Invited talks

Monday, December 8, 2025

Electron spin ensembles for microwave quantum communication

Nadezhda Kukharchyk, *Walther-Meißner-Institut der BAdW, TUM*

Abstract: Microwave quantum communication, encompassing the development of microwave quantum key distribution (QKD), quantum microwave entanglement distribution, and compatible quantum storage elements, is a highly promising area in the evolution of radio technologies toward 6G wireless networks. In our work, we focus on the development of microwave quantum memories that are compatible with microwave quantum circuits, which play a central role in quantum computing and microwave QKD protocols.

In this talk, I will present recent progress in the development of broadband microwave quantum memories based on spin ensembles, discuss their envisioned integration with microwave QKD systems, and explore potential applications in next-generation quantum communication networks.

Quantum networking resources and applications

Eleni Diamanti, *LIP6, Sorbonne University, CNRS*

Abstract: We discuss the main concepts, critical photonic resources, present efforts and challenges ahead aiming at the deployment of quantum communication networks at various stages of development, with both terrestrial and satellite links, at a national and global scale. We present examples of applications of such networks spanning from ultrasecure communication to advanced cryptographic and communication protocols in distributed architectures.

Optimal Control for Robust Quantum Operations and Multi-Qubit State Engineering in Superconducting Circuits

Stefan Filipp, *Walther-Meißner-Institut der BAdW, TUM*

Abstract: Superconducting qubits have emerged as a promising platform for quantum computing, offering scalability, precise controllability, and strong integration potential. A central requirement for reliable quantum information processing is the ability to generate quantum states in a robust fashion, insensitive to control imperfections and noise. In this work, I present an optimal control scheme that enables gate operations resilient to both amplitude and frequency noise. To efficiently generate entanglement, I further introduce a method for single-step GHZ state creation, which can be naturally extended to the preparation of W-states, providing a versatile framework for multi-qubit state engineering. These results underscore the potential of superconducting qubits as a foundational technology for scalable and fault-tolerant quantum architectures.

Self-concordant Schrödinger operators: spectral gaps and optimization without condition numbers

Simon Apers, *IRIF, Paris Cité University, CNRS*

Abstract: Motivated by convex optimization, we study Schrödinger operators associated with self-concordant barriers over convex domains and prove non-asymptotic lower bounds on the spectral gap for this class of operators. Significantly, we find that the spectral gap does not display any condition-number dependence when the usual Laplacian is replaced by the Laplace–Beltrami operator, which takes the curvature of the barrier into account. As an algorithmic application, we construct a novel quantum interior point method that applies to arbitrary self-concordant barriers and shows no condition-number dependence. To achieve this we combine techniques from semiclassical analysis, convex optimization, and quantum annealing.

Tuesday, December 9, 2025

Exploring the Dynamics of Quantum Phases of Matter on Quantum Processors

Frank Pollmann, *TUM School of Natural Sciences*

Abstract: Quantum fluctuations and interactions give rise to exotic phases of matter with remarkable properties, pushing the boundaries of our understanding of many-body quantum systems. Solving these problems is notoriously difficult on classical computers due to the exponential complexity of quantum many-body physics. Quantum processors, however, open new avenues for exploring these systems, offering a direct and potentially transformative approach. In this talk, we will first discuss recent progress in realizing and visualizing dynamics of charges and strings in (2+1)D lattice gauge theories. We will then investigate a class of novel, highly entangled quantum phases that exist only in non-equilibrium settings and demonstrate how to probe their stability using a quantum processor.

Universal non-Gaussian statistics of the order parameter in the superfluid transition

Thomas Chalopin, *LCF, IOGS, Paris-Saclay University, CNRS*

Abstract: Second-order phase transitions describe how a many-body system evolves from an ordered phase, where the order parameter is finite, to a disordered phase, where it vanishes. Near the transition, scale invariance and universality yield algebraic scaling laws for thermodynamic quantities such as the correlation length or the susceptibility, which do not depend on the microscopic details of the model. Moreover, at the transition, the order parameter takes universal non-Gaussian statistics.

In this talk, I will present recent experiments in which we explore the interaction-induced superfluid transition with ultracold lattice bosons and single-atom resolution in momentum space. We measure the statistics of the amplitude of the BEC order parameter and characterise its non-Gaussian behaviour near the transition by exploiting high-order cumulants of the order parameter distribution. We compare datasets with different entropies and observe a universal collapse of the cumulants near the transition. Our experiments enable the measurement of critical exponents compatible with the 3D XY model.

Allemand et al., Observation of universal non-Gaussian statistics of the order parameter across a continuous phase transition, arXiv:2508.21623 (2025)

Probing the spatial distribution of k-vectors in-situ with Bose-Einstein condensate

Saïda Guellati-Khelifa, *LKB, Sorbonne University, CNRS*

Abstract: In this talk, I will present our recent work on the measurement in-situ of the distribution of the wave vectors across a laser beam, using a Bose-Einstein condensate (BEC) as a mobile probe. By displacing the BEC, we measure the photon recoil at various positions using an atom interferometer, allowing us to determine the 2D map of both the local intensity and the dispersion of the wave vectors.

