ICTP-IBM School on Quantum Computing and Simulation | (SMR 4213)

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Overcoming disorder in superconducting globally driven quantum computing

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Quantum complexity across thermal phase transition in the transverse field Ising chain with long-range couplings

P03

Quantum Artificial Intelligence for Near-Term Quantum Devices: Methods and Application Perspectives

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Quantum Artificial Intelligence (Quantum AI) is an emerging research area that combines quantum computing and machine learning. Its goal is to use quantum circuits to support data analysis and learning tasks that are difficult for classical methods. In this poster, we present a clear and practical overview of how Quantum AI models can be implemented on today’s noisy intermediate-scale quantum (NISQ) devices, with a focus on variational quantum algorithms and hybrid quantum–classical learning.

We introduce simple parameterized quantum circuit models for basic supervised and unsupervised learning tasks. We discuss how data can be encoded into quantum states and how circuit depth and entanglement affect training and performance. We also examine the main practical challenges, such as noise and training instabilities, and summarize commonly used mitigation strategies.

We highlight how quantum-enhanced feature representations and hybrid learning workflows can support scientific data analysis and learning problems related to quantum simulation. In addition, we briefly discuss how Quantum AI techniques can be combined with quantum simulation to assist model selection and adaptive control of quantum systems.

Overall, this poster provides an accessible and application-oriented introduction to Quantum AI on current quantum hardware, and outlines open challenges and future research directions toward scalable and useful Quantum AI methods.

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Quantum-Inspired Evolutionary Algorithm Coverage Optimization using a swarm of UAVs

P05

Quantum Machine Learning Approaches in Qiskit's environment for Estimation of Storm Surge height during Extremely Severe Cyclone Hudhud

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Accurate storm surge estimation is critical for effective coastal disaster management, particularly in cyclone-prone regions. Bay of Bengal (BoB) is regarded as one of the most cataclysmic basins in the world from a tropical cyclone (TC) destruction point of view[1]. BoB is prone to high number of cyclogenesis and their land fall in east coast of India, Bangladesh and Myanmar. Hudhud (2014) is a very severe cyclonic storm with gale winds (185km/h) which crossed near Visakhapatnam coast (17.7°N/83.3°E) and caused storm surge inundation. This study evaluates the application of Quantum machine learning techniques in Qiskit's environment for storm surge height estimation using Advanced Circulation (ADCIRC) model[2] output and WXTide32 near Visakhapatnam during Cyclone Hudhud. The QNN model is implemented using Qiskit's quantum circuit framework. The architecture consists of a ZZFeatureMap, which maps classical input data into a quantum state with entanglement between qubits, and a Two Local Ansatz, which consists of parameterized rotational gates (Ry, Rz) and entanglement layers (CZ gates) which was repeated twice. The performance of Quantum Support Vector Regression (QSVR), Quantum Neural Networks (QNN) and classical Support Vector Regression (SVR), Artificial Neural Network (ANN) were validated with ADCIRC numerical model and Indian National Centre for Ocean Information Services (INCOIS) observed storm surge height. Quantum fidelity [4] was employed as the similarity metric to construct the quantum kernel during both training and testing phases. For pre-processing of the ADCIRC model Holland based blended wind field was obtained from India Meteorological Department (IMD) best track and ERA5 reanalysis data. The QSVR model demonstrated superior performance, achieving the lowest Root Mean Square Error (RMSE) (~0.44 m) compared to (~0.46m) ADCIRC, QNN (~0.49m), ANN(~0.54m) and SVR (~0.58m). The observed peak surge height was 1.42m while the estimated ADCIRC model was 1.68m and QSVR provided a more accurate estimation of 1.47m. Taylor diagram analysis further supports QSVR superior performance based on correlation coefficient (0.769), lowest RMSE (0.44), standard deviation (0.474) close to the observations. These findings demonstrate that QML-based approaches, particularly QSVR, can effectively capture complex storm surge dynamics with higher precision than traditional numerical models and feasibility of integrating QML into coastal hazard forecasting.

[1] S. Mohanty, R. Nadimpalli, U. Mohanty, P. Pattanayak, Natural Hazards, 120, 1185–1213 (2024).
[2] J.G. Fleming, C.W. Fulcher, R.A. Luettich, B.D. Estrade, G.D. Allen, H.S. Winer, Estuarine and Coastal Modeling, 893–912 (2007)
[3] Javadi-Abhari, A., Treinish, M., Krsulich, K., Wood, C. J., Lishman, J., Gacon, J., Martiel, S., Nation, P., Bishop, L. S., Cross, A. W., Johnson, B. R., Gambetta, J. M. Quantum computing with Qiskit, arXiv:2405.08810 (2024).
[4] V. Havlicek, A.D. Corcoles, K. Temme, A.W. Harrow, A. Kandala, J.M. Chow, J.M. Gambetta, Supervised learning with quantum-enhanced feature spaces, Nature 567(7747), 209–212 (2019).

P06

Terahertz Characterization and Simulation of Field-Effect Devices for Space-Oriented Quantum and Communication Technologies

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Terahertz (THz) radiation plays a central role in emerging quantum technologies, including quantum sensing, cryogenic electronics, and next-generation communication systems for space platforms. During my undergraduate studies in Physics at Middle East Technical University, I conducted a research project focused on the characterization of Field-Effect Transistor (FET)–based devices using terahertz time-domain spectroscopy (THz-TDS combined with full-wave electromagnetic simulations in CST Microwave Studio. The work aimed to investigate frequency-dependent transmission, resonance behavior, and carrier-driven modulation mechanisms relevant to high-frequency device operation.

In parallel, I explored the integration of engineered metasurface structures with transistor geometries to enhance electromagnetic field confinement and tunability in the THz regime. Simulation results demonstrated strong sensitivity of resonance modes to gate bias and geometrical parameters, highlighting the potential of such hybrid platforms for controllable THz sources and detectors. These device concepts are of particular interest for space-based quantum systems, where compactness, robustness, and spectral selectivity are essential for satellite-borne quantum sensors, inter-satellite quantum communication links, and radiation-tolerant electronic architectures.

This contribution discusses how classical THz spectroscopy and electromagnetic modeling can serve as valuable tools for studying solid-state platforms relevant to quantum hardware development. By connecting experimental characterization techniques with theoretical modeling and device-level simulations, the work provides a pathway toward evaluating materials and structures for quantum-enabled systems operating in harsh space environments. The presented research motivates further exploration of quantum-inspired device architectures and simulation frameworks for optimizing THz components in future space missions and quantum information technologies.

[1] Haji-Ahmadi, M.-J., Nayyeri, V., Soleimani, M., & Ramahi, O. M. (2017). Pixelated checkerboard metasurface for ultra-wideband radar cross-section reduction. Scientific Reports.
[2] Lan, G., Jin, Z., Nong, J., Luo, P., Guo, C., Sang, Z., Dong, L., & Wei, W. (2020). Narrowband perfect absorber based on dielectric-metal metasurface for surface-enhanced infrared sensing. Applied Sciences, 10(7), 2295.

P07

Quantum Extreme Learning Machine for quantum channel discrimination

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Quantum Extreme Learning Machines (QELMs) provide an efficient framework for quantum machine learning, where a fixed reservoir maps input dynamics into a high-dimensional feature space and only a linear readout is trained. We apply this approach to quantum channel discrimination, aiming to classify whether a channel behaves in a more Markovian or non-Markovian manner. Using a collision model to generate system dynamics and a five-qubit reservoir for processing, we consider two tasks: parameter estimation and channel discrimination. In both cases, we show that incorporating memory, by extending the feature vectors with outputs from previous steps, enhances accuracy and robustness. These results highlight the potential of memory-augmented QELMs as lightweight tools for analyzing open quantum dynamics.

P08 **Title:** Nonstabilizerness and Error Resilience in Noisy Quantum Circuits

Abstract:

We investigate how noise impacts nonstabilizerness—a key resource for quantum advantage—in many-body qubit systems. While noise typically degrades quantum resources, we show that amplitude damping, a nonunital channel, can generate or enhance magic, whereas depolarizing noise provably cannot. In an encoding-decoding protocol, we find that, unlike in the coherent case, a sharp decoding fidelity transition does not match a transition in nonstabilizerness. Our results point toward the possibility of leveraging, rather than merely mitigating, noise for quantum information processing.

P09

Compact localized fermions and Ising anyons in a chiral spin liquid

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Quasiparticle hybridization remains a major challenge to realizing and controlling exotic states of matter in existing quantum simulation platforms. We report the absence of hybridization for compact localized states (CLS) emerging in the chiral spin liquid described by the Yao-Kivelson model. The CLS form due to destructive quantum interference at fine-tuned coupling constants and populate perfectly flat quasiparticle bands on an effective kagome lattice. Using a formalism for general Majorana-hopping Hamiltonians, we derive exact expressions for CLS for various flux configurations and both for the topological and trivial phases of the model. In addition to finite-energy matter fermions with characteristic spin-spin correlations, we construct compact localized Majorana zero modes attached to π-flux excitations, which enable non-Abelian braiding of Ising anyons with minimal separation. Our results inform the quantum simulation of topologically ordered states of matter and open avenues for exploring flat-band physics in quantum spin liquids.

[1] T. Bauer, J. Reuther, arXiv:2511.05105, 2025.

Quantum Simulation of Dynamical Symmetry Breaking in the Gross-Neveu Model

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The Gross-Neveu model [1] is a quantum field theory mimicking Quantum Chromodynamics (QCD) in $1+1$ dimensional spacetime. In addition to being exactly solvable in a large flavor limit, the Gross-Neveu model exhibits dynamical symmetry breaking, which can be manifestly seen by introducing an auxiliary field in the four-fermion interaction term. Refining the massless fermionic lattice Hamiltonian in Ref. [2] and mapping it to appropriate qubits, we first estimate the ground state of the system using a Variational Quantum Eigensolver (VQE) with a symmetric Hardware Efficient Ansatz (HEA), and benchmark the performance against more traditional methods like Density Matrix Renormalization Group (DMRG) and other routines such as QuSpin for exact diagonalization in quantum many-body systems. We then study the time evolution of the state and identify suitable observables to function as order parameters to characterize the dynamical mass generation mechanism.

[1] Gross, D. J., and Neveu, A. Physical Review D, 10(10) (1974): 3235.
[2] Asaduzzaman, Muhammad, Goksu Can Toga, Simon Catterall, Yannick Meurice, and Ryo Sakai. Physical Review D 106, no. 11 (2022): 114515.

Abstract template for ICTP-IBM School on Quantum Computing and Simulation

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Quantum coherence is a central resource in quantum information theory and thermodynamics. While standard quantum teleportation transfers an entire quantum state using two classical bits, recent work has asked whether coherence alone can be transmitted more efficiently. Building on the coherence teleportation protocol introduced in Ref. [1] and the resource-theoretic framework of quantum coherence developed in Ref. [2], we show that perfect teleportation of coherence for an arbitrary unknown qubit is impossible with a single classical bit. However, for partially known states restricted to the equatorial or polar circles of the Bloch sphere, coherence can be perfectly teleported using one classical bit and a maximally entangled resource. Moreover, nonzero coherence transfer is possible even with mixed or separable resource states, highlighting a fundamental distinction between teleporting quantum states and teleporting quantum resources.

[1] S. Sohail, A. K. Pati, V. Aradhya, I. Chakrabarty, and S. Patro, Phys. Rev. A **108**, 042620 (2023).
[2] T. Baumgratz, M. Cramer, and M. B. Plenio, Phys. Rev. Lett. **113**, 140401 (2014).

P12

Distributed quantum sensing

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An entangled distributed quantum sensing scheme based on an array of d Mach–Zehnder interferometers (MZIs) is considered for the estimation of relative phase shifts. The protocol employs ddd coherent states and a single squeezed-vacuum state, which is distributed among the interferometers through a quantum circuit. An analytical optimization shows that the scheme surpasses the shot-noise limit and reaches the Heisenberg limit with respect to the average total number of probe particles, enabling the estimation of arbitrary linear combinations of the ddd phases. The entangled strategy is compared with a separable one using d coherent states and ddd squeezed-vacuum states with the same average total number of probe particles. The entangled approach significantly reduces the resource overhead and can achieve a maximum enhancement by a factor of ddd when both strategies use the same total squeezed-light intensity. Notably, the entangled strategy relying on a single squeezed-vacuum state attains the same sensitivity as the separable strategy employing ddd identical squeezed-vacuum states.

[1] F. Albarelli, M. Barbieri, M. G. Genoni, and I. Gianani, A perspective on multiparameter quantum metrology: From theoretical tools to applications in quantum imaging, Phys. Lett. A **384**, 126311 (2020).
[2] Q. Zhuang, Z. Zhang, and J. H. Shapiro, Distributed quantum sensing using continuous-variable multipartite entanglement, Phys. Rev. A **97**, 032329 (2018)

P13

Hamiltonian Expressibility for Ansatz Selection in Variational Quantum Algorithms

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In the context of Variational Quantum Algorithms (VQAs), selecting an appropriate ansatz is crucial for efficient problem-solving. Hamiltonian expressibility has been introduced as a metric to quantify a circuit's ability to uniformly explore the energy landscape associated with a Hamiltonian ground state search problem. However, its influence on solution quality remains largely unexplored. In this work, we estimate the Hamiltonian expressibility of a well-defined set of circuits applied to various Hamiltonians using a Monte Carlo-based approach. We analyze how ansatz depth influences expressibility and identify the most and least expressive circuits across different problem types. We then train each ansatz using the Variational Quantum Eigensolver (VQE) and analyze the correlation between solution quality and expressibility. Our results indicate that, under ideal or low-noise conditions and particularly for small-scale problems, ansätze with high Hamiltonian expressibility yield better performance for problems with non-diagonal Hamiltonians and superposition-state solutions. Conversely, circuits with low expressibility are more effective for problems whose solutions are basis states, including those defined by diagonal Hamiltonians. Under noisy conditions, low-expressibility circuits remain preferable for basis-state problems, while intermediate expressibility yields better results for some problems involving superposition-state solutions.

