QuICS - Quantum: Information, Complexity, Simulation

Report of Contributions

Contribution ID: **2** Type: **not specified**

Quantum functional testing

Tuesday 30 September 2025 10:50 (40 minutes)

With increasing complexity of quantum-information-processing devices, testing their functionality becomes a pressing and difficult problem. "Quantum Functional Testing" refers to the decision problem of accepting or rejecting a quantum device based on specifications provided by the producer and limited experimental evidence, combined with information gathering about failure mechanisms. The decision should be reached as quickly as possible, yet with as high confidence as possible. The task is therefore fundamentally different from quantum tomography, where one seeks as complete characterization of a quantum state or a quantum channel as possible. Here we review and propose several tools and principles for quantum functional testing, ranging from the formalism of truncated moment sequences, over statistics of the lengths of measurement sequences, to automated experimental design for maximum information gain with non-greedy Bayesian parameter estimation, culminating in pattern-based functional testing of quantum memories.

Presenter: BRAUN, Daniel

Session Classification: Keynote Speakers

Contribution ID: **3** Type: **not specified**

Multiple-observable entropic uncertainty relations and entanglement detection

Tuesday 30 September 2025 09:00 (40 minutes)

We review the concepts of entropic uncertainty relations (EUR) and consider the case of multiple observables. We investigate the corresponding additivity properties for both bipartite and multipartite systems where the EUR are defined in terms of the joint Shannon entropy of probabilities of local measurement outcomes. We show that the additivity of EUR holds only for EUR that involve two observables, while this is not the case for inequalities that consider more than two observables or the addition of the von Neumann entropy of a subsystem.
Moreover, we address also the case of a single high dimensional system and show that the amount of complementarity that a quantum system can exhibit depends on which complementary properties one is considering. Complementary properties can be connected to mutually unbiased bases (MUBs): if the value of one property is known (i.e. the system state is in one of the basis states), then the complementary properties are completely unknown: the measurement of another property will find any of its possible outcomes with uniform probability. We show that a 5-dimensional system can have different degrees of complementarity, depending on which three of the six MUBs we choose. The degree of complementarity is assessed using EUR and variance. Interestingly, this result was first found and demonstrated experimentally.

Presenter: MACCHIAVELLO, Chiara

Session Classification: Keynote Speakers

Contribution ID: **4** Type: **not specified**

Structural transitions in two-dimensional Coulomb crystals

Tuesday 30 September 2025 09:40 (40 minutes)

Understanding how strongly interacting particles self-organize in confined geometries is central to both fundamental physics and the development of controllable quantum systems. Two-dimensional Coulomb crystals of trapped ions provide an ideal platform for this purpose since their confinement can be precisely tuned, and they are considered one of the most promising routes toward scaling up ion-based quantum computers.
We report on two structural effects observed in such crystals. First, we investigate orientational melting, a transition specific to mesoscopic two-dimensional systems in which ions lose angular order while remaining radially localized. This transition, strongly dependent on particle number, can be suppressed or enhanced by modifying the trap geometry or introducing impurities. Second, we study structural bistability and show how configuration changes can emulate molecular isomerization. Using Monte Carlo simulations, we map the potential energy surface of a six-ion system and identify a double-well structure, revealing two coexisting metastable isomers. Experimentally, we monitor the occupation probability of each isomer and extract relaxation dynamics with sub-millisecond resolution.
Furthermore, we will present the perspective of integrating two-dimensional Coulomb crystals into a bow-tie cavity. Unlike Fabry–Perot geometries, this design ensures optimal collective coupling between the entire ion crystal and an optical mode, while also enabling the creation of a deep optical potential to trap crystals in a static configuration free of micromotion. Such a hybrid electro-optical trap will make it possible to reach lower temperatures, paving the way to study the role of quantum fluctuations in structural transitions and the creation of a quantum superposition of crystal configurations.

Presenter: SIAS, Carlo

Session Classification: Keynote Speakers

Contribution ID: **5** Type: **not specified**

Quantum-noise-limited and quantum enhanced optical magnetometry

Tuesday 30 September 2025 11:30 (30 minutes)

Optically pumped magnetometers (OPMs), in which an atomic ensemble is optically polarized and its spin evolution is optically detected, represent a paradigmatic quantum sensing technology that applies to medical diagnostics, geophysics, space science and searches beyond the standard model. In this talk I will describe quantum-noise limited magnetic gradiometers [1,2], which can operate with femtotesla sensitivity up to Earth-scale fields, and quantum enhancement of a high-density OPM using squeezed light [3]. Finally, I'll introduce a novel quantum enabling technology based on laser-written vapor cells [4].