Using a laser beam diffracted by a diaphragm, our method reveals an extra recoil, with an amplitude exceeding the magnitude *hν/c* of the individual plane waves into which the beam can be decomposed. This approach offers a precise way to characterize wavefront distortions and evaluate one of the main systematic biases that limit the accuracy of atom interferometers.

Optically addressable spin systems in diamond and proteins for quantum sensing and imaging

Dominik Bucher, *TUM School of Natural Sciences*

Abstract: Optically addressable spins have attracted significant interest for their potential in quantum sensing technologies. In the first part of this talk, I will present our recent advances using nitrogen-vacancy (NV)

centers in diamond chips for nuclear magnetic resonance (NMR) microscopy. NV-doped diamond platforms enable the transduction of local magnetic resonance signals into optical signals, which can be captured over a wide field using a camera. This novel approach eliminates the need for traditional k-space sampling with magnetic field gradients, as used in conventional MRI. I will discuss the current limitations of this novel microscopy technique and outline prospects for future developments. [1]

In the second part, I will highlight our latest research on optically addressable spins in proteins—specifically flavin-based cryptochrome proteins. Upon excitation, these proteins generate radical pairs that can be detected optically and manipulated through radio wave-controlled spin chemistry. We further show that this optical spin interface is tunable by the protein structure. I will explain how these systems differ from the well-established NV center and discuss their potential as genetically encoded quantum sensors for future applications. [2]

[1] K. D. Briegel et al. Optical Widefield Nuclear Magnetic Resonance Microscopy. Nature Comm, 16, 1281 doi.org/10.1038/s41467-024-55003-5 (2025)

[2] K. Meng et al. Optically detected and radio wave-controlled spin chemistry in cryptochrome, BioRxiv https://doi.org/10.1101/2025.04.16.649006 (2025).

Contributed talks

Quantum Communication using single photon emitters in 2D materials

Mostafa Abasifard, *TUM School of Natural Sciences*

Abstract: The global deployment of quantum key distribution (QKD) requires free-space quantum communication via satellite constellations that can operate efficiently and continuously, day and night. Maximizing the secret key rate in these links requires space-qualified, bright, true single-photon sources. We develop and fabricate single-photon sources (SPSs) based on color centers in hexagonal boron nitride, which emit distinct wavelengths for free-space quantum links and are simultaneously compatible with fiber-based quantum networks. We implement QKD protocols to demonstrate the advantages of these SPSs.

Long-range CCPhase gates via radio-frequency-induced Förster resonances

Ivan Ashkarin, *LAC, Université Paris-Saclay, CNRS*

Abstract: Registers of trapped neutral atoms, excited to Rydberg states to induce strong long-distance interactions, are extensively studied for direct applications in quantum computing. Here we present a CCPhase quantum phase gate protocol based on radio-frequency-induced Förster resonant interactions in the array of highly excited ^{87}Rb atoms. The extreme controllability of interactions provided by rf field application enables high-fidelity and robust gate performance for a wide range of parameters of the atomic system, as well as it significantly facilitates the experimental implementation of the gate protocol. Taking into account finite Rydberg states lifetimes, we achieve.

Utilizing Tree Tensor Networks for Classical Simulation of Quantum Systems

Richard Milbradt, *TUM*

Abstract: Tree tensor networks (TTN) are an efficient ansatz for the classical simulation of quantum systems, whose hierarchical structure efficiently captures entanglement. We developed the Python-based PyTreeNet library to ease the use of this structure. The library supports the automatic construction of near-optimal TTN operators. In combination with TTN states, they can be utilised in the time-evolution algorithms or in the search for low-energy states. Furthermore, there exist efficient algorithms for the TTN operator application to TTN states and the compression of states. PyTreeNet additionally includes a quantum circuit simulator that allows for the exploitation of entanglement patterns in a given circuit.

Quantum sensing with critical systems: advantages and challenges

Sara Murciano, *LPTMS, Université Paris-Saclay, CNRS*

Abstract: Entangled states are a key resource for quantum sensing, enabling highly precise measurements of physical quantities such as magnetic fields. Common examples include Greenberger–Horne–Zeilinger (GHZ) states, squeezed states, and quantum critical states, which can be viewed as superpositions of different cat-like states. In this work, we compare the strengths and weaknesses of using many-body critical states for interferometric quantum sensing relative to other types of entangled probes. We first identify the optimal measurement strategies for exploiting the advantages of critical states and relate these strategies to the system's internal and spatial symmetries. We then examine whether these advantages persist in realistic noisy environments, including local and global decoherence, bit-flip errors, qubit loss, and imperfect teleportation. By systematically comparing critical states with GHZ states, we show that critical systems can, on average, outperform GHZ states under these noisy conditions. Importantly, we also find that when a critical state is imperfectly teleported, it can sometimes exhibit an improved quantum Fisher information (QFI) compared to the perfectly teleported case, making such states a promising resource for practical quantum sensing.