P14

Chiral graviton modes on lattice FQHE

P15

Revealing non-classicality of a molecular nanomagnet

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Molecular nanomagnets, also known as single-molecule magnets (SMMs), consist of organometallic molecules featuring a high-spin magnetic core protected by organic ligands, often carboxylates. They have recently gained attention as potential quantum information carriers in solid-state quantum computing platforms and exhibit – simultaneously – classical macroscopic properties and quantum features in light of their complex nature and configuration [1]. Addressing the condition when they manifest unquestionable quantum behavior is key to guarantee their effectiveness as resources for quantum information processing.

We address the quantumness of molecular nanomagnets using a recently formulated criterion [2] according to which a system in a genuine quantum state can generate entanglement between suitably arranged non-interacting probes, while a classical state could not.
In this work, the SMM, modelled as a giant-spin surrounded by a nuclear spin bath, is placed inside a driven multi-mode Fabry-Perot cavity where it interacts with some cavity modes. We show that the intracavity modes, which do not interact directly with each other but only through the SMM, become entangled. The emergence of such entanglement therefore provides strong evidence of the non-classical nature of molecular nanomagnets. Our analysis, which is performed addressing various dynamical regimes, paves the way to the design of experimentally viable tests of non-classicality in multipartite registers consisting of ensembles of molecular nanomagnets.

Based on these results, one aspect of my PhD project is to combine the study of non-classicality with quantum machine learning techniques within a neuromorphic framework, along the lines of what has been proposed in Ref. [3]. In our setup, the experimentally accessible quantities are the travelling output modes of the system. By exploiting the input–output formalism, we propose to allow for interactions among the output modes, for instance through an interferometric pathway. After a finite evolution time, suitable observables are measured, allowing the output modes to be interpreted as nodes of a quantum neural network with a trainable readout layer.

[1] A. Chiesa, P. Santini, Reports on Progress in Physics. 87, 034501 (2024).
[2] T. Krisnanda, M. Zuppardo, Phys. Rev. Lett. 119, 120402 (2017).
[3] T. Krisnanda, T. Paterek, Phys. Rev. D. 107, 086014 (2023).

P16

MACHINE LEARNING-AIDED OPTIMAL CONTROL OF A QUBIT UNDER NON-MARKOVIAN DYNAMICS

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High-fidelity quantum control in realistic devices is often limited by environmental noise with temporal correlations. In this regime, purely analytic (whitebox) modeling can become inaccurate or impractical, while purely data-driven approaches may require large datasets and can violate physical constraints. We address this by developing a graybox machine-learning framework that embeds exact, physics-informed layers into a neural architecture, so that learning is focused on the genuinely unknown noise contribution while the quantum-mechanical structure is enforced by construction. This approach is motivated by the central role of low-frequency noise (often with approximate $1/f$ spectra) in solid-state qubits and by established microscopic models of dephasing due to bistable fluctuators [1, 2, 3, 4].

We consider a single qubit in the driftless regime ($\Omega = 0$) in the interaction picture, driven by two-axis controls and affected by classical pure-dephasing noise: $H(t) = H_{\text{ctrl}}(t) + g\,\beta(t)\sigma_z$, with $H_{\text{ctrl}}(t) = f_x(t)\sigma_x + f_y(t)\sigma_y$. Each control quadrature is parametrized by $N = 5$ Gaussian pulses; pulse centers and widths are fixed, while the amplitudes are the trainable (input) parameters, yielding 10 real inputs in total. The key theoretical ingredient is that noise-averaged expectation values of qubit observables can be written in the form $E[O(T)]_\rho = \text{tr}_S\Big[V_O\, U_{\text{ctrl}}(T)\rho(0)U^\dagger_{\text{ctrl}}(T)\, O\Big]$, where all stochastic effects are captured by an effective operator V_O. For classical noise and traceless observables, V_O is fully determined by only four real parameters $(\mu, \theta, \psi, \Delta)$ with $\mu \in [0, 1]$. The whitebox layers compute U_{ctrl} exactly from the applied pulses and evaluate a tomographically complete set of 18 expectation values (six Pauli-eigenstate preparations and three Pauli measurements). A lightweight Transformer-style blackbox then predicts the parameters of V_O (one branch per Pauli observable), and dedicated gate-specific refinement heads further adjust the intermediate predictions before reconstructing the process matrix and outputting process fidelities for the universal gate set $\{I, X, Y, Z, H, R_X(\pi/4)\}$. Training data are generated by Monte Carlo simulation with total evolution time $T = 3.2\ \mu$s, $M = 3000$ time steps, and $K = 2000$ noise realizations for averaging. We study both non-Gaussian Random Telegraph Noise (RTN) and Gaussian Ornstein–Uhlenbeck (OU) noise with matched power spectra, at fixed noise rate $\gamma = k/2 = 1$ MHz and coupling strengths $g \in \{0.1, 0.2, 0.3, 0.4, 0.5\}$ MHz (datasets of 5000 points for $g \leq 0.4$ and 10000 points for $g = 0.5$, split 80/20 for train/test). The trained model achieves low test errors that increase smoothly with coupling (sub-percent level at $g = 0.1$ MHz and a few percent at $g = 0.5$ MHz), with stable generalization across gates. Crucially, the differentiable emulator enables gradient-based optimal control: we minimize the cost $J(u, \Theta; G) = 1 - F(u, \Theta; G)$ (with F the process-matrix fidelity) using a BFGS-type optimizer, obtaining Monte-Carlo-validated gate fidelities above 99% at weak coupling and around 90% even at the strongest coupling considered, with comparable performance for RTN and OU.

[1] A. Youssry, G. A. Paz-Silva, and C. Ferrie, npj Quantum Inf. **6**, 95 (2020).
[2] A. Vaswani *et al.*, in *Advances in Neural Information Processing Systems* (NeurIPS 2017) (2017).
[3] E. Paladino, Y. M. Galperin, G. Falci, and B. L. Altshuler, Rev. Mod. Phys. **86**, 361 (2014).
[4] E. Paladino, L. Faoro, G. Falci, and R. Fazio, Phys. Rev. Lett. **88**, 228304 (2002).

Tensor Network simulation of Multi-Emitter Waveguide QED

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Waveguide Quantum Electrodynamics (Waveguide QED) is a promising and versatile platform for studying fundamental *light-matter interactions* and *quantum technology* implementations [1]. 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) [2, 3].

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.

[1] F. Ciccarello, P. Lodahl, and D. Schneble, Optics and Photonics News, **35**(5), 34-41 (2024).
[2] G. Calajó, Y. L. Fang, H. U. Baranger, and F. Ciccarello, J. Sci. Phys. Rev. Lett. **122**, 073601 (2019).
[3] K. Sinha, P. Meystre, E. A. Goldschmidt, F. K. Fatemi, S. L. Rolston, P. Solano, Phys. Rev. Lett. **124**, 043603 (2020)

Probing Quantum Nonlocality and Entanglement in Coupled Double Quantum Dots under an External Magnetic Field

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Double quantum dot (DQD) systems are promising platforms for implementing quantum information and computing technologies. We investigate quantum correlations (QCs) in a coupled AlGaAs/GaAs DQD system under varying temperature, energy detuning, coupling strength, and external magnetic fields. Quantum correlations are quantified using uncertainty-induced nonlocality (UIN) and Bell-type nonlocality, while entanglement is measured via logarithmic negativity. The results show that QCs are strongly dependent on thermal and system parameters: low temperatures enhance correlations, whereas higher temperatures suppress them due to thermal decoherence. Magnetic fields crucially influence resonance conditions, with maximum QCs occurring at zero detuning between DQDs. Conversely, large detuning or excessive coupling reduces correlations. These findings provide insight into the interplay between entanglement, nonlocality, and control parameters in DQD systems, offering valuable guidance for the design of future quantum devices.

[1] Ait Mansour, H., Chouiba, A., Mansour, M., & El Baz, M. (2024). Nonlocal correlations and entanglement in two coupled double quantum dots under external magnetic field. Laser Physics Letters, 21(12), 125209.

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[1] aicha.chouiba1-etu@etu.univh2c.ma

Towards Tensor Network Models for Low-Latency Jet Tagging on FPGAs

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We present a systematic study of Tensor Network (TN) models — Matrix Product States (MPS) and Tree Tensor Networks (TTN) — for real-time jet tagging in high-energy physics, with a focus on low-latency deployment on Field Programmable Gate Arrays (FPGAs). Motivated by the strict requirements of the HL-LHC Level-1 trigger system [1, 2], we explore TNs as compact and interpretable alternatives to deep neural networks[5, 6]. Using low-level jet constituent features [3], our models achieve competitive performance compared to state-of-the-art deep learning classifiers [4]. We investigate post-training quantization to enable hardware-efficient implementations without degrading classification performance or latency. The best-performing models are synthesized to estimate FPGA resource usage, latency, and memory occupancy, demonstrating sub-microsecond latency and supporting the feasibility of online deployment in real-time trigger systems. Overall, this study highlights the potential of TN-based models for fast and resource-efficient inference in low-latency environments.

[1] ATLAS Collaboration, Proceedings of 42nd International Conference on High Energy Physics — PoS(ICHEP2024) **476**, 879 (2025).
[2] CMS Collaboration, J. Inst. **12**, P01020 (2017).
[3] M. Pierini et al., Zenodo (2020), 10.5281/zenodo.3602260
[4] Sun Chang et al., Mach. Learn.: Sci. and Technol., **6**, 035025 (2025)
[5] T. Felser, M. Trenti, L. Sestini, A. Gianelle, D. Zuliani, D. Lucchesi, S. Montangero, npj Quantum Information.**7**, 111 (2021)
[6] L. Borella, A. Coppi et al., Mach. Learn.: Sci. and Technol., **6**, 045062 (2025)

Channel Capacity of Small Modular Quantum Networks in the Ultrastrongly Coupled Regime

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We investigate state transfer in modular quantum computer architectures exploiting the ultrastrong coupling regime of interaction between quantum processing units and ICs. We show that protocols based on adiabatic coherent transport may achieve near-ideal single-letter quantum capacity and robustness against parametric fluctuations suppressing leakage induced by the dynamical Casimir effect.

[1] G. Benenti, A. D'Arrigo, S. Siccardi, G. Strini, Phys. Rev. A **90**, 052313 (2014).
[2] M. Stramacchia, A. Ridolfo, G. Benenti, E. Paladino, F.M.D. Pellegrino, D. Maccarrone, G. Falci, Proceedings **12**(1), 35 (2019).
[3] G. A. Falci, L. Giannelli, G. Benenti, S. Montangero and E. Paladino, (preprint 2025).
[4] Greentree, A.D., Cole, J.H., Hamilton, A.R., Hollenberg, L.C.L., Phys. Rev. B **70**, 235317 (2004).
[5] Nielsen, M. A., Chuang, I. L. Quantum Computation and Quantum Information: 10th Anniversary Edition. Cambridge University Press (2011).

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Generating Highly Entangled Quantum States via Symmetric Phase Matrices

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We introduce a framework to construct pure quantum states with uniform subsystem purities by optimizing symmetric phase matrices over finite fields. Specifically, we define a family of states ψ using a symmetric matrix P over $\mathbb{Z}_d$ and a primitive d-th root of unity. By minimizing deviations of reduced purities from the ideal $1/d^k$ across all k-qudit subsets, we identify phase configurations that produce highly entangled states with maximally mixed marginals. This approach generalizes known quantum designs and provides a scalable method for engineering multipartite entanglement with tunable locality. Our results uncover a rich variety of phase-driven entanglement structures, offering new tools for quantum scrambling, benchmarking, and state preparation in near-term quantum devices.

[1] Raissi, Z., Teixidó, A., Gogolin, C., & Acín, A. (2020). Constructions of k-uniform and absolutely maximally entangled states beyond maximum distance codes. Physical Review Research, 2(3), 033411.

[2] Li, M. S., & Wang, Y. L. (2019). K-uniform quantum states arising from orthogonal arrays. Physical Review A, 99(4), 042332.

[3] Mansour, M., & Daoud, M. (2019). k-uniform maximally mixed states from multi-qudit phase states. Modern Physics Letters A, 34(19), 1950151.

[4] Mansour, M., & Dahbi, Z. (2020). Quantum secret sharing protocol using maximally entangled multi-qudit states. International Journal of Theoretical Physics, 59(12), 3876-3887.

Rényi-Order regime where trusted noise enhances DV QKD finite-size key rates.

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In Quantum Key Distribution (QKD), *discrete-variable* (DV) protocols the encoding of private information is performed on the discrete degrees of freedom of the electromagnetic fields, then measurements are usually performed complementary bases. Among the various DV protocols, the BB884 is the most well-known example [1]. It is worth noting that composable, information-theoretic approaches offer general bounds on the key rate and clarify the impact of classical post-processing steps on overall security [2]. One important example is *trusted local randomization*, where one party flips each bit of the sifted key with a given probability before information reconciliation. This procedure is often referred to as *trusted-noise injection*; in this way, one of the legitimate user adds local randomness which is inaccessible to a possible eavesdropper. In asymptotic analyses based on von Neumann entropy, this technique has been proven to increase the secret-key rate, especially when the quantum bit error rate (QBER) is high, as shown in early studies [3]. Recent work on finite-size security suggests that using *Rényi entropies* can lead to tighter key-rate bounds for practical block lengths [4, 5]. These developments motivate a deeper analysis on the role of trusted noise in finite-size settings when the key rate is estimated using sandwiched Rényi entropies.