References
[1] V. G. Lucivero et al. "Femtotesla nearly quantum-noise-limited pulsed gradiometer at Earth-scale fields"Phys. Rev. Applied 18, L021001 (2022)
[2] M. E. Limes et al. "Portable magnetometry for detection of biomagnetism in ambient environments", Phys. Rev. Applied 14, 011002 (2020)
[3] C. Troullinou et al. "Quantum-enhanced magnetometry at optimal number density", Accepted in Phys. Rev. Lett. (2023)
[4] V. G. Lucivero et al. "Laser-written vapor cells for chip-scale atomic sensing and spectroscopy" , Optics Express 30, 27149-27163 (2022)

Presenter: LUCIVERO, Gianvito

Session Classification: Invited Speakers

Contribution ID: **6** Type: **not specified**

Measurement incompatibility in Bayesian multiparameter quantum estimation

Tuesday 30 September 2025 12:00 (30 minutes)

Estimating physical parameters with high precision is a fundamental task in science and technology. In multiparameter scenarios, trade-offs between the precisions of different parameters naturally arise. For quantum systems, an additional intrinsic trade-off originates from measurement incompatibility, whereby the measurements optimal for individual parameters cannot be jointly implemented. This phenomenon hinders multiparameter quantum estimation, both practically and mathematically, making its characterisation essential. While extensively studied in the framework of local estimation theory based on asymptotic Cramér–Rao bounds, its role in Bayesian estimation, valid even at the single-shot level, has received far less attention.
Here we provide a comprehensive account of Bayesian multiparameter quantum estimation. We show that measurement incompatibility can increase the average mean squared error of the estimation by at most a factor of two, thus strictly limiting its impact. This finding mirrors a known result in local estimation theory, but extends its validity beyond the asymptotic regime. We further illustrate our theoretical results with numerical studies of two paradigmatic quantum optical models: discrete phase imaging and joint estimation of phase and phase diffusion.

Presenter: ALBARELLI, Francesco

Session Classification: Invited Speakers

Contribution ID: **7** Type: **not specified**

Nonstabilizerness in the monitored dynamics of complex quantum systems

Tuesday 30 September 2025 15:00 (40 minutes)

We study the nonstabilizerness, also named "quantum magic", in a variety of interacting quantum systems coupled with an environment. We first consider an infinite-range interacting spin-1/2 model, undergoing periodic kicking. In the thermodynamic limit, it is described by classical mean-field equations exhibiting regular and chaotic regimes. At finite size, the dynamics can be described through stochastic quantum trajectories. We find that the magic, averaged over trajectories, mirrors to some extent the classical chaotic behavior, while the entanglement entropy does not. Then we consider the Sachdev-Ye-Kitaev model, as well as nearest-neighbor XXZ-staggered spin chains. In the absence of measurements, the SYK model is the only one where the magic saturates the random-state bound and its scaling with the system size is well described by the theoretical prediction for quantum chaotic systems. In the presence of measurements, the magic always increases linearly with the size and displays no measurement-induced transitions in any of the considered models.

Presenter: ROSSINI, Davide

Session Classification: Keynote Speakers

Contribution ID: **8** Type: **not specified**

Quantum networks with Neutral Atoms in Optical Cavities

Tuesday 30 September 2025 15:40 (30 minutes)

Quantum networks rely on efficient light–matter interfaces to connect optical photons with long-lived quantum memories. In this talk, I will present two complementary approaches using neutral atoms coupled to optical cavities. The first employs ordered arrays of individually trapped atoms in a hybrid tweezer–lattice architecture, enabling precise control, low decoherence, and highly efficient atom–photon entanglement generation with multiplexing capabilities. The second approach uses a cold atom cloud in a low-finesse cavity, where collective spin-wave excitations couple strongly to the cavity field, leading to enhanced retrieval efficiencies and clear signatures of vacuum-Rabi splitting. Together, these results demonstrate distinct pathways toward scalable and versatile quantum network nodes.

Presenter: DISTANTE, Emanuele

Session Classification: Invited Speakers

Contribution ID: **9** Type: **not specified**

Maxwell's demon for open quantum systems

Tuesday 30 September 2025 16:10 (30 minutes)

Feedback control of open quantum systems is of fundamental importance for practical applications in various contexts, ranging from quantum computation to quantum error correction and quantum metrology. Its use in the context of thermodynamics further enables the study of the interplay between information and energy, as exemplified by the famous Maxwell's demon thought experiment that led to the notorious and important Landauer's bound. In this talk I will start by investigating the impact of genuine quantum features on Landauer's erasure in the slow driving regime, demonstrating that quantum coherence generated in the energy eigenbasis of a system undergoing a finite-time information erasure protocol yields rare events with extreme dissipation. The second part of this talk will be devoted to a different aspect of the same problem, namely the one of deriving optimal feedback control strategies. This highly challenging task gets even richer in the quantum regime, as it involves the optimal control of open quantum systems, the stochastic nature of quantum measurement, and the inclusion of policies that maximize a long-term time- and trajectory-averaged goal. In a recent work we employed a reinforcement learning approach to automate and capture the role of a quantum Maxwell's demon: the agent takes the literal role of discovering optimal feedback control strategies in qubit-based systems that maximize a trade-off between measurement-powered cooling and measurement efficiency.