Protecting collective qubits from non-Markovian dephasing

Alexei Ourjoumtsev, *JEIP Collège de France, CNRS*

Abstract: In quantum technologies, qubits encoded as collective atomic or solid-state excitations present important practical advantages, such as strong directional coupling to light. Unfortunately, they are affected by inhomogeneities between the emitters, which make them decay into dark states. In most cases, this process is non-Markovian. Through a simple formalism, we unveil a regime where this decay is suppressed by a combination of driving and non-Markovianity. We experimentally demonstrate this "driving protection" using a Rydberg superatom, making its coherent Rabi oscillations last about 14 times longer than the free lifetime of the collective qubit.

Superconducting Qubit Gates Robust to Parameter Drifts and Fluctuations

Emily Wright, *Walther-Meißner-Institut der BAdW, TUM*

Abstract: High fidelity gate operations are a key ingredient to achieve error corrected quantum computations. State-of-the-art single-qubit gates on superconducting transmon qubits can achieve the required fidelities; however, parameter fluctuations due to instabilities in the qubit, changes in the environment, and inaccuracies in the control instruments necessitate frequent re-calibration to maintain this performance. To mitigate the effects of these parameter variations, we numerically derive gates robust to amplitude and frequency errors using gradient ascent pulse engineering (GRAPE). We analyze how fluctuations in time of qubit frequency, drive amplitude, and qubit coherence affect gate performance. The robust pulses suppress coherent errors from amplitude drifts over 15 times more than DRAG. The gates, originally designed to compensate for quasi-static errors, are also shown to be robust to time-dependent noise. They suppress added errors during random increases in dephasing by as much as 1.7 times more than DRAG.

Downfolding a quantum many-body system: the quasi-1D Fermi polaron

Lovro Anto Barišić, *LPENS, PSL Université, CNRS*

Abstract: We investigate the properties of a single impurity—the Fermi polaron—in a quasi-one-dimensional (quasi-1D) quantum gas of spin-polarized fermions confined by a tight transverse potential, a system relevant to both solid-state quantum wires and ultracold atomic gases. Quasi-1D fermionic systems are compelling due to their connection to exactly solvable 1D models, such as the Yang-Gaudin model, in the limit of strong transverse confinement, yet they exhibit a critical 1D-3D crossover driven by the interplay between

confinement and interactions. Using a non-perturbative variational approach that accounts for virtual transverse excitations and regularizes the zero-range interaction, we calculate the polaron's energy, effective mass, and spectral weight, with a focus on elucidating the 1D-3D crossover. In the weakly interacting regime, our results align with the purely 1D Yang-Gaudin model, but in the strongly attractive limit, we uncover significant deviations, including a dramatic divergence of the effective mass and the emergence of a polaron-to-molecule transition—a hallmark of three-dimensional (3D) physics absent in strictly 1D systems. This crossover arises from enhanced transitions to excited transverse states, which invalidate the 1D approximation and reveal the underlying 3D character of the system. Our findings quantify the extent to which quasi-1D systems deviate from ideal 1D behavior, highlighting the limitations of using such systems as analog quantum simulators of purely 1D physics. These theoretical insights are directly relevant to ongoing experiments with quasi-1D fermionic systems of potassium-40, which aim to probe the 1D-3D crossover and explore the rich physics of confined, strongly interacting quantum gases.

Dynamic Stark and Autler-Townes Splittings in Classical Systems

Ahmed Barakat, *TUM School of Computation, Information and Technology*

Abstract: The dynamic Stark effect and the Autler–Townes splitting (ATS) are well-established hallmarks of two-level systems driven by time-varying fields. Remarkably, an analogous splitting arises in parametrically excited systems of two coupled classical oscillators, known as parametric normal mode splitting (PNMS). We demonstrate that a one-to-one mapping connects these quantum and classical descriptions. Moreover, we show that applying a two-tone parametric drive with a frequency ratio of 1:2 introduces an additional splitting at half the modal difference frequency - an effect that has been observed before in parametrically driven classical systems but was not considered in the original ATS framework. Furthermore, we develop a rigorous and general mathematical formulation of PNMS applicable to any linearly coupled two-mode dynamical system. This framework enables accurate estimation of coupling strength across both weak and strong coupling regimes, regardless of the degree of modal hybridization. Applying the theory to the vibrations of a nanomechanical two-mode system realized in a tunable nanostring resonator, we find excellent agreement between experiment and model, capturing both the fundamental and second-subharmonic ATS, and allowing quantitative extraction of the modal coupling irrespective of the degree of modal hybridization.

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