In this work, we analyze the BB84 protocol with trusted noise under collective (i.i.d.) attacks, estimating the finite-size key rate via a sandwiched Rényi entropy approach. First, we identify the range of Rényi orders for which trusted noise remains beneficial by comparing key rates with and without optimally tuned randomization. Then, we determine the maximum achievable finite-size lower bound by jointly optimizing over the randomization parameter and the Rényi order. We evaluate the required entropic quantities numerically by recasting the problem into a form suitable for efficient convex optimization and performing a systematic outer optimization over both parameters. Methodologically, our numerical evaluation builds on the reliable two-step framework for key rate computation in [6], based mainly on the Frank–Wolfe algorithm [7]. Adapting this approach to our setting required handling an objective of fundamentally different nature, since the privacy term is expressed through sandwiched Rényi entropies rather than von Neumann entropies. In particular, the Frank–Wolfe iterations require explicit analytical gradients of the Rényi-based objective. In our setting, we work with a fully variational Rényi entropy objective that retains the auxiliary optimization, so the Frank–Wolfe updates must be driven by gradients with respect to *two* coupled variables rather than one.

[1] C. H. Bennett and G. Brassard, Theor. Comput. Sci. **560**, 7 (2014).
[2] R. Renner, N. Gisin, and B. Kraus, Phys. Rev. A **72**, 012332 (2005).
[3] B. Kraus, N. Gisin, and R. Renner, Phys. Rev. Lett. **95**, 080501 (2005).
[4] L. Kamin, A. Arqand, I. George, N. Lütkenhaus, and E. Y.-Z. Tan, PRX Quantum **6**, 020342 (2025).
[5] G. Staffieri, G. Scala, and C. Lupo, arXiv:2509.14345 (2025).
[6] A. Winick, N. Lütkenhaus, and P. J. Coles, Quantum **2**, 77 (2018).
[7] M. Frank and P. Wolfe, Nav. Res. Logist. Q. **3**, 95 (1956).
[8] R. R. B. Chung, N. H. Y. Ng, and Y. Cai, Phys. Rev. A **112**, 012612 (2025).

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Testing Neural-Shadow Quantum State Tomography with different ansätze

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Neural-network quantum states (NQS) have emerged as a powerful framework for representing and reconstructing many-body quantum states by combining variational principles with modern machine-learning architectures. In parallel, classical shadow tomography has enabled scalable reconstruction of quantum states from randomized measurements. Recently, these two approaches were unified in the Neural Shadow Quantum State Tomography (NSQST) framework, which leverages neural quantum states as expressive priors for learning quantum states directly from classical shadow data [1]. This method demonstrated efficient and accurate reconstruction of complex quantum states while mitigating the exponential scaling typically associated with full state tomography.

In this work, we systematically compare the performance and expressivity of the NSQST framework across different neural quantum state ansätze, with particular emphasis on a modified Restricted Boltzmann Machine (RBM) architecture introduced here. Building on the standard RBM neural quantum state formulation [2,3], we propose a modified RBM ansatz designed to enhance phase representation and entanglement capacity while preserving analytical marginalization of hidden units. This modification aims to address known limitations of shallow RBMs, such as restricted entanglement scaling and limited expressivity for frustrated or highly entangled states.

We benchmark the modified RBM within the NSQST protocol against several established NQS architectures, including feedforward neural networks, convolutional neural networks, and autoregressive neural quantum states [4–7]. The comparison focuses on reconstruction fidelity, sample efficiency, stability under noisy measurement data, and scalability with system size. Our results indicate that while autoregressive and transformer-based NQS achieve superior expressivity in large or critical systems, the modified RBM offers a competitive trade-off between interpretability, computational efficiency, and reconstruction accuracy, particularly for small-to-intermediate system sizes and near-area-law states.

This study clarifies the role of architectural choices in neural shadow tomography and highlights how physically motivated modifications of classical NQS ansätze can remain relevant within modern quantum learning pipelines. Our results suggest that RBM-based neural quantum states, when appropriately extended, continue to provide a valuable and conceptually transparent tool for quantum state reconstruction and tomography.

[1] Y. Wang, S. Liu, and X. Li, Neural shadow quantum state tomography, Phys. Rev. Lett. 132, 150401 (2024).
[2] G. Carleo and M. Troyer, Solving the quantum many-body problem with artificial neural networks, Science 355, 602 (2017).
[3] Y. Nomura, A. Darmawan, Y. Yamaji, and M. Imada, Restricted Boltzmann machine learning for solving strongly correlated quantum systems, Phys. Rev. B 96, 205152 (2017).
[4] K. Choo, T. Neupert, and G. Carleo, Symmetries and many-body excitations with neural-network quantum states, Phys. Rev. Lett. 121, 167204 (2018).
[5] K. Choo, A. Mezzacapo, and G. Carleo, Convolutional neural networks for the quantum many-body problem, Phys. Rev. B 98, 224409 (2018).
[6] D. Sharir, Y. Levine, N. Wies, Y. Carleo, and A. Shashua, Deep autoregressive models for the efficient variational simulation of many-body quantum systems, Phys. Rev. Lett. 124, 020503 (2020).
[7] G. Torlai and R. G. Melko, Neural-network quantum state tomography, Nat. Phys. 14, 447 (2018).

A Noisy Gates-based learning model to characterize Quantum Devices

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Quantum computing is an emerging technology that is progressing rapidly and has the potential to significantly impact computational methods in the coming decades. However, current state-of-the-art devices are affected by noise resulting from interactions with the surrounding environment, which limits their computational reliability. To address this challenge, Quantum Error Correction (QEC) techniques have been developed, but their implementation requires a large number of qubits and high connectivity, making them impractical for current Noisy Intermediate-Scale Quantum (NISQ) devices [1, 2]. Consequently, Quantum Error Mitigation (QEM) techniques have emerged as a more viable short-term alternative [3]. However, these methods require prior knowledge of the device's noise model, which is not trivial to characterize comprehensively.

In this work, we introduce a novel learning model based on the concept of noisy gates to characterize the noise affecting quantum devices [4]. The noisy gates framework integrates noise effects directly into gate operations through perturbative solutions of the Lindblad equation, providing a more accurate simulation of quantum hardware [5].

Building on this approach, we develop a learnable noise model based on a generic Lindbladian formulation, incorporating suitable assumptions to ensure computational tractability. Specifically, we assume m-locality of the noise maps, meaning that noise acts only on a subset of qubits involved in each gate operation, drastically reducing the number of learning parameters while still capturing the main noise sources in the device. The model is parameterized by damping rates and jump operators in the Lindblad equation. We optimize these parameters through a learning algorithm that minimizes a loss function based on measured observables in quantum circuits, comparing outputs from the simulator with those from a target device. We adapt the Noisy Gates Python package to build the learning model and run simulations [6].

To validate our approach, we conduct experiments on one- and two-qubit systems using simulators of superconducting devices with fixed simple noise models as targets, demonstrating the effectiveness of the proposed method as a proof of concept. Our results show that the model successfully captures key noise characteristics, with the ADAM optimizer proving most effective for parameter convergence, but more experiment with more complex noise structure and a more sophisticated loss function is request to be apply on real devices and larger systems.

This work lays the foundation for future research on scaling the approach to larger quantum systems, refining observable selection strategies, and integrating more sophisticated machine learning algorithms. The learned noise models can facilitate the application of targeted QEM techniques and provide valuable insights for device calibration and real-time error mitigation.

[1] P. W. Shor, Phys. Rev. A **52**, R2493 (1995).
[2] J. Preskill, Quantum **2**, 79 (2018).
[3] Z. Cai et al., Rev. Mod. Phys. **95**, 045005 (2023).
[4] G. Di Bartolomeo et al., Phys. Rev. Res. **5**, 043210 (2023).
[5] G. Lindblad, Commun. Math. Phys. **48**, 119 (1976).
[6] Quantum Gates – CERN IT Innovation, https://github.com/CERN-IT-INNOVATION/quantum-gates.

Dipolar quantum matter in ultracold Rydberg atoms and polar molecule platforms with multiple internal states

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Rydberg atoms and polar molecules interact via dipole-dipole interactions. With advances in tweezer technology, it is now possible to individually trap and control these quantum particles independently, allowing for their use in quantum simulation of dipolar quantum matter [5, 6, 7]. This has led to the realization of XYZ-type models in these platforms with the use of two internal states [10]. Recent studies [2, 3, 4, 1] have revealed a rich phase diagram of a quantum many-body system of ultracold atoms (or polar molecules) with a set of more than two Rydberg states (or rotational states) as a synthetic dimension where the real particles are arranged in optical microtrap or optical tweezer arrays and interact via dipole-dipole exchange interaction. The Rydberg or the rotational states are coupled via microwaves which are easily tuned to the desired tunneling scheme. Three non-trivial symmetry-broken phases were characterized: two of which are string (1 synthetic dimension) or membrane (2 synthetic dimension) -like phase wherein only a few synthetic states are populated, and one which is non-localized but ordered.

I first show my results from past work [1] that include the quantum and thermal phases of this system. The internal spin states obey a dihedral symmetry, and the thermal phase diagram shows some similarity to the classical Potts and p-clock models [11]. Then, I discuss the effects of frustrated lattices in these systems. Past studies on two-state spin-$1/2$ dipolar models have revealed that spin liquid states are stabilized by dipolar interactions in triangular and kagome lattices. We explore the multi-state version with the Potts-like internal symmetry. Finally, I conclude with a brief overview of future directions with Rydberg and polar molecule dipolar quantum simulator platforms, in the context of quantum simulation of novel spin liquids, lattice gauge theories and other topological quantum matter [8, 9].

[1] S. Dasgupta, C. Feng, B. Gadway, R. T. Scalettar, K. R. A. Hazzard Phys. Rev. A **109**, 063322 (2024).

[2] B. Sundar, B. Gadway, K. R. A. Hazzard Sci. Rep. **8**, 3422 (2018).

[3] B. Sundar, M. Thibodeau, Z. Wang, B. Gadway, K. R. A. Hazzard, Phys. Rev. A **99**, 013624 (2019).

[4] C. Feng, H. Manetsch, V. G. Rousseau, K. R. A. Hazzard, Phys. Rev.. A. **105**, 063320 (2022).

[5] T. Chen, C. Huang, I. Velkovsky, K. R. A. Hazzard, J. P. Covey, B. Gadway, Nat. Comm. **15**:2675 (2024).

[6] T. Chen, C. Huang, I. Velkovsky, T. Ozawa, H. M. Price, J. P. Covey, B. Gadway, Nat. Phys. **21**, 221-227 (2025).

[7] D. K. Ruttley, T. R. Hepworth, A. Guttridge, S. L. Cornish, Nature **637** 827-832 (2025).

[8] T. Ozawa, H. M. Price, Nat. Rev. Phys. **1**, 349-357 (2019).

[9] J. Argüello-Luengo, U. Bhattacharya, A. Celi, R. W. Chhajlany, T. Grass, M. Płodzień, D. Rakshit, T. Salamon, P. Stornati, L. Taurrell, M. Lewenstein, Comm. Phys **7**:143 (2024).

[10] C. Chen, G. Bornet, M. Bintz, G. Emperauger, L. Leclerc, V. S. Liu, P. Scholl, D. Barredo, J. Hauschild, S. Chatterjee, M. Schuler, A. M. Läuchli, M. P. Zaletel, T. Lahaye, N. Y. Yao, A. Browaeys, Nature **616**, 691-695 (2023).

[11] G. Ortiz, E. Cobanera, Z. Nussinov, Nuc. Phys. B **854** 780-814 (2012).

Emergent symmetry breaking in quantum circuit compilation

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The execution of quantum circuits on real hardware is inherently affected by errors. To mitigate these errors, quantum circuit transpilation reschedules the gates of a quantum circuit, exploiting a set of local transformations that preserve the global unitary transformation. A strongly parallelized realization of an algorithm maximizes the number of simultaneous gates, reducing the execution time and thus decoherence error. Differently, a serial realization minimizes crosstalk errors and spurious correlations between neighbouring gates. We interpret quantum circuits as many-body states defined on a time-register two-dimensional lattice and governed by a Hamiltonian that encodes the circuit implementation error. By simulating the thermodynamics of the resulting many-body system, we observe the emergence of phase transitions in the space of equivalent circuits. At moderately low crosstalk error, the optimal circuit is parallel and characterized by an emergent $\mathbb{Z}_2$ displacement of the gates. The transition between the unoptimized and optimal circuit configuration falls into the Ising universality class. Moreover, for increasing crosstalk error strength, new $\mathbb{Z}_n$-ordered phases emerge until the fully serial regime is reached. Beyond circuit optimization, our results shed light on the connection between the computational complexity of equational optimization and the emergent criticality of the associated many-body system.

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Dual Fraunhofer pattern in a quasicharge device

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A Josephson junction between two superconductors can behave either as a superconducting weak link or as an insulating break, depending on whether the circuit in which the junction is embedded suppresses or enhances phase fluctuations [1]. Understanding the transition between these two regimes is of fundamental interest and has potential applications in both metrology and quantum computing.

Here, we investigate the ground-state properties and transport characteristics of a N-Josephson-junction array controlled via external gate voltages, with the entire array shunted by a large inductance. We exploit the phase–charge duality to describe the system within a quasicharge approximation [2, 3] and highlight the emergence of a critical voltage with a Fraunhofer-like dependence on the gate charges, analogous to the critical current arising from a parallel of N-Josephson junctions [4].

We finally verify the validity of the quasicharge approximation for the case of a two-junction circuit, showing that it behaves as the dual of a SQUID, with the role of the external flux played by the gate-induced charges.

[1] J. E. Mooij and Yu. V. Nazarov, *Quantum Phase Slip Junctions*, Nature Physics **2**, 169–172 (2006).

[2] E. M. Lifshitz and L. P. Pitaevskii, *Statistical Physics, Part 2*, Chapter 6, Butterworth–Heinemann, Oxford (1980).

[3] J. Koch, V. Manucharyan, M. H. Devoret, and L. I. Glazman, *Charging effects in the inductively shunted Josephson junction*, Phys. Rev. Lett. **103**, 217004 (2009).

[4] R. De Luca, T. Di Matteo, A. Tuohimaa, and J. Paasi, *Quantum interference in parallel Josephson junction arrays: a perturbative analysis for finite inductances*, Physics Letters A **245**, 301–306 (1998).