Presenter: GUARNIERI, Giacomo

Session Classification: Invited Speakers

Contribution ID: **10** Type: **not specified**

Environment-induced quantum phase transitions and quantum Fisher information in two-level systems

Tuesday 30 September 2025 17:00 (30 minutes)

We investigate the dynamical and thermodynamic properties of the open Rabi model, a two-level system coupled to an oscillator beyond the rotating-wave approximation, and its two-qubit extension, focusing on equilibrium quantum phase transitions (QPTs) and dynamical quantum phase transitions (DQPTs) induced by environmental interactions. To address these problems, we employ the Density-Matrix Renormalization Group (DMRG) algorithm for equilibrium states and the Time-Dependent Variational Principle (TDVP) for non-equilibrium dynamics, both based on a tensor-network variational ansatz, representing open quantum systems as Matrix Product States (MPSs). These approaches are complemented by worldline Monte Carlo simulations at equilibrium and methods inspired by Feynman and Mori for dynamical analysis. On the thermodynamic side, we show that increasing the coupling to the oscillator mediating environmental interactions triggers a Berezinskii-Kosterlitz-Thouless (BKT) transition in both single- and two-qubit models within the deep-strong coupling regime. Dynamically, we observe a coherent-to-incoherent crossover and the BKT transition: weak coupling leads to Rabi oscillations, whereas stronger coupling induces exponential relaxation, with relaxation functions flattening at the BKT point [1]. As an application, we compute local ergotropy in a work-extraction protocol, finding that both its static and dynamical behavior witness the BKT transition [2]. Furthermore, quenches of the qubit–oscillator coupling reveal two distinct classes of DQPTs, depending on qubit interactions and entanglement, each with unique critical exponents. These are signaled by non-analyticities in the Loschmidt echo, occurring in the same parameter regime as the thermodynamic BKT transition [3]. Finally, we employ DMRG and TDVP to analyze the Quantum Fisher Information Matrix (QFIM) as a metrological probe in a paradigmatic two-level open quantum system: the spin-boson model. Its static component exhibits peaks near the BKT transition, allowing the critical coupling to be extrapolated, and these sensitivity enhancements correlate with the monotonic growth of von Neumann entropy, linking parameter estimation precision to entanglement. Dynamically, QFIM displays oscillations in the coherent regime, and their suppression across the coherent-to-incoherent crossover, providing a quantitative signature of non-Markovian effects [4]. These results clarify how criticality and non-Markovian effects manifest in open quantum systems and suggest possible strategies for exploiting these features in quantum sensing protocols.

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(2025).

Presenter: DI BELLO, Grazia

Session Classification: Junior Speakers

Contribution ID: **11** Type: **not specified**

Finite Group Lattice Gauge Theories and their Quantum Simulations

Wednesday 1 October 2025 09:00 (40 minutes)

I will first describe some theoretical peculiarities in the definition of gauge theories with finite abelian or non-abelian groups on a lattice and then give some examples of quantum emulations of these hamiltonians with both hybrid and digital algorithms.

Presenter: ERCOLESSI, Elisa

Session Classification: Keynote Speakers

Contribution ID: **12** Type: **not specified**

The Josephson effect moving Quantum Computation through the Macroscopic Quantum

Wednesday 1 October 2025 09:40 (40 minutes)

Superconducting circuits have been up to now the most successful platform to build a quantum computer, being developed and used by major international companies since early stages. Napoli has a long-standing experience on superconducting electronics and on its key device i.e. the Josephson junction, and has assembled the first quantum computer in Italy "Partenope"based on a 25-qubits processor produced by Quantware aiming at a QPU with 64-qubits in the close future. Partenope has been the platform where to create a solid expertise for the characterization, calibration, benchmarking and implementation of subregisters of QPUs and to focus on all hardware aspects including control and read out. A full control of Partenope also due to a comprehensive handling of the physics behind including its noise issues, such as decoherence, error in the gate implementation, readout error, has allowed the run of various algorithms, paving the way more and more towards an open-source quantum computing platform. A profound understating of all the physics of the hardware has promoted progress in developing independent pathways with innovative solutions for novel quantum components. These range from a new type of qubit based on ferromagnetic Josephson junctions and a novel tunable qubits coupler to qubit readout based on Josephson digital phase detectors and to novel schemes of microwave demultiplexer. The path from the physics of the hardware to operation of a quantum computer will be the focus of the contribution.

