen

Contribution

Title: Some Applications of Scattering Metrology
Abstract:

Matheus Eiji Ohno Bezerra #11

Personal Data

Affiliation: Universidade Federal do ABC (UFABC)

Contribution

Title: Simultaneous estimation of phase and loss using Gaussian states

Abstract: The estimation of a phase encoded in an optical interferometer is a problem already well settled and which have some applications, for example in the quantum enhancement in the detection of gravitational waves. In this context, the photon loss is an important source noise that is manifested in any interferometric scheme, being therefore an important parameter to be estimated. The estimation of photon loss is also well settled and besides being a noise parameter, also can be considered as the parameter of interest, for example in absorption measurements. However, when we look for estimating both phase and loss simultaneously, it becomes into a problem not yet fully solved. When a state with a fixed number of photons is considered, that are an incompatibility in the level of the state probe used, i.e. in the quantum Fisher information. Otherwise, by using certain classes of Gaussian states, which have an indefinite number of photons, this trade-off can be asymptotically eliminated. However the incompatibility still persists in the level of the measurement.

Marti Perarnau Llobet #37

Personal Data

Affiliation:

Contribution

Title:
Abstract:

Ricard Puig i Valls #32

Personal Data

Affiliation: EPFL

Contribution

Title: Achieving Heisenberg Scaling via interacting many body dynamics

Abstract: Theoretical models describing quantum metrology schemes and the corresponding experimental demonstrations have so far mainly described step-by-step protocols that involve the preparation of the sensor into a carefully engineered quantum state; interaction of the sensor with an external (unknown) field and measurement of the sensor to retrieve information about the signal. However, the process of preparation can sometimes be lengthy, require fine tuning in time as well as be very sensible to noise and decoherence. The main goal of this project is to contribute to this challenge by using many-body interactions to entangle the state while field encodes its information into it. Thus, we eliminate the preparation process and we add some dynamics that can recover the entanglement lost because of the noise.

Marco Radaelli #29

Personal Data

Affiliation: School of Physics, Trinity College Dublin, Ireland

Contribution

Title: Parameter Estimation for Quantum Jump Unravelling

Abstract: We consider the estimation of parameters encoded in the measurement record of a continuously monitored quantum system in the jump unravelling. This unravelling picture corresponds to a single-shot scenario, where information is continuously gathered. Here, it is generally difficult to assess the precision of the estimation procedure via the Fisher Information due to intricate temporal correlations and memory effects. In this work we provide a full set of solutions to this problem. First, for multi-channel renewal processes we relate the Fisher Information to an underlying Markov chain and derive a easily computable expression for it. For non-renewal processes, we introduce a new algorithm that combines two methods: the monitoring operator method for metrology and the Gillespie algorithm which allows for efficient sampling of a stochastic form of the Fisher Information along individual quantum trajectories. We show that this stochastic Fisher Information satisfies useful properties related to estimation in the single-shot scenario. Finally, we consider the case where some information is lost in data compression/post-selection, and provide tools for computing the Fisher Information in this case. All scenarios are illustrated with instructive examples from quantum optics and condensed matter. We finish with a detailed analysis of the single-atom maser, an important experimental example where our framework could be directly applied.

Ricard Ravell Rodríguez #34

Personal Data

Affiliation: BCAM

Contribution

Title: Strongly coupled fermionic probe for nonequilibrium thermometry

Abstract: We characterise the measurement sensitivity, quantified by the Quantum Fisher Information (QFI), of a single-fermionic thermometric probe strongly coupled to the sample of interest, a fermionic bath, at temperature T. For nonequilibrium protocols, in which the probe is measured before reaching equilibrium with the sample, we find new behaviour of the measurement sensitivity arising due to non-Markovian dynamics. First, we show that the QFI displays a highly non-monotonic behaviour in time, in contrast to the Markovian case where it grows monotonically until equilibrium, so that non-Markovian revivals can be exploited to reach a higher QFI. Second, the QFI rate is maximised at a finite interrogation time t^*, which we characterize, in contrast to the solution $t^* \rightarrow 0$ known in the Markovian limit [Quantum 6, 869 (2022)]. Finally, we consider probes make up of few fermions and discuss different collective enhancements in the measurement precision.

Alberto Rolandi #3

Personal Data

Affiliation: University of Geneva

Contribution

Title: Collective Advantages in Finite-Time Thermodynamics

Abstract: A central task in finite-time thermodynamics is to minimize the excess or dissipated work Wdiss when manipulating the state of a system immersed in a thermal bath. We consider this task for an N-body system whose constituents are identical and uncorrelated at the beginning and end of the process. In the regime of slow but finite-time processes, we show that Wdiss can be dramatically reduced by considering collective protocols in which interactions are suitably created along the protocol. This can even lead to a sublinear growth of Wdiss with N: Wdiss□N^x with x < 1; to be contrasted to the expected Wdiss □N satisfied in any noninteracting protocol. We derive the fundamental limits to such collective advantages and show that x = 0 is in principle possible; however, it requires long-range interactions. We explore collective processes with spin models featuring two-body interactions and achieve noticeable gains under realistic levels of control in simple interaction architectures. As an application of these results, we focus on the erasure of information in finite time and prove a faster convergence to Landauer’s bound.