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The efficiency of Feynman's design for a quantum computer is analysed. It is then argued that it is in fact not a very realistic model and a more physical clock model is proposed.

Quantum Speed Limit in Driven-dissipative Systems

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Every quantum operation that takes a system from one state to another is known to have bounds on operation time, due to Heisenberg uncertainty principle. In open quantum systems (OQS), such bounds have been principally affected by system environment coupling. In the recent past, drives on OQS have shown to give rise to drive-induced dissipation (DID). In this work, we investigate how DID affects the quantum speed limits. To this end, we use a recently-reported fluctuation-regularized quantum master equation that takes into account environment fluctuations and provide a closed form estimate of DID. On such a system, we use Gradient Ascent Pulse Engineering (GRAPE) to find optimal route to move from an initial state to a desired final state. Our key result is that there exists an optimal evolution time that maximizes fidelity. This work enables robust quantum control in open systems, addressing a key challenge in scaling quantum technologies. By improving fidelity and efficiency, our method advances practical quantum computing under realistic dissipative conditions.

[1] Fency, S., Chatterjee, R., & Bhattacharyya, R. (2025), arXiv:2504.07931.

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Modeling of Fast Quantum Gates in Fluxonium-like Superconducting Qubits

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In a context where low-frequency superconducting qubits are gaining increasing attention due to their long coherence times, the search for fast quantum gates has motivated the development of experimental and theoretical techniques based on high frequency, large-amplitude sinusoidal pulses.

In this thesis, we investigate the implementation of a universal set of quantum gates in a fluxonium superconducting qubit, incorporating its multilevel structure and realistic device parameters. In the first part, analytical results known for two-level systems are extended, and it is verified that the analytical parameter curve agrees with numerical simulations in the low-amplitude regime, while deviations arise as the pulse intensity increases. By calculating the fidelity of the gates, the dominant source of error is identified as population loss to states outside the computational subspace. Furthermore, as an optimization strategy, it is shown that this effect can be mitigated by tuning the device parameters in order to reduce the qubit frequency and increase the anharmonicity of the energy levels.

In the second part, we include the effects of the interaction with the environment in the fidelity calculation, by solving the Born–Markov master equation in the Floquet basis. It is observed that, for very low qubit frequencies, the error increases again due to temperature effects, allowing the identification of an optimal parameter region for device design.

For the two–qubit case, an effective model of tunable coupling in the flux variables is proposed. Within this simplified framework, the results are analogous to the single-qubit case, with gate times at least two orders of magnitude faster than traditional resonant schemes, providing a foundation for future research with more complete coupling models.

[1] Cáceres, J. J., Domínguez, D., & Sánchez, M. J., Physical Review A (Vol. 108, Issue 5) (2023).
[2] Reparaz, V., Sánchez, M. J., Gatto, M., Domínguez, D., Tosi, L., Physical Review B (Vol. 112, Issue 5) (2025).
[3] Nguyen, L. B., Koolstra, G., Kim, Y., Morvan, A., et al. PRX Quantum (Vol. 3, Issue 3) (2022)

Exploiting Quantum Many-Body Scars for Coherent Quantum Simulation

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We study quantum many-body scars as a resource for quantum simulation and near-term quantum technologies. Considering a one-dimensional spin-$1/2$ system described by the PXP Hamiltonian, we analyze the coherent dynamics of scarred states under weak time-dependent control fields. We show that the nonthermal nature of scarred dynamics leads to long-lived coherence and highly structured energy spectra, which can be selectively addressed through resonant driving. Using the quantum Fisher information as a diagnostic tool, we demonstrate that information about external control parameters can accumulate over extended times, in contrast to thermalizing many-body systems. We derive a semi-analytical description of the dynamics that captures its essential features and reveals the scaling of the response with system size. Our results connect quantum many-body scars with practical aspects of quantum simulation and control, and are directly relevant to implementations on programmable quantum simulators and near-term quantum hardware.

Benchmarking quantum algorithms for eigenvalue estimation on early fault-tolerant quantum devices

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Quantum computers (QCs) with a few protected logical qubits and limited depth are expected to become available in the near future, in the so-called early fault-tolerant regime [1]. Among the most promising algorithms for these first QCs are eigenvalue estimation methods, which focus on finding the ground-state and excited-state energies of physical systems. A large number of these algorithms with theoretical guarantees or performance heuristics, have been developed for the early fault-tolerant regime. These methods can work with limited resources and a few qubits. Two main subclasses of protocols have emerged: stochastic phase estimation techniques [2, 3, 4] and subspace-based methods [5, 6]. Both protocols rely on extracting a multitude of measurements from the quantum device, most commonly based on time-evolving the system of interest for different times, and then post-processing these measurements classically. Stochastic phase estimation techniques typically sample time-domain signals stochastically and use advanced filtering methods, while subspace-based methods usually use discretely spaced time grids and construct generalized eigenvalue problems. A wide range of algorithms exists within these approaches. Benchmarking and comparing these algorithms is a crucial task, as it provides realistic estimates for the scaling of runtimes, circuit depth, robustness, accuracy, and number of shots. In this work, we present preliminary findings from our benchmarking study. We show a unified picture of early fault-tolerant eigenvalue estimation algorithms and report numerical simulations of their empirical scaling with respect to accuracy and runtime for various quantum chemical systems.

[1] Amara Katabarwa et al. In: *PRX Quantum* 5 (2024), p. 020101.

[2] Lin Lin and Yu Tong. In: *PRX Quantum* 3 (2022), p. 010318.

[3] Zhiyan Ding and Lin Lin. In: *PRX Quantum* 4 (2023), p. 020331.

[4] Guoming Wang et al. In: *Quantum* 7 (2023), p. 1167.

[5] Cristian L. Cortes and Stephen K. Gray. In: *Phys. Rev. A* 105 (2022), p. 022417.

[6] Katherine Klymko et al. In: *PRX Quantum* 3 (2022), p. 020323.

Failure of the mean-field Hartree approximation for a bosonic many-body system with non-Hermitian Hamiltonian.

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I will present the results from our latest work [1] on the mean-field regime of non-Hermitian Hamiltonians. Mean-field theory approximates complex many-body quantum dynamics through an effective single-particle evolution governed by nonlinear equations. In the standard setting of Hermitian Hamiltonians, such a mean-field limit is by now well understood and leads to the Hartree or Gross–Pitaevskii equations [2]. We work on the extension of this results to non-Hermitian Hamiltonians, it would have applications in many-body quantum physics for describing open quantum systems [5], gain/loss dynamics, or PT-symmetry [4]. It would also have applications on quantum algorithms for nonlinear partial differential equations [3].

I will present a specific counterexample where the nonlinear Hartree approximation fails to accurately capture the many-body dynamics. This example allow us to solve the many-body dynamic and to obtain the correct single-particle nonlinear equation asociated to this particular Hamiltonian. It shades light into a possible theory generalizing the mean-field approximation. Finally, I will discuss recent progress toward the understanding and rigorous proof of this phenomenon.

[1] M. Ginzburg, G. De Palma, S. Rademacher,arXiv:2601.13038 (2026)
[2] N. Benedikter, M. Porta, B. Schlein, Effective Evolution Equations from Quantum Dynamics, Springer (2016).
[3] S. Lloyd, G. De Palma, C. Gokler, B. Kiani, Z.-W. Liu, M. Marvian, F. Tennie, T. Palmer, arXiv:2011.06571 (2020).
[4] R. El-Ganainy, K. G. Makris, M. Khajavikhan, Z. H. Musslimani, S. Rotter, D. N. Christodoulides, Nat. Phys. **14**, 11 (2018).
[5] I. Rotter, J. Phys. A: Math. Theor. **42**, 153001 (2009).

Digital Quantum Simulation of Flat-Band and All-Bands-Flat Dynamics for Tunable Quantum Transport

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Flat-band systems offer a uniquely powerful tool for quantum control in dynamics due to their characteristic feature of having a dispersionless energy band. Simulating such highly sensitive systems on current digital quantum computers is a challenging task, due to the intrinsic limitations of the noisy intermediate-scale quantum (NISQ) devices. Here we present high-fidelity digital quantum simulations of flat-band (FB) and all-bands-flat (ABF) lattices, using an advanced tensor-network-based circuit compression method. Starting from single-particle dynamics, we observe two distinct behaviours: strong localization in ABF lattices and delocalization in FB lattices. By integrating FB and ABF lattices within one-dimensional structures, we demonstrate a mechanism to regulate quantum transport, where the ABF lattice acts as a quantum switch. Extending to two-particle dynamics, we show that transport remains controllable by tuning the hopping amplitude alone, even in the presence of interactions. These results establish flat-band engineered systems as a promising pathway for scalable control of quantum transport in emerging quantum technologies, with potential applications in qubit isolation, particle trapping, and state transfer.

Keywords: quantum computation, quantum control, quantum simulation, tensor network, Flat band dynamics

On the Identification of Active Electronic Subspaces in Quantum-Enhanced Surface Chemistry

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Surface chemistry involves electronic processes spanning multiple length and energy scales, from localized bond formation at the surface–adsorbate interface to extended metallic screening. While mean-field electronic structure methods efficiently capture the latter, chemically relevant adsorption and reaction phenomena are often governed by a small subset of orbitals localized in the reactive region, motivating a separation between an active electronic subspace and its environment. Such a separation underlies recent hybrid quantum–classical embedding frameworks and is central to assessing the feasibility of quantum-enhanced simulations of surface processes. A key bottleneck in applying quantum algorithms to realistic surface chemistry problems is therefore not the quantum solver itself, but the construction of a compact and physically meaningful active space. In this contribution, general criteria for active-space identification based on diagnostics available from mean-field electronic structure calculations are discussed. In particular, orbital localization measures and projected spectral features are considered as tools for distinguishing states directly involved in bond formation from the extended electronic background that primarily provides screening and charge-reservoir behavior. Building on this distinction, a workflow is outlined in which classical calculations serve as a diagnostic tool for defining a minimal Hamiltonian capturing the essential physics of adsorption [1], while the remaining degrees of freedom are retained at a lower level of theory. Rather than presenting a system-specific study, the focus is on general principles underlying active-space selection and their implications for the scalability and practical relevance of quantum-enhanced approaches to surface chemistry.

[1] S. Battaglia, M. Rossmannek, V. V. Rybkin, I. Tavernelli, and J. Hutter, npj Comput. Mater. **10**, 297 (2024).

Quantum-enhanced Quantum Monte Carlo for Defect Calculations

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Quantum Monte Carlo is one of the most precise methods available to simulate molecular and condensed matter systems. However, it suffers from efficiency issues that limit its applicability when used to obtain very accurate calculations. Nevertheless, initializing the simulation with a better estimation of the ground state of the studied system allows for more efficient convergence, making the accurate simulation of larger systems feasible. This is in line with the idea of warm starts, which also play a significant role in other quantum algorithms like the variational quantum eigensolver and quantum phase estimation. Here, we use a quantum computer to generate the initial state of a variational Quantum Monte Carlo calculation and benchmark its convergence against that obtained when using other starting configurations. As use case, we choose the technologically relevant and well understood NV center in diamond, whose localized electronic orbitals make it the ideal playground.

G. Mazzola, J. Chem. Phys. **160**, 010901 (2024).
T. Jiang, et. al., Chem. Rev. **125**, 9, 4569–4602 (2025).
K. A. Simula and I. Makkonen, Phys. Rev. B **108**, 094108 (2023)
D. Pfau et. al., Science **385**, eadn0137 (2024)

Simulating Magic State Cultivation with Matrix Product States

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Magic State Cultivation (MSC) is a recent and promising new scheme aimed at preparing high-fidelity logical magic states [1], which are commonly used with teleportation to implement non-Clifford gates, a key element in fault-tolerant quantum computing. This new technique improves the required computing resources by orders of magnitude compared to the previous state-of-the-art, magic state distillation [2]. However, due to its heavy reliance on post-selection, both the scheme's fidelity and associated overheads are highly sensitive to the noise model and the specific implementation [1, 3]. Thus, careful simulation is key to accelerating and optimizing full-scale fault-tolerant quantum computing.

MSC is hard to simulate due to the presence of non-Clifford gates, which prevents the direct use of high-performance stabilizer simulators. A common workaround is to study an approximation of the circuit wich only rely on Clifford gates. However, this approximation has been shown to lead to large discrepancies with the exact fidelity [1, 4].

In this project, we explore the application of Matrix Product State (MPS) simulators [5] for the exact simulation of MSC, focusing on the recently proposed T state cultivation protocol based on the so-called Fold-transversal S gate on the rotated surface code [6], and the CX cultivation [3]. We use the high-performance, universal, MPS simulator MIMIQ [7, 8] to evaluate the required resources and logical error rate of cultivation schemes. To mitigate the unfavorable scaling of MPS with increasing entanglement, we optimize the qubits' layout and MIMIQ's internal parameters, and we reduce the required number of samples through the use of Monte Carlo reweighting. We extend the simulation to realistic noise models, especially taking care of noises inherent to neutral atom hardware platforms, such as atom losses, movement noise, and long-range gates noise profile. This enables us to evaluate and optimize different strategies for neutral atom implementations of MSC and space-time scheduling of operations in full-scale fault tolerant quantum computing.

In conclusion, we accelerate neutral atom fault tolerant quantum computing by evaluating and optimizing the performance of MSC via exact MPS simulation.

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[1] C. Gidney, N. Shutty, and C. Jones, Magic state cultivation: growing t states as cheap as cnot gates (2024), arXiv:2409.17595 [quant-ph].

[2] S. Bravyi and A. Kitaev, Physical Review A **71**, 10.1103/physreva.71.022316 (2005).

[3] Y. Vaknin, S. Jacoby, A. Grimsmo, and A. Retzker, Efficient Magic State Cultivation on the Surface Code (2025), arXiv:2502.01743 [quant-ph].

[4] R. Li, K. Zheng, Y. Zhang, H. Lou, S. Ying, K. Liu, and X. Sun, SOFT: A high-performance simulator for universal fault-tolerant quantum circuits (2025), arXiv:2512.23037 [quant-ph].