Presenter: TAFURI, Francesco

Session Classification: Keynote Speakers

Contribution ID: **13** Type: **not specified**

Hidden Markov models - classical and quantum mechanisms, and beyond

Wednesday 1 October 2025 10:50 (40 minutes)

A fundamental problem of inference is that of the observation of a long (ideally infinite) stationary time series of events, generated by a hidden Markov chain. What can we say about the internal structure of the hidden Markov model, aka the latent variables? If the system generating the observations is classical, we are looking to reconstruct the hidden" Markov chain from its "visible" image.
Here, we are studying the case that the hidden system is quantum mechanical, giving rise to a special class of finitely correlated states, which we call quantum hidden Markov models; and even more generally, a general probabilistic theory (GPT). The latter case is entirely described in terms of the rank of the so-called Hankel matrix of the process, and an associated canonical vector space with associated positive cone preserved under the hidden dynamics of the model. For the quantum case, we describe the structure of the possible GPTs via semidefinite representable (SDR) cones. It turns out that these GPTs are all finitely presented operator systems, i.e. induced subspaces of quotients of B(H) for a finite-dimensional Hilbert space H. Unlike operator systems, for which complete positivity can be very hard to decide, the SDR models come with a subset of the completely positive maps, which is itself an SDR cone [1].
We also describe the first known example of a process generated via a finite-dimensional GPT as the hidden system, which however cannot be reproduced by any quantum hidden Markov model with finite state space [2], answering a question of Fannes, Nachtergaele and Werner [4]. Processes generated via a finite-dimensional GPT which cannot be reproduced by a classical hidden Markov chain had been known before [1,3].

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Presenter: WINTER, Andreas

Session Classification: Keynote Speakers

Contribution ID: **14** Type: **not specified**

Spectral characterisation of biphoton states

Wednesday 1 October 2025 11:30 (30 minutes)

Encoding information in the time–frequency domain demonstrates its potential for quantum information processing. It offers a novel scheme for communications with large alphabets, computing with large quantum systems, and new approaches to metrology. It is then crucial to secure full control on the generation of time–frequency quantum states and their properties. Characterizing the spectral phase in particular poses a great challenge, one that has similarly been taken up by classical ultrafast metrology to control ultrashort pulses. In this seminar we will explore novel approaches to the spectral phase characterization of biphoton states spanning from techniques borrowed from classical ultrafast metrology to more directly quantum approaches.

Presenter: GIANANI, Ilaria

Session Classification: Invited Speakers

Contribution ID: **15** Type: **not specified**

Continuous-variable QKD in modular star-network setup: advantage, limits and potential use with constrained devices

Wednesday 1 October 2025 12:00 (30 minutes)

Continuous-variable systems offer a promising platform for quantum networks achieving high rates, while employing the existing infrastructure. Modular star networks was one of the attempts to extend CV-QKD towards networking schemes exploiting MDI setup. We first discuss the performance of this approach to implement quantum conferencing key agreement and quantum secret-sharing then, adopting recent finite-size composable security proofs we bound the key-rates for coherent state protocols under collective attacks. We study the extension of the star network to thermal states by considering frequency regimes beyond the optical one, like the THz regime and we then discuss some results when we consider using CV-QKD in the framework of constrained devices.

Presenter: OTTAVIANI, Carlo

Session Classification: Invited Speakers

Contribution ID: **16** Type: **not specified**

Tensor Network Algorithms for Quantum Simulation

Wednesday 1 October 2025 15:00 (40 minutes)

We review recent advances in the development of efficient tree tensor network algorithms and their applications to quantum simulation, benchmarking, and theoretical interpretation. In particular, we present results on two- and three-dimensional systems, both in and out of equilibrium, including scattering processes and induced false vacuum decay in the two-dimensional quantum Ising model. We further highlight the use of tree tensor network methods beyond traditional quantum simulation, such as addressing hard classical combinatorial problems through mappings to many-body quantum Hamiltonians, optimizing quantum compilation tasks, and enabling quantum equational reasoning.

Presenter: MONTANGERO, Simone

Session Classification: Keynote Speakers

Contribution ID: **17** Type: **not specified**

Static and dynamic topological phase transitions in open quantum systems

Wednesday 1 October 2025 15:40 (30 minutes)

A topological dynamical phase transition is induced between two planar superconducting phases. Using the Lindblad equation to account for the interactions of Bogoliubov quasiparticles among themselves and with the fluctuations of the superconducting order parameter, the relaxation dynamics of the order parameter is analyzed [1]. To characterize the phase transition, the fidelity and the spin-Hall conductance of the open system are computed [2]. The approach provides crucial information for experimental implementations, such as the dependence of the critical time on the system-bath coupling. The modern theory of electric polarization is generalized to the case of one-dimensional non-Hermitian systems with a line-gapped spectrum [3]. Moreover, the nonperturbative effects induced by the environment are investigated in the prototype Su-Schrieffer-Heeger chain coupled to local harmonic oscillator baths through either intracell or intercell transfer integrals [4]. Despite the common view, this type of coupling, if suitably engineered, can even induce a transition to topological phases. By using a world-line quantum Monte Carlo technique, the phase diagram of the model is determined proving that the bimodality of the probability distribution of the polarization signals the emergence of the topological phase. Finally, a qualitative description can be obtained by using an approach based on the cluster perturbation theory providing, in particular, a non-Hermitian Hamiltonian for the fermionic subsystem.