Jesús Rubio Jiménez #27

Personal Data

Affiliation: University of Surrey

Contribution

Title: Global quantum metrology beyond phase estimation

Abstract: Quantum metrology is often thought of as inseparable from phase estimation, but modern quantum technologies are inspiring new metrology problems beyond this framework. Two of such problems are quantum thermometry and the estimation of decay rates in dissipative processes, which replace the familiar circular symmetry of phases by scale invariance. In this talk, a new, more general framework for global quantum metrology is presented. Symmetries satisfied by the prior information are taken as defining the metrological framework to be employed. This is shown to lead to a multiplicity of metrologies where the category of the parameter to be estimated acquires a fundamental role. Two practical consequences follow from this. First, the use of Bayesian principles, which are needed to exploit prior information symmetries, guarantees valid estimates and errors even in scenarios with scarce or noisy data. Secondly, Bayesian uncertainty optimisers enable the derivation of optimal strategies with minimum estimation error, thus rendering the search for error bounds unnecessary. The potential of the new framework is finally demonstrated by addressing the estimation of parameters that are neither shifts, nor scales.

Pavel Sekatski #42

Personal Data

Affiliation: University of Geneva

Contribution

Title:
Abstract:

Alice Sinatra #10

Personal Data

Affiliation: Laboratoire Kastler Brossel ENS

Contribution

Title: Quantum-enhanced multiparameter estimation and compressed sensing of a field

Abstract: We show that a significant quantum gain corresponding to squeezed or over-squeezed spin states can be obtained in multiparameter estimation by measuring the Hadamard coefficients of a 1D or 2D signal. The physical platform we consider consists of two-level atoms in an optical lattice in a squeezed-Mott configuration, or more generally by correlated spins distributed in spatially separated modes. Our protocol requires the possibility to locally flip the spins, but relies on collective measurements. We give examples of applications to scalar or vector field mapping and compressed sensing.

Michalis Skotiniotis #2

Personal Data

Affiliation: University of Granada

Contribution

Title:
Abstract:

Anubhav Kumar Srivastava #24

Personal Data

Affiliation: ICFO, Spain

Contribution

Title: Topological quantum thermometry

Abstract: An optimal local quantum thermometer [L. Correa, et. al., Phys. Rev. Lett. 114, 220405 (2015)] has a particular energy level structure with a single ground state and highly degenerated excited states manifold, with an energy gap proportional to the estimated temperature. We show [arXiv:2311.14524] that such a spectrum can be engineered in a system of spinless fermions confined in a one-dimensional optical lattice described by the experimentally realizable topological Rice-Mele model at specific lattice fillings, resulting in a close-to-optimal sensitivity of the system to the temperature changes. We characterize the system's sensitivity to temperature changes in terms of quantum Fisher information. We also study the thermalisation dynamics of the proposed topological thermometer coupled with a quantum many-body system.

Alejandro Vivas-Viaña #35

Personal Data

Affiliation: Departamento de Física Teórica de la Materia Condensada and Condensed Matter Physics Center (IFIMAC), Universidad Autónoma de Madrid.

Contribution

Title: Quantum metrology through spectral measurements in quantum optics

Abstract: Quantum optical systems can emit light with very complex spectral properties. For instance, the emergence of dressed states from coherently driven quantum emitters, hybridized excitonic states or hybrid light-matter states (polaritons) in cavity QED translate into rich fluorescence spectra with multiple peaks that reflect the complex structure of eigenstates. These spectra exhibit equally complex dependences with the parameters that govern the dynamics of the system, and therefore offer the opportunity to improve the inference of unknown parameters by frequency-filtering the emitted signal. Here, we explore this idea in quantum optical systems consisting of coherently driven quantum emitters in dissipative scenarios. Specifically, in Ref. [1], we focus on the estimation of the inter-emitter distance between two nonidentical interacting quantum emitters driven by a coherent field by measuring the fluorescence spectrum. We identify, by means of the Fisher information [2], that the two-photon resonance (i.e., when the laser frequency is at half of the energy of the doubly excited state) and the onset of the two-photon saturation regime (i.e., when the two-photon dressing effects begin to be resolved in the spectrum) are the most sensitive points for distance estimation. It is known that hybridized light-matter systems, e.g., a strongly driven two-level system [3], give complex correlations in frequency space. Following this idea, we discuss the role of quantum correlations and quantify their impact on the precision by which unknown atomic parameters can be estimated, assessing the potential of frequency-resolved correlation measurements for the task of parameter estimation in driven-dissipative quantum optical systems. [1] A. Vivas-Viaña and C. Sánchez Muñoz, Two-photon resonance fluorescence of two interacting nonidentical quantum emitters, Phys. Rev. Research 3, 033136 (2021). [2] M. G. Paris, Quantum estimation for quantum technology, Int. J. Quantum Inf. 07, 125 (2009). [3] C. Sánchez Muñoz, E. del Valle, C. Tejedor, and F. P. Laussy, Violation of classical inequalities by photon frequency filtering, Phys. Rev. A 90, 052111 (2014).