[5] G. Vidal, Physical review letters **91**, 147902 (2003).

[6] K. Sahay, P.-K. Tsai, K. Chang, Q. Su, T. B. Smith, S. Singh, and S. Puri, Fold-transversal surface code cultivation (2025), arXiv:2509.05212 [quant-ph].

[7] MIMIQ, Quantum Circuit Simulator, `https://github.com/qperfect-io`.

[8] A. Leonteva, G. Masella, M. Outteryck, A. P. Orioli, and S. Whitlock, Comparative benchmarking of utility-scale quantum emulators (2025), arXiv:2504.14027 [quant-ph].

Non-stabilizerness and symmetries in chaotic many-body quantum systems

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Understanding the statistical structure of quantum resources is essential for both quantum information theory and quantum computation. The Haar measure provides a rigorous framework for characterizing uniform randomness in quantum states and unitary evolutions, serving as a benchmark for state-dependent quantities such as entanglement, coherence, and non-stabilizerness (magic). Its statistical properties underpin the analysis of random quantum circuits and quantum many-body systems, where randomness becomes a powerful tool to uncover universal features of complex quantum states. We first explore the statistical behaviour of magic in Haar-random pure states and clarify its interplay with entanglement [1, 2]. We then move beyond fully random settings and investigate the role of symmetries in shaping the structure of quantum many-body eigenstates. Focusing on non-integrable Hamiltonians, we show that the presence of a U(1) symmetry associated with magnetization conservation leads to a substantial suppression of non-stabilizerness in middle-of-the-spectrum eigenstates compared to the symmetry-breaking case. To explain this effect, we analyze ensembles of constrained random states [3, 4] that reproduce the observed behaviour analytically. Our results demonstrate that stabilizer entropy is not only a resource-theoretic measure of magic, but also a sensitive probe of symmetry constraints in quantum systems [5], revealing how global conservation laws fundamentally reshape the landscape of quantum complexity [6].

[1] D. Iannotti, G. Esposito, L. Campos Venuti, and A. Hamma, Quantum **9**, 1797 (2025).
[2] D. Iannotti, L. Campos Venuti, and A. Hamma, arXiv:2510.22253 [quant-ph] (2025).
[3] E. Bianchi and P. Donà, Phys. Rev. D **100**, 105010 (2019).
[4] E. Bianchi, L. Hackl, M. Kieburg, M. Rigol, and L. Vidmar, PRX Quantum **3**, 030201 (2022).
[5] P. R. N. Falcão, P. S. Tarabunga, M. Frau, E. Tirrito, J. Zakrzewski, and M. Dalmonte, Phys. Rev. B **111**, L081102 (2025).
[6] E. Tirrito, P. S. Tarabunga, D. S. Bhakuni, M. Dalmonte, P. Sierant, and X. Turkeshi, arXiv:2506.12133 (2025).

Bidirectional Multi-nodes Quantum Teleportation using Discrete-time Quantum Walk

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This document is the template for contributed abstracts (posters) and gives the guidelines for preparing and submitting abstracts for the *ICTP-IBM School on Quantum Computing and Simulation | (smr 4213)* to be held online from *20 Apr 2026* to *30 Apr 2026.*
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Abstract:

We suggest a new technique for bidirectional quantum teleportation (BQT) that combines coherent-state encoding with discrete-time quantum walks to allow two users to communicate quantum information simultaneously. Our method enables Alice and Bob to simultaneously teleport quantum states to one another within a single protocol, as compared to unidirectional teleportation, which only transmits quantum states in one direction. To allow for a qubit-like representation and fidelity analysis using Bloch vector formalism, the quantum information is encoded using non-orthogonal coherent states that are converted into an orthonormal basis of even and odd Schrödinger cat states. Four different quantum walk steps, each acting on a three-part quantum system made up of position and coin spaces, drive the teleportation process. We use density matrix overlaps in the even–odd basis to derive closed-form formulas for teleportation fidelity in both directions analytically. Using the SeQUeNCe discrete-event simulator, we simulate large-scale quantum network settings with realistic limitations, including photon loss, memory decoherence, entanglement swapping degradation, and various channel capacities in order to evaluate the potential of our approach. We evaluate quantum memory utilization, throughput, and end-to-end fidelity in various network topologies and scenarios. Our findings demonstrate that BQT allows symmetric communication with strong fidelity, particularly in high-capacity and large-scale network situations, but requires a greater resource overhead than unidirectional protocols. The hybrid framework developed in this study offers a scalable and analytically simple solution for next-generation quantum communication systems by combining discrete-time quantum evolution with continuous-variable state encoding.

[1] Kurzyński, P. & Wójcik, A. Discrete-time quantum walk approach to state transfer. Phys. Rev. A 83, 062315 (2011).

[2] Bidirectional quantum teleportation in multi-hop communication network. Quantum Inf. Process.22(5) (2023).

Advancing Molecular Dynamics Simulations with Quantum Computing

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Molecular dynamics (MD) simulations are a cornerstone of computational science, providing atomistic insight into the structural, dynamical, and thermodynamic properties of molecular and biological systems. Despite substantial progress in classical algorithms and high-performance computing, conventional MD simulations face intrinsic limitations in accurately capturing electronic structure effects, long time-scale phenomena, and strongly correlated many-body interactions. Quantum computing offers a fundamentally different computational paradigm that has the potential to address these challenges by exploiting quantum superposition and entanglement to simulate biological systems more efficiently than classical approaches [1,2].

Recent advances in quantum algorithms for quantum chemistry, including variational quantum eigensolvers and quantum time-evolution methods, enable more accurate computation of molecular energies and forces, which are central to MD simulations [2,3]. These methods promise improved scaling for electronic structure calculations, allowing quantum processors to complement classical MD by handling the most computationally demanding components, such as force evaluations and potential energy surface refinement. Hybrid quantum–classical frameworks are therefore emerging as a practical pathway for integrating quantum computing into existing MD workflows while remaining compatible with near-term quantum hardware [3,4].

Beyond molecular systems, these developments are increasingly relevant to the emerging field of quantum neuroscience, which explores whether quantum effects may influence neural processes at the molecular and subcellular levels. Quantum-enhanced MD simulations could provide deeper insight into ion channel dynamics, protein conformational transitions, and neurotransmitter interactions, key mechanisms underlying neural signaling and brain function [4,5]. By improving the physical fidelity of simulations at the molecular scale, quantum computing may help bridge the gap between atomic-level dynamics and higher-order neural behavior.

Overall, the convergence of quantum computing, molecular dynamics, and neuroscience represents a promising interdisciplinary direction with significant implications for biophysics, drug discovery, and brain science. Continued development of quantum simulation techniques is expected to expand the scope and accuracy of MD simulations, enabling the study of complex biological systems beyond the reach of classical methods and opening new avenues for quantum-informed computational neuroscience.

[1] Cao, Yudong, et al. "Quantum chemistry in the age of quantum computing." *Chemical reviews* **119**.19 (2019): 10856-10915.

[2] Motta, Mario, and Julia E. Rice. "Emerging quantum computing algorithms for quantum chemistry." *Wiley Interdisciplinary Reviews: Computational Molecular Science* **12**.3 (2022): e1580.

[3] O'Brien, Thomas E., et al. "Calculating energy derivatives for quantum chemistry on a quantum computer." *npj Quantum Information* **5**.1 (2019): 113.

[4] Gaidai, Igor, et al. "Molecular dynamics on quantum annealers." *Scientific Reports* **12**.1 (2022): 16824.

[5] Fisher, Matthew PA. "Quantum cognition: The possibility of processing with nuclear spins in the brain." *Annals of Physics* **362** (2015): 593-602.

Mitigating the detector resolution problem and dealing Post-Selection Barrier via Initial-State Engineering in Monitored Quantum Systems

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Quantum simulation platforms increasingly allow for real-time monitoring of many-body dynamics, enabling access to individual quantum trajectories beyond ensemble-averaged descriptions [1, 2]. Such monitored systems provide a natural setting to study non-equilibrium entanglement dynamics and measurement-driven phenomena, but their experimental characterization is severely constrained by the post-selection overhead associated with frequent measurement events and finite detector resolution [3, 4].

In this work, we study a collectively driven and monitored spin model relevant to quantum simulation architectures such as trapped ions and cavity-QED systems [5]. Using quantum trajectory methods [6], we demonstrate that the statistics of measurement-induced quantum jumps can be efficiently controlled through the preparation of spatially inhomogeneous initial states. Without modifying the Hamiltonian or the measurement scheme, this approach allows one to strongly reduce the rate of collective decay events, leading to significantly longer waiting times between measurement outcomes as the system size increases.

Importantly, this suppression of measurement activity does not inhibit coherent many-body dynamics. We find that the system continues to generate substantial entanglement, with steady-state scaling consistent with an entangled phase accessible to quantum simulators [2, 5]. As a result, the number of measurement records required to reconstruct individual trajectories is drastically reduced, mitigating both post-selection and detector-resolution constraints.

Our results highlight initial-state engineering as a simple and experimentally accessible tool to improve the scalability of monitored quantum simulations, offering a promising route for exploring measurement-driven dynamics and entanglement growth on near-term quantum hardware.

[1] B. Skinner, J. Ruhman, and A. Nahum, Phys. Rev. X **9**, 031009 (2019).
[2] Y. Li, X. Chen, and M. P. A. Fisher, Phys. Rev. B **98**, 205136 (2018).
[3] M. J. Gullans and D. A. Huse, Phys. Rev. Lett. **125**, 070606 (2020).
[4] A. Delmonte *et al.*, arXiv:2410.05394 (2024).
[5] G. Passarelli *et al.*, Phys. Rev. Lett. **132**, 163401 (2024).
[6] A. J. Daley, Adv. Phys. **63**, 77 (2014).

Loss-Tolerant Remote Mølmer-Sørensen Entangling Gates for Coupled Cavity QED Systems

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We discuss a scheme for realizing a high-fidelity Mølmer–Sørensen entangling gate in a coupled-cavity quantum electrodynamics (QED) system. The Mølmer–Sørensen interaction was originally proposed for qubits coupled to a single cavity mode [1]; here we extend this concept to a coupled-cavity setting, enabling entanglement generation between spatially separated qubits via collective photonic modes.

By operating the gate in a dark-mode [2] regime, we show that the entangling operation is inherently tolerant to photon loss in the connecting fiber, making it robust against one of the main limitations of long-distance implementations. We further demonstrate that, even in the presence of non-identical cavities arising from fabrication imperfections or experimental asymmetries, an artificial dark mode can be constructed to retain this loss-tolerant behavior.

The effective interaction is engineered using a bichromatic driving scheme, and high gate fidelities are achieved by optimizing experimentally accessible laser parameters such as amplitudes and detunings. Our results illustrate how robust entangling gates can be realized under realistic conditions and highlight the potential of coupled-cavity systems for distributed quantum computing and quantum networking applications.

[1] H. Takahashi, P. Nevado, and M. Keller, *J. Phys. B: At. Mol. Opt. Phys.* **50**, 195501 (2017).
[2] S. Kato *et al.*, *Nat. Commun.* **10**, 1160 (2019).

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Quantum machine learning for cancer diagnosis

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Cancer is the second biggest cause of human deaths. Early diagnosis is a key element of full recovery or long overall survival. Liquid biopsies are excellent alternatives to traditional biopsies and imaging for cancer detection as they are minimally invasive and their cost is decreasing. In recent years, there has been a growing interest in machine learning techniques and models regarding liquid biopsy analysis. Both fields of artificial intelligence and quantum computation are growing rapidly in recent years. Intersection between machine learning and quantum computation promises great possibilities. It this work I am presenting the Support Vector Machine method in its classical version and in the version enriched by quantum computation. I am comparing both approaches and presenting applications of Quantum Support Vector Machine in biomedical research.

Measurement-Induced Phase Transitions in Monitored Collective Spin Models

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Collective spin models provide a paradigmatic setting for exploring many-body quantum dynamics with long-range interactions and experimentally relevant measurement schemes. Among them, the Lipkin–Meshkov–Glick (LMG) model [1] captures essential features of a collection of N self-interacting spin-1/2 particles acted on by an external field.

Measurement-induced phase transitions (MIPTs) were originally discovered in random qubit lattices subjected to local projective measurements [2]. These transitions manifest as sharp changes in the scaling of entanglement entropy along individual quantum trajectories, from volume-law growth to area-law suppression, controlled by the measurement rate [3].

In this work, we investigate the emergence of MIPTs in the LMG model under continuous monitoring. Since measurement-induced transitions are often obscured at the ensemble-averaged level, we analyze entanglement entropy at the level of individual quantum trajectories, where the effects of measurement backaction become manifest. By combining different diagnostic tools such as entanglement entropy and inverse participation ratio, we uncover the nature of these transitions in monitored collective spin systems.

[1] Lipkin, Meshkov, and Glick, Nucl. Phys. **62**, 188 (1965).
[2] B. Skinner, J. Ruhman, and A. Nahum, Phys. Rev. X **9**, 031009 (2019).
[3] Cao, Tilloy, De Luca, SciPost Phys. **7**, 024 (2019).

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Fusion-Based Quantum Networks with GKP Graph Codes

P46

Emergence of Generic Entanglement Structure in Doped Matchgate Circuits

Predicting Magic from very few measurements

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A necessary ingredient for universal quantum computation, magic is elusive: To be quantified, an exponential amount of measurements must be made, and a doubly-exponential of classical compute must be expended to estimate its monotones. In this work, we further show how it is also in the eyes of the beholder: We show that it can be witnessed and quantified by any set of m n-qubit Pauli measurements, if they host anti-commuting pairs, and give an algorithm to estimate magic with Pauli expectation values in $O(\exp(m) \times \mathrm{poly}(n))$ time. We also show NP-hardness of this problem, by relating it to a version of the quantum marginal problem restricted to stabilizer states, showing that no algorithm polynomial in the number of measurements exists if P $\neq$ NP. In the end, we also discuss numerical experiments, demonstrating the praticality of the algorithm.