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Presenter: PERRONI, Carmine Antonio

Session Classification: Invited Speakers

Contribution ID: **18** Type: **not specified**

Multimode-cavity picture of non-Markovian waveguide QED

Wednesday 1 October 2025 16:10 (30 minutes)

We introduce a picture to describe and intrepret waveguide-QED problems in the non-Markovian regime of long photonic retardation times resulting in delayed coherent feedback. The framework is based on an intuitive spatial decomposition of the waveguide into blocks. Among these, the block directly coupled to the atoms embodies an effective lossy multimode cavity leaking into the rest of the waveguide, in turn embodying an effective white-noise bath. The dynamics can be approximated by retaining only a finite number of cavity modes which grows with the time delay. This description captures the atomic as well as the field's dynamics, even with many excitations, in both emission and scattering processes. As an application, we show that the recently identified non-Markovian steady states can be understood by retaining very few or even only one cavity modes.

Presenter: CILLUFFO, Dario

Session Classification: Invited Speakers

Contribution ID: **19** Type: **not specified**

Observational entropy of quantum correlations and entanglement

Wednesday 1 October 2025 17:00 (30 minutes)

The use of coarse graining to connect physical and information theoretic entropies has recently been given a precise formulation in terms of "observational entropy", a measure of the uncertainty about a system's state that incorporates the specific operation an observer performs to acquire information about that state. Observers with access to limited sets of measurements observe an entropy excess above the absolute minimal represented by von Neumann's entropy, an excess that we denote as "entropy gap". In this work, we first investigate entropy gaps in their full generality, then explore their emergence in multipartite systems where observers are subject to various locality restrictions. By examining different classes of measurements, we demonstrate that each class's entropy gap provides a distinct and useful perspective on quantifying quantum correlations. Furthermore, we establish connections between entropy gaps and well-known measures of quantum correlations and entanglement, while also presenting analytical calculations of the gaps for widely studied multipartite quantum states

Presenter: ROSSETTI, Leonardo

Session Classification: Junior Speakers

Contribution ID: **20** Type: **not specified**

Transitions in monitored quantum circuits

Thursday 2 October 2025 09:00 (40 minutes)

Presenter: FAZIO, Rosario

Session Classification: Keynote Speakers

Contribution ID: **21** Type: **not specified**

False vacuum decay in ferromagnetic superfluids

Thursday 2 October 2025 09:40 (40 minutes)

In quantum field theory, quantum fluctuations can trigger the decay of a field from a metastable state (false vacuum) to the ground state (true vacuum) through the macroscopic tunneling across a many-body energy barrier [1]. False vacuum decay, which is thought to manifest via the spontaneous nucleation of spatially localized bubbles, is a fascinating phenomenon for a rich variety of systems, ranging from condensed matter [2] to cosmology [3]. Nevertheless, its experimental verification has been elusive so far, due to the extreme energy scales involved and the lack of tunable parameters. Here, I will present the first experimental evidences [4,5] of false vacuum decay in a metastable ferromagnetic superfluid. In this novel platform, realized with ultracold sodium atoms in two coherently-coupled internal states [6] in an ultrastable magnetic field environment [7], the superfluid acts as the quantum field, and macroscopic tunneling events are observed through the nucleation of spin bubbles via thermal fluctuations. Our results find good agreement with numerical simulations and instanton theory, opening the way for the simulation of out-of-equilibrium phenomena in a highly controllable and tunable atomic system.

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Presenter: LAMPORESI, Giacomo

Session Classification: Keynote Speakers

Contribution ID: **22** Type: **not specified**

Certified many-body physics

Thursday 2 October 2025 10:50 (40 minutes)

When studying many-body systems, two approaches have been considered so far: analytical derivations and variational methods. The first provide exact results, as they do not involve any approximations, but scale exponentially with the number of particles, while the second scale much better but only provide estimates with no theoretical guarantees. Polynomial optimisation methods offer an alternative approach somehow combining the advantage of exact and variational methods: it provides rigorous results, now in the form of upper and lower bounds, in a scalable way. We illustrate this new approach in two paradigmatic many-body problems: the estimation of expectation values in ground states of Hamiltonian operators and in steady states of quantum open systems.