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Time series data for Finance Data using QML algorithms

Semiclassical Structure of Multiphoton Interference Amplitudes from Tensor Power Decompositions of Fock States

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Multiphoton interference in linear-optical networks is governed by many-body probability amplitudes between initial and final Fock states. These amplitudes underpin photonic quantum simulation tasks, including boson sampling, where output probabilities are controlled by matrix functions such as permanents. In the two-mode setting, the same transition amplitudes reduce to SU(2) dynamics and connect directly to Wigner rotation matrix elements.

In this work we develop a semiclassical viewpoint for transition amplitudes between bosonic Fock states in the large particle number regime. Our starting point is a discrete coherent phase state expansion that represents each Fock state through a tensor power decomposition: a controlled superposition of fully symmetric product states built from a single particle mode state. This single-particle building-block representation of Fock states is not the standard route in multiphoton interference, but it offers a practical advantage: it converts the many-body amplitude into a structured sum over phase grids of simple single-particle overlaps raised to the Nth power [2,3].

Focusing on the two-mode case $M = 2$, we show that the resulting phase sums admit a controlled continuum limit as $N \to \infty$, leading to an oscillatory integral dominated by saddle points [1,3]. These saddle points have a direct geometric interpretation on the Bloch sphere, linking multiphoton interference to the phases of single particle probability amplitudes [1]. This formulation sets the stage for extensions to multimode systems with $M > 2$, including the $M = 3$ case with $SU(3)$geometry, offering tools to interpret and approximate many-body interference effects relevant to quantum simulation.

[1] Braun, P. A., Gerwinski, P., Haake, F., & Schomerus, H. Semiclassics of rotation and torsion (1995).
[2] Villalobos, M. E., Valencia, A., & Botero, A. The quantum beam splitter with many partially indistinguishable photons: multiphotonic interference and asymptotic classical correspondence (2023).
[3] Littlejohn, R. G. The semiclassical evolution of wave packets, Physics Reports, 138, 193–291 (1986).

Simulating Quantum Field Theories on Gate-Based Quantum Computers

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This poster is based on the published work titled ‘Simulating Quantum Field Theories on Gate-based Quantum Computers’ [1]. Here, we implement a simulation of a quantum field theory in 1+1 space-time dimensions on a gate-based quantum computer using a particular formulation of quantum field theories called the *light front quantization* [2, 3]. The non-perturbative simulation of the Yukawa model field theory is verified on IBM’s simulator and is also demonstrated on a small-scale IBM circuit-based quantum processor, on the cloud, using IBM Qiskit. The light front formulation provides a systematic truncation of the Hilbert space of the quantum fields, and allows for controlling the resource requirement and complexity of the computation with commensurate trade-offs in accuracy and detail by modulating a single parameter, namely the *harmonic resolution*. A reference frame travelling in a particular direction at the speed of light is chosen for quantizing the fields. With the restriction on the number of logical qubits available on the existent gate-based Noisy Intermediate-Scale Quantum (NISQ) devices, the trotterization approximation [4] was also used. The Bosonic field operators are particularly challenging to implement on the NISQ devices, and our implementation, based on the convention used in [5] suggests one path forward. These qubit operators created for the bosonic excitations were used along with the fermionic ones already available, to simulate the theory involving all of these particles. The circuit construction and execution were done using IBM Qiskit (version $0.39.5$) [6]. Our focus here was more on the technical aspects of implementing such a computation on a NISQ device and on clarifying the limitations as well as the way forward.

The model we considered has a Bosonic field ϕ with quanta of mass m_B coupled to a Fermion field ψ with particles and anti-particles both with mass m_F. The fields are coupled through a Yukawa type term, $\lambda\phi\bar{\psi}\psi$, with λ as the bare coupling strength. In 1+1 dimensions, the transformation to light-front coordinates is given by $x^+ = x^0 + x^1$ and $x^- = x^0 - x^1$, where x^0 and x^1 are time and position coordinates in the lab frame while x^+ and x^- are the light-front time and light-front position coordinates, respectively. Here, H is not diagonal, and it is made up of four terms as $H = H_M + H_V + H_S + H_F$. The first term, H_M, is the mass term, and the other three terms are the ones involving the interactions, containing interaction terms that are cubic and quartic in the creation and annihilation operators, respectively [7].

As a further step, a realistic process involving the production of a pair of pions in a proton-proton collision of the form $pp \longrightarrow pp\pi^+\pi^-$ was studied and the variation of the probabilities of this required valid state was also investigated on the simulator. Tracking such states in time allows for the computation of cross sections of specific processes that would be of interest in the relatively near future when the computation can be scaled up to $3+1$ dimensions with more modes for each field. We also explored the inaccuracies introduced by the bounds on achievable harmonic resolution and Trotter steps placed by the limited number of qubits and circuit depth supported by the available NISQ devices.

[1] G. M. Vinod, A. Shaji, IEEE Transactions on Quantum Engineering **5**, 3101214 (2024).
[2] H. C. Pauli, S. J. Brodsky, Phys. Rev. D **32**, 1993–2000 (1985).
[3] H. C. Pauli, S. J. Brodsky, Phys. Rev. D **32**, 2001-2013 (1985).
[4] H. F. Trotter, Proc. Amer. Math. Soc. **10**, 545-551 (1959).
[5] X. Huang, Progress in High Energy Physics **1**, (2025).
[6] A. Javadi-Abhari, et al. arxiv.org/abs/2405.08810 (2024).
[7] M. Kreshchuk, et al. Phys. Rev. A **105**, 032418 (2022).

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Quantum Optimal Control of Entangling Gates in Trapped-Ion Qudit Systems

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The Mølmer–Sørensen [1] (MS) gate is one of the most widely used entangling gates in trapped-ion platforms. We consider its generalization to qudit-based platforms, where multiple transitions may be simultaneously driven. In this case, the Stark effect becomes the dominant source of error, since cross-influences among the different driven transitions lead to nontrivial energy level shifts which significantly complicate compensation. In this work, we present a calibration protocol to improve the implementation fidelity of the MS gate under realistic experimental considerations. The protocol is tested on a simulator using both a simple quasi-square pulse ansatz and a more complex pulse obtained via quantum optimal control, successfully decreasing the gate infidelity in both cases.

[1] A. Sørensen, K. Mølmer, Phys. Rev. L. **82**, 1971 (1999).

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Title: Real-Time Quantum Dynamics in 3D with Neural Quantum States: Quenches and Kibble–Zurek Scaling

Abstract: Advances in quantum-simulation platforms now probe nonequilibrium dynamics in two and three dimensions, but classical simulation remains limited by the exponential complexity of many-body wavefunctions. Scalable, controlled numerics are therefore essential for benchmarking quantum devices and uncovering dynamical mechanisms with experimentally testable signatures. In this context, Neural quantum states (NQS) have been successful in low dimensions, yet their scalability and reliability in 3D remain largely unexplored. Here we develop an NQS framework tailored to 3D spin lattices and apply it to large-scale real-time dynamics of the 3D transverse-field Ising model, capturing behavior beyond the reach of conventional controlled methods. We provide a first large-scale demonstration of the quantum Kibble–Zurek mechanism in 3D, resolving universal scaling and the logarithmic corrections expected at the upper critical dimension. These results establish NQS as a practical benchmark and discovery tool for 3D quantum dynamics relevant to near-term quantum simulators.

AQUA: A Software Engineering Process to Develop Quantum Annealing Applications

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Quantum Annealing (QA) offers high potential for solving complex Quadratic Unconstrained Binary Optimization (QUBO) problems [1]. However, developing practical QA applications remains challenging due to mathematical complexity, hardware constraints, and the absence of tailored software engineering methodologies [1, 2]. Thus, the goal of our project, named "QUBO-HPC", was to produce a structured software engineering life-cycle approach to help in solving QUBO problems using QA. To this purpose, we applied Design Science Research (DSR) [3], a development and validation standard method to develop solutions for practical engineering problems, and we created AQUA (Agile QUantum Annealing)–a novel agile process for QUBO/QA application development [4]. AQUA adapts Scrum to address QUBO and QA specific requirements, including the use of HPC as a further tool to pre- and post-process large QUBO problems. The method involves various roles, including Operations Researcher, QA Specialist, HPC Developer, Data Science Expert and Quality Assurance Expert. It structures development into four phases: (1) initial assessment and mathematical formulation; (2) algorithm evaluation using prototypes; (3) agile implementation; and (4) deployment and lifecycle maintenance management. The development is controlled by specific milestones aimed at managing risks and accurately planning project costs and times. As prescribed by DSR, we validated AQUA using two real-world case studies - credit risk management and optimal selection of network nodes, showing its feasibility to this type of problems. To the best of our knowledge, AQUA is the first explicit proposal of a structured process to develop QA applications, grounded on sound software engineering practices, and in particular on Agile principles, which emphasize team collaboration, rapid development cycles, and continuous delivery. Our approach can thus provide significant benefits to the development of QUBO/QA applications. QUBO-HPC project was funded by NextGenerationEU PNRR, National Centre for HPC, Big Data and Quantum Computing, and by CINECA ISCRA grant IsCc2_QAHLOP.

[1] S. Yarkoni, E. Raponi, T. Back, and S. Schmitt. Quantum annealing for industry applications: Introduction and review. Reports on Progress in Physics, 85(10):104001 (2022).

[2] M. Piattini, M. Serrano, R. Perez-Castillo, G. Petersen, and J. Hevia. Toward a quantum software engineering. IT Professional, 23(1):62-66 (2021).

[3] K. Peffers, T. Tuunanen, M. A Rothenberger, and S. Chatterjee. A design science research methodology for information systems research. Journal of management information systems, 24(3):45-77 (2007).

[4] L. Marchesi, A. Nasharti, and M. Marchesi. AQUA: an Agile Process to Develop Quantum Annealing Applications. arXiv preprint arXiv:2601.14501 (2026).

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Digital simulations of non-Hermitian knots and links on a quantum processor

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Knots and links have been studied in non-Hermitian models and these have been experimentally demonstrated on various platforms. In this work, we realize braids in the spectra of a family of non-Hermitian twister models and devise a measurement protocol to reconstruct the eigenstates in multi-band models on a quantum processor which encode information about energy without directly probing it. By exploiting the fact that the eigenstates contain information about energies, the winding between the eigenstates captures the spectral winding in the band structure. We characterize the braids by measuring winding number matrices from which the braid words can be extracted, and compute knot polynomials. Our work opens up the possibility of simulating knots in other exotic models on a quantum processor.

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A Hybrid Quantum–inspired Prototype for Solving Nonlinear Continuous Optimization Problems

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Quantum annealing is a recent advancement in the field of optimization metaheuristics. Quantum annealers, such as the D-Wave machines, are primarily designed to solve *discrete* optimization problems; nevertheless, solving nonlinear continuous optimization problems remains a very challenging task, particularly when nonconvex objective functions and multiple local optima are involved. While convex problems can often be solved efficiently using standard classical methods, the potential of quantum annealing in solving continuous optimization problems has not been explored in sufficient detail. In this work, we develop a prototype quantum-inspired solver for nonlinear continuous optimization problems. The proposed solver is hybrid, as it has two solution pathways – *classical* and *quantum–inspired*. Given a continuous optimization problem via the web-based graphical interface that allows users to define and edit optimization problem formulations, our solver first computes a nonconvexity index for the problem, which determines the appropriate solution pathway. Problems with low nonconvexity indices are sent through the classical pathway and solved using standard separable programming techniques, while the others are transformed into mixed integer linear programming (MILP) problems via separable reformulations and subsequently restated as quadratic unconstrained binary optimization (QUBO) problems—the problem format compatible for quantum annealers. These QUBO problems are then solved through the quantum pathway using D-Wave's Neal sampler. Overall, this hybrid framework provides a practical step toward using quantum annealing-based methods for solving complex nonlinear continuous optimization problems.

[1] S. J. Wright., "Continuous optimization (nonlinear and linear programming)," Foundations of Computer-Aided Process Design, Elsevier, New York, (1999).

[2] A. Mahasinghe, R. Hua, M. J. Dinneen, and R. Goyal, "Solving the hamiltonian cycle problem using a quantum computer," Proceedings of the Australasian Computer Science Week Multiconference, pp. 1–9, (2019).

[3] A. Mahasinghe, V. Fernando, and P. Samarawickrama, "QUBO formulations of three NP problems," Journal of Information and Optimization Sciences, vol. 42, no. 7, pp. 1625–1648, (2021).

[4] F. Glover, G. Kochenberger, and Y. Du, "Quantum Bridge Analytics I: A tutorial on formulating and using Qubo Models," 4OR, vol. 17, no. 4, pp. 335–371, (2019).

[5] C. Papalitsas, T. Andronikos, K. Giannakis, G. Theocharopoulou, and S. Fanarioti, "A QUBO model for the traveling salesman problem with time windows," Algorithms, vol. 12, no. 11, p. 224, (2019).

[6] P. Codognet, "Comparing QUBO models for quantum annealing: integer encodings for permutation problems," International Transactions in Operational Research, vol. 32, no. 1, pp. 18–37, (2024).

[7] M. Cattelan and S. Yarkoni, "Modeling routing problems in QUBO with application to ride-hailing," Scientific Reports, vol. 14, no. 1, (2024).

[8] A. C. Mahasinghe, L. Lakshitha, E. A. Bakare, K. K. W. H. Erandi, "A performance comparison of two nonconvex separable programming techniques," Palestine Journal of Mathematics, vol. 13, no. 4, (2024).

[9] M. A. Bolender and D. B. Doman, "Nonlinear Control Allocation Using Piecewise Linear Functions: A Linear Programming Approach," Journal of Guidance, Control, and Dynamics, vol. 28, no. 3, pp. 558–562, (2005).

[10] Y. Davydov, E. Moldavskaya, and R. Zitikis, "Searching for and Quantifying Nonconvexity Regions of Functions*," Lithuanian Mathematical Journal (2019).

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Extension of complementarity relations for X states using IBM quantum devices

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Concurrence (C) and the degree of polarization (P) are fundamental measures of entanglement and local properties in bipartite quantum systems. For pure states, these quantities satisfy the complementarity relation $C^2 + P^2 = 1$ [1], whereas for mixed states this relation remains elusive. In this work, we experimentally study this complementarity for X states by allowing a bipartite state to evolve under controlled noisy quantum channels, specifically the amplitude-damping [2] and depolarizing channels, implemented using ancilla-assisted quantum circuits on IBM quantum devices. The concurrence is extracted from two-qubit state tomography, while the degree of polarization is obtained from direct measurements. In this way, we experimentally verify previous theoretical proposals on complementarity relations by using quantum circuits to simulate bipartite quantum systems under realistic open-system dynamics.

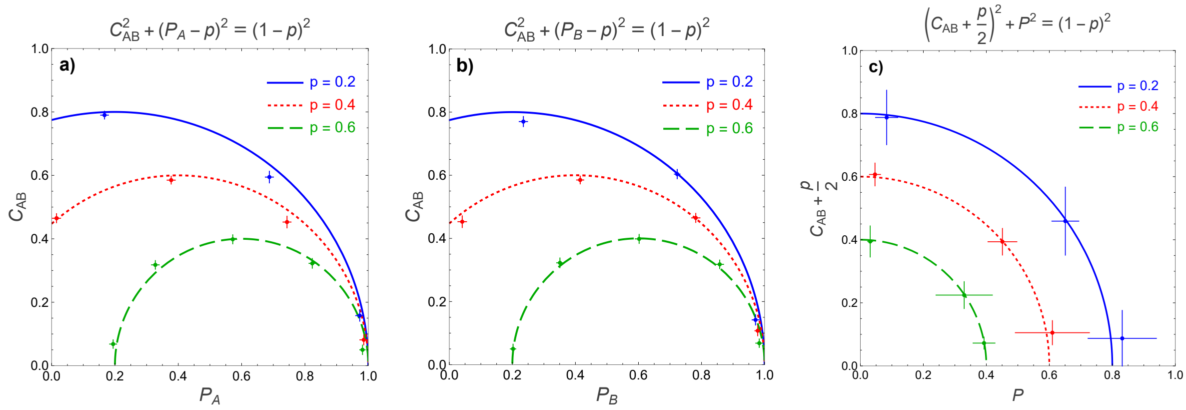

Figure 1: Experimental verification of complementarity relations for X states. Each point represents a measured ordered pair (P, C), while the curves correspond to theoretical predictions for different values of the noise parameter p. a) and b) show the results for subsystems of mixed states obtained from the evolution of an initially pure bipartite state under the amplitude-damping channel, with decay probability p, whereas c) shows the results for an initial Werner-type state with mixing parameter p evolving under the depolarizing channel.

References

[1] X. F. Qian, T. Malhotra, A. N. Vamivakas and J. H. Eberly, Phys. Rev. Lett. **117**, 153901 (2016)

[2] Y. Yugra, C. Montenegro and F. De Zela, Phys. Rev. A **105**, 063710 (2022).

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Analyzing Classical vs Quantum Temporal Correlations in Discrete-Time Counting Processes

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Based on Heisenberg's statement about existence of uncertainties in measuring physical incompatible quantities, and Schrödinger's cat thought experiment; Leggett and Garg introduced macroscopic realism models. A physical quantity in a macrorealist model has a definite value at each instant of time, and can be measured with an arbitrary small disturbance on its subsequent dynamics [1]. In this project, we consider a model that is be called automata, in a sense that there are sequences of operations (constructed from unitary evolutions and measurements) without any input, but with some outputs. While previous works identified dimension as a key resource, the role of other control parameters still remain unexplored [2]. In such a case, people have looked at the dimension of the system and found it can be considered as the limited resource [2]. In our research, we want to study the same system more generally and find which other control parameters of the system can be considered as resources such that they maximize the figure of merit called accuracy or minimize the cost function. Minimizing the cost function turns out to solving the nested discrete time Lyapunov equation problem under some constraints.

[1] C. Budroni and G. Vitagliano, Leggett-Garg macrorealism and temporal correlations, Phys. Rev. A. **107**, 040101 (2023).

[2] C. Budroni, G. Vitagliano, and M. P. Woods, Ticking-clock performance enhanced by non-classical temporal correlations, Phys. Rev. Res. **3**, 033051 (2021).

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Nontrivial entanglement passively mediated by a quenched magnetic impurity

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We investigate the entanglement properties of a Kondo system undergoing a transition to a state with a quenched magnetic impurity, using the density matrix renormalization group method. We focus on a two-channel spin-1 Kondo impurity with single-ion anisotropy, where a quantum phase transition occurs between two topologically distinct local Fermi liquids. In the fully screened Kondo phase, realized at lower anisotropies, the entangled region surrounding the magnetic impurity mimics the Kondo screening cloud, although its length does not follow the conventional behavior. In contrast, beyond the transition, the system enters a {\it non-Landau} Fermi liquid phase with a markedly different entanglement structure: as the impurity is quenched and disentangled from the rest of the system due to the breakdown of the Kondo effect, the two conduction channels \textemdash coupled only through the impurity\textemdash develop a significant degree of entanglement with one another. Our findings demonstrate that a quenched magnetic impurity can passively and efficiently mediate entanglement between spatially separated conduction bands.

[1] R. Žitko, G. G. Blesio, L. O. Manuel, and A. A. Aligia. Nature Comm. 12, 6027 (2021).

[2] G. G. Blesio, L. O. Manuel, P. Roura-Bas, and A. A. Aligia, Phys. Rev. B 98, 195435 (2018).

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Cavity mediated long range interacting Bose Hubbard Model

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Abstract. We consider a cavity induced long range interacting model such that the external optical potential is incommensurate with the cavity mode wavelength leading to a Bose-glass to superfluid (first-order) phase transition in addition to the mott-insulator to superfluid (second order) phase transition. We explore the behaviour and scaling of entanglement entropy and entanglement spectrum for these two types of phase transitions in this strongly interacting system of bosons on a lattice using a controlled approximation in all the regimes of the model. by following this templet write abstract and also reffer the uploaded article 1st author is chitrangada pradhan and 2nd author is Dr. shraddha shrama .give a perpect latex code [1].

References

[1] Phys. Rev. A **99**, 043633 (2019).

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Quantum-Accelerated Computational Fluid Dynamics: GPU-Based Quantum Simulation Framework for Flow Applications

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We present the planned development and deployment of a GPU-accelerated quantum simulation framework for computational fluid dynamics (CFD) within the Helmholtz Initiative project qFLOW (Quantum-Accelerated Solutions for Fluid Dynamics and Environmental Systems). The goal is to couple classical high-performance computing (HPC) resources with quantum algorithms to address computational bottlenecks in CFD and related environmental flow simulations.

The framework is based on NVIDIA CUDA-Q and will be deployed on the HAICORE and ROSI clusters at HZDR. Our objectives are: (1) scalable multi-node, multi-GPU quantum-circuit simulation, (2) automated and reproducible software-stack deployment and containerization for quantum workflows, and (3) integration with established CFD pipelines to enable hybrid quantum–classical execution.

As demonstrators, we will port and benchmark quantum solver classes relevant to flow modeling, first on high-performance simulators and, where available, on quantum hardware accessed via JUNIQ[1, 2].

[1] K. Michielsen and N. Küchler, *JUNIQ—Jülich UNified Infrastructure for Quantum computing*, ML4Q Conference (2022).

[2] H. De Raedt, J. Kraus, A. Herten, V. Mehta, M. Bode, M. Hrywniak, K. Michielsen, and T. Lippert, *Universal Quantum Simulation of 50 Qubits on Europe's First Exascale Supercomputer Harnessing Its Heterogeneous CPU-GPU Architecture*, arXiv:2511.03359 (2025).

Abstract preparation for Statistical mechanics of multipartite entanglement in Hadamard quantum state submanifolds

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We investigate multipartite entanglement in a specific class of pure n-qubit quantum states, the uniform real-phased states referred to as Hadamard states, through a statistical mechanics framework, where the average bipartite purity maps onto an effective Hamiltonian of 2^n binary classical spins. In this correspondence, each Hadamard state uniquely corresponds to a classical spin configuration, while temperature emerges as a control parameter that continuously interpolates between randomly sampled states at high temperature and maximally multipartite entangled states (MMES) in the zero-temperature limit. Remarkably, the zero-temperature entropy directly counts the MMES within the class of Hadamard states. For small system sizes ($n \leq 5$), we perform exact enumeration, fully characterizing the energy landscape and associated thermodynamic observables, and validating known MMES counts. For larger systems ($n = 6$ and 7), where exact methods become computationally infeasible, we employ simulated annealing and parallel tempering algorithms to efficiently sample the high-dimensional state space. Our analysis yields quantitative predictions of MMES counts and reveals how entanglement is statistically distributed across the Hadamard state manifolds. The results establish this family of states as an ideal platform for exploring multipartite entanglement through thermodynamic methods, offering both computational advances and physical insights into the structure of quantum entanglement in constrained Hilbert spaces.

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Superconducting Qubits

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Rényi-Order regime where trusted noise enhances DV QKD finite-size key rates.

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In Quantum Key Distribution (QKD), *discrete-variable* (DV) protocols the encoding of private information is performed on the discrete degrees of freedom of the electromagnetic fields, then measurements are usually performed complementary bases. Among the various DV protocols, the BB884 is the most well-known example [1]. It is worth noting that composable, information-theoretic approaches offer general bounds on the key rate and clarify the impact of classical post-processing steps on overall security [2]. One important example is *trusted local randomization*, where one party flips each bit of the sifted key with a given probability before information reconciliation. This procedure is often referred to as *trusted-noise injection*; in this way, one of the legitimate user adds local randomness which is inaccessible to a possible eavesdropper. In asymptotic analyses based on von Neumann entropy, this technique has been proven to increase the secret-key rate, especially when the quantum bit error rate (QBER) is high, as shown in early studies [3]. Recent work on finite-size security suggests that using *Rényi entropies* can lead to tighter key-rate bounds for practical block lengths [4, 5]. These developments motivate a deeper analysis on the role of trusted noise in finite-size settings when the key rate is estimated using sandwiched Rényi entropies.

In this work, we analyze the BB84 protocol with trusted noise under collective (i.i.d.) attacks, estimating the finite-size key rate via a sandwiched Rényi entropy approach. First, we identify the range of Rényi orders for which trusted noise remains beneficial by comparing key rates with and without optimally tuned randomization. Then, we determine the maximum achievable finite-size lower bound by jointly optimizing over the randomization parameter and the Rényi order. We evaluate the required entropic quantities numerically by recasting the problem into a form suitable for efficient convex optimization and performing a systematic outer optimization over both parameters. Methodologically, our numerical evaluation builds on the reliable two-step framework for key rate computation in [6], based mainly on the Frank–Wolfe algorithm [7]. Adapting this approach to our setting required handling an objective of fundamentally different nature, since the privacy term is expressed through sandwiched Rényi entropies rather than von Neumann entropies. In particular, the Frank–Wolfe iterations require explicit analytical gradients of the Rényi-based objective. In our setting, we work with a fully variational Rényi entropy objective that retains the auxiliary optimization, so the Frank–Wolfe updates must be driven by gradients with respect to *two* coupled variables rather than one.

[1] C. H. Bennett and G. Brassard, Theor. Comput. Sci. **560**, 7 (2014).
[2] R. Renner, N. Gisin, and B. Kraus, Phys. Rev. A **72**, 012332 (2005).
[3] B. Kraus, N. Gisin, and R. Renner, Phys. Rev. Lett. **95**, 080501 (2005).
[4] L. Kamin, A. Arqand, I. George, N. Lütkenhaus, and E. Y.-Z. Tan, PRX Quantum **6**, 020342 (2025).
[5] G. Staffieri, G. Scala, and C. Lupo, arXiv:2509.14345 (2025).
[6] A. Winick, N. Lütkenhaus, and P. J. Coles, Quantum **2**, 77 (2018).
[7] M. Frank and P. Wolfe, Nav. Res. Logist. Q. **3**, 95 (1956).
[8] R. R. B. Chung, N. H. Y. Ng, and Y. Cai, Phys. Rev. A **112**, 012612 (2025).

Three-qubit Quantum Refrigerator: Theory and Implementation on a Quantum Computer

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This work presents a unified theoretical and experimental study of thermodynamic processes [1], focused on a three-qubit quantum refrigerator.

We introduce a protocol that leverages ergotropy [2], the maximal work extractable via cyclic (unitary) operations, to maximize energy extraction from a cold subsystem while minimizing work input and implementation complexity [3]. Theoretical analysis reveals that cooling is feasible only within a specific temperature regime governed by the ordering of thermal populations relative to energy eigenvalues.

We implement this protocol on IBM's superconducting quantum processors [4], tackling challenges in thermal state preparation, circuit synthesis, and noise mitigation through circuit complexity reduction, particularly by minimizing the number of two-qubit entangling gates. Measurements demonstrate a temperature-dependent cooling efficiency that peaks when hot and cold qubit temperatures closely match, validating the protocol's viability on NISQ hardware.

A critical examination of correlations in multipartite systems shows their dual role [5]: depending on the thermodynamic quantity of interest, they can either support or hinder energy transfer. Yet when correlations become too pronounced, they drive up dissipation and ultimately impair performance.

This work bridges fundamental quantum thermodynamics and near-term quantum computing, delivering optimized unitary designs, real hardware validation, and a nuanced understanding of correlations' impact on quantum thermal machines.

[1] M. Campisi, J. Pekola, and R. Fazio, *New J. Phys.* **17**, 035012 (2015).
[2] A. E. Allahverdyan, R. Balian, and Th. M. Nieuwenhuizen, *Europhys. Lett.* **67**, 565 (2004).
[3] L. Bassman Oftelie, A. De Pasquale, and M. Campisi, *PRX Quantum* **5**, 030309 (2024).
[4] A. Solfanelli, A. Santini, and M. Campisi, *AVS Quantum Sci.* **4**, 026802 (2022).
[5] M. Campisi and R. Fazio, *J. Phys. A: Math. Theor.* **49**, 345002 (2016).