Presenter: ACIN, Antonio

Session Classification: Keynote Speakers

Contribution ID: **23** Type: **not specified**

Polariton quantum simulators: condensation and emerging supersolidity

Thursday 2 October 2025 11:30 (30 minutes)

Supersolidity is a counter-intuitive and very fascinating phase of matter, predicted more than 50 years ago and realized only in recent years in various configurations by using condensates of cold atomic clouds: a very coherent quantum system that simultaneously behaves as a superfluid, i.e., having the characteristic property of flowing without viscosity or friction, and as a system possessing characteristics that are typical of crystalline solids, such as the periodic arrangement in space. In this seminar, a recent realization of this very exotic phase in a nanostructured semiconductor platform will be described, showing how supersolidity can arise as an emerging property in suitably engineered nanostructures supporting exciton-polaritons, elementary excitations arising from the strong light-matter coupling between quantum well excitons and low-loss photonic eigenmodes in periodically patterned planar waveguides, i.e., photonic crystal polaritons. First, it will be shown how this platform allows to explore the rich analogies between nonlinearly interacting polaritons and weakly interacting Bose gases [1,2,3]. Then, the subtle analogies and differences between such an emerging supersolid phase and its atomic counterpart will be discussed [4,5]. Photonic crystal polaritons propose themselves as an ideal analog quantum simulator to study exotic phases of matter.

References

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Presenter: GERACE, Dario

Session Classification: Invited Speakers

Contribution ID: **24** Type: **not specified**

Quantum (inspired) algorithms for combinatorial optimization and equational reasoning

Thursday 2 October 2025 12:00 (30 minutes)

Tensor network (TN) methods have emerged as a powerful tool for addressing high-dimensional problems, with applications spanning quantum many-body physics and machine learning. We show how combinatorial problems can be tackled through a synergy of quantum-inspired algorithms and novel quantum formulations. First, we address mission planning for Earth-observation satellites, mapping a constrained knapsack scheduling problem into a QUBO formulation and efficiently finding ground-state solutions with TN solvers. Second, we enhance Schnorr's algorithm for RSA factorization by using TN methods to solve closest vector problem (CVP) instances, achieving factorization of semiprimes up to 100 bits —the largest with this approach to date. Finally, we introduce a quantum computational framework for equational reasoning, encoding equivalence classes of symbolic expressions into Hamiltonian ground states to solve the word problem, count equivalent expressions, and analyze their structure.

Presenter: SILOI, Ilaria

Session Classification: Invited Speakers

Contribution ID: **25** Type: **not specified**

Quantum spin liquids in cavity QED

Thursday 2 October 2025 15:00 (40 minutes)

One of the most exciting directions associated with the rapid advance of quantum science is the possibility to utilize synthetic quantum systems to realize and explore strongly correlated quantum phenomena. Generally, however, this regime remains challenging to access with quantum atom-light interfaces for two reasons. First, such systems still suffer from significant dissipation, particularly at the level of individual quanta, in the form of spontaneous emission of light into unwanted directions. Second, there is a prevailing strategy to reduce the effects of dissipation, by encoding phenomena within the collective optical response of many atoms, which improves atom-light interaction efficiencies. Unfortunately, this same collective response typically results in collective spin or mean-field descriptions of the physics, which is incompatible with most known strongly correlated phenomena in physics. Within this context, atom arrays with sub-wavelength lattice constant constitute an exciting opportunity to break beyond these boundaries. In these systems, wave interference effects in light emission are strongly enhanced, resulting in highly correlated dissipation. This gives rise to the phenomenon of subradiance, where certain classes of states are highly protected from emission, and which provides a potential mechanism to evade mean-field behavior. Here, we describe our ongoing efforts to identify and understand paradigms by which strongly correlated and emergent phenomena might arise from the natural resources of long-range interactions and collective dissipation in quantum optical arrays. We will focus on an example involving the realization of quantum spin liquids in Rydberg atom arrays interfaced with high-finesse cavities, where the long-range interactions are used to project atoms into resonating valence bond states that are dark to cavity-mediated photon emission.

Presenter: CHANG, Darrick

Session Classification: Keynote Speakers

Contribution ID: **26** Type: **not specified**

Perfect state transfer between qubits by dispersion engineering in waveguide QED

Thursday 2 October 2025 15:40 (30 minutes)

A propagating photon emitted by a qubit via spontaneous decay has an exponential spatial profile that is not time-reversal invariant [1,2]. As a consequence, if such photon propagates in a medium with linear dispersion relation, it cannot be perfectly absorbed by a second qubit. Even in the ideal case of a lossless, perfectly chiral 1D waveguide the maximum achievable occupation of the second qubit is limited to 4/e^2 » 0.54 [3]. This poses a serious fundamental limitation to quantum state transfer between nodes in waveguide QED. Current proposed solutions are active, i.e., they rely on active time-dependent control of system parameters [4-5].
In my talk I will present an alternative approach to perfect transfer, namely to passively tailor the dispersion relation of the waveguide. I will show that, for two qubits separated by a large fixed distance d, the optimal dispersion relation can be analytically derived using Wigner- Weisskopf theory. This dispersion optimally time-reverses the single-photon pulse emitted by one qubit, thus achieving perfect absorption by the second qubit. In the limit of short d, an alternative dispersion relation can be derived using resolvent methods, that also achieves perfect absorption. I will also discuss how numerical optimization allows to obtain, for every fixed distance d, the optimal dispersion relation to achieve near-perfect absorption. Finally, I will show how to engineer a waveguide able to achieve perfect transfer for arbitrary distances between qubits, by tailoring the dispersion relation only of a section of the waveguide between them. Our work paves the way toward harnessing dispersion engineering for waveguide QED.

References

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[4] J. I. Cirac, P. Zoller, H. J. Kimble, H. Mabuchi, Phys. Rev. Lett 78, 3221 (1997)

[5] G. Peñas, R. Puebla, J. J. Garcia-Ripoll, Quantum Sci. Technol. 8, 045026 (2023)

Presenter: GONZALEZ-BALLESTERO, Carlos

Session Classification: Invited Speakers

Contribution ID: **27** Type: **not specified**

Tensor network simulation of a waveguide QED architecture with multiple emitters

Thursday 2 October 2025 16:10 (30 minutes)

Waveguide Quantum Electrodynamics (Waveguide QED) is a promising and versatile platform for studying fundamental light-matter interactions and quantum technology implementations. Notably, interesting effects emerge when two or more quantum emitters are coupled to the waveguide, including collective phenomena, e.g., superradiance and formation of bound states in the continuum (BICs). An effective approach to address the behaviour of such systems is via Tensor Network quantum-inspired simulation techniques, enabling to efficiently simulate the real-time dynamics of many-body quantum systems, i.e, a waveguide QED platform. In particular, I will present a method based on Matrix Product States (MPS) to model a waveguide QED architecture featuring multiple emitter pairs and simulate its dynamics in the non-Markovian regime. Then, I will discuss the obtained results, focusing on the emergence of BICs and other collective effects in the long-time limit.

Presenter: CAPURSO, Rosa Lucia

Session Classification: Junior Speakers

Contribution ID: **28** Type: **not specified**

Reliable quantum advantage in quantum battery charging

Thursday 2 October 2025 17:00 (30 minutes)

Quantum technologies must be both miniaturized and effectively scaled in order to achieve a high level of competitiveness and efficiency. However, devices operating at the nanoscale necessitate the management of extremely small quantities of energy. But how can fluctuations be properly accounted for? Indeed, the smaller the amount of energy involved, the more significant the relative impact of energy fluctuations becomes. Here, quantum batteries come into play. They are quantum systems capable of storing energy upon being charged
and subsequently delivering it on demand. Such systems can be analyzed from a thermodynamic perspective, particularly through the study of energy exchanges and fluctuations. As such, they serve as well-suited models for proof-of-principle investigations of the thermodynamic efficiency of quantum devices. Moreover, quantum batteries could be a valuable resource capable of enhancing control over the processes necessary for the deployment of quantum technologies. In our work, we investigate a Jaynes–Cummings quantum battery, namely a device composed of a flying qubit interacting with an optical resonator. By employing the Full Counting Statistics technique, we demonstrate that the charging performance of the battery can be enhanced by preparing the single-mode resonator in a genuinely quantum, non-Gaussian state. Specifically, when the cavity mode is initialized in a Fock state, the charging process proves to be more efficient than in alternative situations, e.g. where classical or even Gaussan (yet quantum) cavity states are involved. We substantiate this advantage of the Fock-state protocol by evaluating the signal-to-noise ratio (SNR), which quantifies the quality of the signal (i.e., the average energy injected into the battery) comparing it to its fluctuations (i.e., the variance). This advantage is shown to be reliable, as it accounts for the dynamical energy fluctuations that arise during the process.

Presenter: RINALDI, Davide

Session Classification: Junior Speakers

Contribution ID: **29** Type: **not specified**

Semiclassical simulations of dissipative quantum many-body systems

Friday 3 October 2025 09:00 (40 minutes)

In this talk, I will present recent and ongoing work on the application of semi-classical methods, such as the discrete truncated Wigner approximation and quantum state diffusion simulations, for simulating dissipative quantum spin models. Specifically, I will discuss the use of these techniques in the context of superradiance and demonstrate that, even in the presence of squeezing correlations in the photonic bath or strong disorder, semi-classical approaches involving little or no entanglement can accurately capture the superradiant decay process and provide new insights into the mechanisms underlying collectively enhanced emission. If time permits, I will also briefly discuss ongoing work on the steady states of dissipative Heisenberg models, where semi-classical methods enable the study of critical scaling relations for system sizes that are currently inaccessible with other approaches.

Presenter: RABL, Peter

Session Classification: Keynote Speakers

Contribution ID: **30** Type: **not specified**

Correlation imaging, from 3D to hyperspectral

Friday 3 October 2025 09:40 (40 minutes)

We shall present recent advances in correlation imaging modalities enabling scanning-free high-resolution hyperspectral imaging, 3D imaging and 3D microscopy, with at least one order of magnitude advantage over typical tradeoffs such as resolution versus depth of field and spatial versus spectral resolution.Both entangled light beams and chaotic light are employed, depending on the specific application scenario.Speed-up unabled by both SPAD arrays and Deep Learning denoising approaches are presented, demonstrating the effective capability of the presented approaches to compete with state of the art approaches, while overcoming their intrinsic limitations.

Presenter: D'ANGELO, Milena

Session Classification: Keynote Speakers

Contribution ID: **31** Type: **not specified**

Quantum metrology - almost perfect theoretical framework with just a few cracks

Friday 3 October 2025 10:50 (40 minutes)

Recent theoretical developments have rendered quantum metrology a mature field, where some of the most fundamental question have been answered and efficient computational tools developed. We have now a full understanding of quantum metrological potential in case of noisy single parameter estimation models, provided the noise may be assumed to be Markovian. Nevertheless, non-Markovian models remain challenging and efficient universal theoretical tools are still missing. Apart from that, multi-parameter estimation scenarios may pose a challenge even in the Markovian regime, not to mention non-Markovian one. Do not despair, though, some progress is being made…

Presenter: DEMKOWICZ-DOBRZAŃSKI, Rafał

Session Classification: Keynote Speakers

Contribution ID: **32** Type: **not specified**

A photon-atom interface at telecom wavelengths

Friday 3 October 2025 11:30 (30 minutes)

Enabling communication between quantum devices, such as clocks, computers, and simulators has the potential to significantly enhance the capabilities of their applications, such as quantum sensing and computing.The key to achieving this lies in establishing efficient communication channels among these quantum devices even over a long distance, which involves the exchange of qubits encoded in light at telecom wavelengths through optical fibers. In this context, I will present an overview of the new experiment that we are building in Florence, which focuses on interfacing single photons at telecom wavelengths with individual neutral ytterbium atoms trapped in optical tweezers. By leveraging the unique properties of the ytterbium clock state and its telecom transitions, our objective is to interface a long-lived ”matter”qubit and resonant light, including atom-resonant heralded single photons or photons forming entangled pairs. I will discuss the first developments, the motivation for exploring this research line and its impact as a crucial foundation for distributing entanglement between light and matter.

Presenter: BRUNO, Natalia

Session Classification: Invited Speakers

Contribution ID: **33** Type: **not specified**

Thermodynamic analysis of uniform real-phased qubits states

Friday 3 October 2025 12:00 (30 minutes)

We investigate the thermodynamic properties of the uniform real-phased submanifold in n-qubit systems (($\pm$)-state), represented as a classical ensemble of 2^n spins subject to a potential encoding multipartite entanglement. For small system sizes ($n \leq 6$), we perform exact enumeration, enabling a complete statistical characterization of the energy landscape and associated thermodynamic observables. For larger systems ($n = 6$), where exact methods become computationally prohibitive, we employ a stochastic annealing approach to efficiently sample the high-dimensional state space. This method accurately reproduces known benchmarks and captures key features of the system's thermodynamic behavior. Our analysis reveals intricate entropic structures arising from the interplay between entanglement constraints and the underlying combinatorial geometry of quantum state spaces. These findings provide new insights into the statistical mechanics of constrained quantum systems and highlight the utility of thermodynamic tools in characterizing complex entangled states.

Presenter: SCARAFILE, Paolo

Session Classification: Junior Speakers

Contribution ID: **34** Type: **not specified**

Optimal and robust error filtration for quantum information processing

Friday 3 October 2025 12:30 (30 minutes)

Error filtration is a hardware scheme that mitigates noise by exploiting auxiliary qubits and entangling gates. Although both signal and ancillas are subject to local noise, constructive interference and post-selection allow us to reduce the noise level in the signal qubit. Here we highlight the relation between error filtration and error detection codes, and determine the optimal codes that make the qubits interfere most effectively.We examine our optimized scheme under imperfect implementation, where ancillary qubits may be noisy or subject to cross-talk. Even with these imperfections, we find that adding more ancillary qubits helps in protecting quantum information.We benchmark our approach against figures of merit that correspond to different applications, including entanglement fidelity, quantum Fisher information (for applications in quantum sensing), and CHSH value (for cryptographic applications), with one, two, and three ancillary qubits.By using the entanglement fidelity as a figure of merit, we suggest a general condition for error filtration and, for one and two ancillas, we obtain some explicit expressions for the optimal codes. We also compare our method with the recently introduced Superposed Quantum Error Mitigation (SQEM) scheme based on superposition of causal orders, and show that, for a wide range of noise strengths, our approach may outperform SQEM in terms of effectiveness and robustness.

Presenter: ALI, Aaqib

Session Classification: Junior Speakers