Nonequilibrium thermometry via an ensemble of initially correlated qubits

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We investigate a nonequilibrium quantum thermometry protocol in which an ensemble of qubits, acting as temperature probes, is weakly coupled to a macroscopic thermal bath. The temperature of the bath, the parameter of interest, is encoded in the dissipator of a Markovian thermalization process. For some relevant initial states, we observe a peak in the Quantum Fisher Information (QFI) during the transient of the thermalization, indicating enhanced sensitivity in early-time dynamics. This effect becomes more pronounced at higher bath temperatures and is further enhanced when the initial reduced state of the qubits has a large ground-state population and/or it is highly coherent. We also focus on the role of initial quantum correlations in the thermometric performance, which emerge as a central feature of this work. We find strong numerical evidence that, given same single-qubit reduced states, the inclusion of quantum correlations among the qubits of the ensemble always yields an enhanced QFI. Moreover, even if none of the considered states outperform the (pure, separable) ground state, maximally entangled states display QFIs values remarkably close to the standard quantum limit when probing extremely hot thermal baths. Finally, although the Markovian dynamics does not permit superlinear scaling of the QFI with the number of probes, we identify the most effective initial states for designing high-precision quantum thermometers within this setting. We also provide concrete guidelines for experimental implementations.

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Multipartite entanglement of random states

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We investigate multipartite entanglement via the statistical properties of pure quantum states of n-qubits. By analyzing the distribution of purity among balanced bipartitions, we compare Haar-typical states with the so called Hadamard states, the latter being characterized by equal weights in the computational basis. We analyze different classes of Hadamard states distinguished by their phase distributions. Through analytical and numerical calculations, we show that Hadamard states exhibit, on average, a higher degree of entanglement than Haar-typical states. In addition, we show that a particular class of Hadamard states, characterized by real coefficients with alternating signs, referred to as $(\pm)$-states, appears especially relevant in the search for maximally multipartite entangled states, both for their structural simplicity and the increased likelihood of sampling highly entangled states. These results identify Hadamard states as a tractable yet promising class for exploring multipartite entanglement structures and advancing the characterization of maximally entangled quantum states.

Exact analysis of AC sensors based on Floquet Time Crystals

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In this work [1], we present a study of general Floquet Time Crystals (FTCs) in closed quantum systems [2] acting as AC field sensors with quantum-enhanced performance. [3, 4] We provide a complete analytical analysis of quantum Fisher information (QFI) dynamics, which characterizes the ultimate precision limits of the sensing protocol. Based on provided analysis we discuss the problem of construction optimal observables in the system.

By tuning the frequency and direction of the applied AC field, we show that resonant transitions can be induced between macroscopic paired Schrödinger cat states within the FTC phase. This mechanism enables robust Heisenberg-limited precision, with QFI scaling as $\mathcal{F}_Q \sim N^2 t^2$, persisting for times that grow exponentially with the system size. The resulting QFI dynamics display a characteristic step-like dynamics, originating from dephasing processes within the cat-state subspaces.

We analyze the sensing performance for a variety of initial sensor preparations, including ground states as well as weakly and strongly correlated states. Furthermore, we investigate the behavior of the sensor across the FTC phase transition, demonstrating that the QFI captures the associated critical exponents.

Finally, we address the problem of optimal estimation of an unknown AC field amplitude h. By establishing an analytical connection between the QFI dynamics and the symmetric logarithmic derivative (SLD) [5], we discuss how to construct optimal measurement observables that saturate, or closely approach, the quantum Cramér–Rao bound using SLD. Our results provide practical guidance for future experimental implementations of FTC-based AC quantum sensors, enabling application across different experimental settings.

[1] Tsypilnikov, A., Fibiger, M., and Iemini, F., “Exact analysis of ac sensors based on Floquet time crystals”, *arXiv:2505.22731 [quant-ph]* (2025).

[2] Russomanno A., Iemini F., Dalmonte M., and Fazio R., “Floquet time crystal in the Lipkin–Meshkov–Glick model”, *Phys. Rev. B* **95**, 214307 (2017).

[3] Iemini F., Fazio R., and Sanpera A., “Floquet time crystals as quantum sensors of ac fields”, *Phys. Rev. A* **109**, L050203 (2024).

[4] Montenegro V., Mukhopadhyay C., et al., “Review: Quantum metrology and sensing with many-body systems”, *Phys. Rep.* **1134**, 1–62 (2025).

[5] Paris M. G. A., “Quantum estimation for quantum technology”, *Int. J. Quantum Inf.* **7**, 125–137 (2009).

Quantum assisted rendezvous on graphs

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The emergence of quantum technologies has led to an ever-expanding range of applications. Here we study a novel application in the field of Operational Research, namely rendezvous problems [1]. We investigate the advantage gained in one-step [2] and two-step [3] rendezvous games on simple graphs analytically, numerically, and using noisy intermediate-scale quantum (NISQ) processors. We systematically explore the complex space of possible strategies for each case. Among our surprising findings is the fact that multi-step strategies utilise quantum resources in a non-trivial way, only using them in the first step to skew the probability distribution so that a classical second step maximizes the probability. The NISQ processor experiments realise the expected quantum advantage with high accuracy for both the one-step game on the complete graph K3 [2] and the two-step game on the cycle graph C5 [3]. In other cases, the performance of the NISQ hardware is sub-classical. We discuss this in light of circuit depth and known qubit decoherence and gate error rates. Our work paves the way to novel applications of future, long-lived, portable quantum memories in the field of logistics.

[1] P.Mironowicz, New J. Phys. **25** 013023 (2023)
[2] J.Tucker, P.Strange, P.Mironowicz and J.Quintanilla, New J. Phys. **26** 093038 (2024)
[3] J.Tucker, P.Strange and J.Quintanilla [Unpublished] (2025)

From pure to mixed altermagnets: A study of Sr_2RuO_4 and Sr_2IrO_4

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Altermagnetism has recently emerged as a distinct magnetic phase with strong potential for spintronic applications, characterized by momentum-dependent spin splitting in the absence of net magnetization [1]. In real materials, the presence of unavoidable spin–orbit coupling (SOC) further enriches this picture. Recent studies [2] have shown that the presence or absence of an anomalous Hall effect (AHE) distinguishes two types of altermagnets: mixed and pure altermagnets, a classification rooted in the ireducible representations (irreps) of the point group of the underlying crystal. When the altermagnetic order parameter and a Hall vector transform according to the same irreps, they can coexist in superposition, giving rise to a mixed altermagnetic phase with a finite AHE; otherwise, the phase remains purely altermagnetic.

Motivated by this framework, we investigate the evolution from pure to mixed altermagnetic behavior in two paradigmatic layered oxides, Sr_2RuO_4 and Sr_2IrO_4. In Sr_2RuO_4 [3], the surface of RuO_6 octahedra has point group C_{4v}, a collinear compensated magnetic order with moments polarized along the z axis transforms as a pure altermagnet, which is symmetry-incompatible with a Hall vector and therefore does not generate an AHE. Importantly, additional symmetry lowering—arising from strain, or secondary electronic orders—can transmute the nominally pure z-polarized altermagnetic state into a mixed one, thereby enabling a finite AHE.

By comparison, Sr_2IrO_4 [4] exhibits a more intricate situation. Depending on the stacking of single or multiple IrO_6 layers, the allowed magnetic order parameters transform according to different irrps, permitting both pure and mixed altermagnetic phases.

Through symmetry analysis, we show how structural distortion or other secondary orders govern the transition from pure to mixed altermagnetism, and outline experimental signatures in transport measurements. Our results identify layered ruthenates and iridates as fertile ground for realizing and tuning altermagnetic phenomena, and suggest concrete pathways for engineering altermagnetism in correlated materials and future quantum technologies.

[1] L. Šmejkal, J. Sinova, and T. Jungwirth, Phys. Rev. X **12** (2022).
[2] R. M. Fernandes, V. S. de Carvalho, T. Birol, and R. G. Pereira, Phys. Rev. B **109** (2024).
[3] A. Ramires, Phys. Rev. Res. **7** (2025).
[4] C. Wang, A. Hernández-Melián, H. Zhao, H. Luetkens, A. Ramires, T. Lancaster, and G. Cao, under preparation.

Low-Depth Circuit Co-Design and Problem-Tailored Optimization for Variational Quantum Algorithms on NISQ Hardware

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Variational quantum algorithms (VQAs) provide a flexible framework for near-term quantum computation, however, their practical impact depends critically on resource-efficient circuit design and robust optimization. Consequently, low-depth circuit implementations that reduce gate counts and error accumulation are central to achieving reliable performance on current hardware. This poster presents a unified, device-oriented variational framework, explicitly focusing on low-depth circuit construction [1] and an efficient classical optimisation scheme [1, 2]. First, a low-depth implementation of a class of Hadamard-test circuits is introduced, together with a Hadamard-test-tailored variational ansatz design. This circuit design leverages the qubit-connectivity constraints of the target hardware platform, alongside the algorithm's logical requirements, to achieve marked reductions in single- and two-qubit gate counts and overall circuit depth on both superconducting and trapped-ion-based quantum platforms [1].

Secondly, a problem-tailored optimisation methodology is introduced that represents a parameterised circuit as a weighted sum of unitary operators, enabling cost functions, and their arbitrary derivatives, to be evaluated efficiently and exploited through a sequential, nonlocal-information-driven update rule [1, 2]. The resulting variational framework is then applied to study the nonlinear dynamics of fluid configurations governed by the one-dimensional Burgers' equation. Our proof-of-principle simulations achieve state fidelities of up to 99.9% relative to classical benchmark solutions across both the laminar and turbulent regimes, accurately reproducing the nonlinear shockwave formation characteristic of Burgers' dynamics. Moreover, our analysis highlights that low-depth circuit construction yields a threefold reduction in two-qubit gate count and circuit depth for implementing the variational circuits on IBM Quantum processors of the Heron R2 and Eagle R3 types, as well as on arbitrary trapped-ion-based processors. These gate reductions enable implementation of the variational circuits on the trapped-ion-based IBEX quantum device from Alpine Quantum Technologies (AQT), where the resulting variational states are prepared with high overlap against classical benchmarks, in the turbulent regime, demonstrating reliable performance on a real quantum processor. Overall, these results establish a coherent framework for deploying VQAs for simulation through optimisation strategies and circuit architectures explicitly co-designed for current devices. The techniques are broadly applicable to quantum simulation, quantum chemistry, and other structured optimisation problems where circuit depth is the primary limiting factor.

[1] E. Mastorakis, M. Umer, M. G. Bertsch, J. Ulmanis, F. Rohde, and D. G. Angelakis, arXiv 2507.19250 (2025).
[2] M. Umer, E. Mastorakis, and D. G. Angelakis, Quantum Sci. and Tech. 10, 035022 (2025).

A programmable quantum computing platform based on Rydberg ytterbium atom arrays

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We report on the ongoing efforts in developing, as well as initial implementation stages, of an experimental setup for the realization of a quantum computational platform based on neutral fermionic ^{171}Yb atoms trapped in optical tweezers with reconfigurable geometries. Leveraging on a richer electronic structure compared to alkali atoms, Ytterbium, amongst alkaline-earth(-like) atoms, enables a variety of different qubit encoding schemes drawing upon the so-called omg (optical-metastable-ground) architecture [1]. Indeed, having ^{171}Yb a nuclear spin I= 1/2, it is extremely well suited to be used as a purely nuclear-spin qubit, offering a naturally more environmentally isolated system than what achievable with encodings on hyperfine Zeeman states usually employed in alkalies. Moreover, besides a J = 0 ground state, the excited 6s6p ^{3}P$_0$ metastable state, offers an additional purely nuclear-spin manifold, which can be pivotal for the implementation of quantum error correction schemes relying on ancilla and data qubits. The chosen approach for our setup will allow the possibility of coherent control of the ground and metastable nuclear-spin qubits, as well as the optical clock ^{1}S$_0$ $\rightarrow$ ^{3}P$_0$ transition, so as to fully exploit Ytterbium's structure. Multi-qubit gates will instead be implemented exploiting state-selective coupling to Rydberg states.

[1] Lis, Joanna W. and Senoo, Aruku and McGrew, William F. and Rönchen, Felix and Jenkins, Alec and Kaufman, Adam M., Phys. Rev. X **13**, 041035 (2023).

Quantum Advantage in the Graph Domination Game

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Rapid advancements in quantum technologies continuously opens up opportunities for new fields of application. One such field is Operations Research. Here we look at games involving mobile agents coordinating their actions on a graph. It was recently discovered that there is advantage when playing these games [1, 2] if they use entangled quantum qubits. We study quantum advantage in the 1-step graph domination game on cycle graphs numerically, analytically and through the use of Noisy intermediate scale quantum (NISQ) processors. We find explicit strategies that realise the recently found upper bounds [1] for small graphs and generalise them to larger cycles [3]. We demonstrate that NISQ computers realise the predicted quantum advantages with high accuracy.

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[1] G. Viola P. Mironowicz, Phys. Rev. A **109**, 042201 (2024)
[2] J. Tucker, P. Strange, P. Mironowicz, J. Quintanilla, New J. Phys. **26**, 093038 (2024)
[3] C. Weeks, P. Strange, P. Mironowicz, J. Quintanilla, https://arxiv.org/abs/2511.15802 (2025)

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Adiabatic Versions of Oracular Quantum Algorithms

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Adiabatic Quantum Computing (AQC) is a quantum computation model that uses a time-dependent Hamiltonian to generate a time evolution that transforms an initial state to a desired final state. In contrast, the gate based quantum computational model uses a finite number of gates to build a circuit that acts on an initial state to produce a desired final state. In the literature, the final Hamiltonians used in the former process are always given in a form that assumes knowledge of the problem's solutions. This presentation aims to present final Hamiltonians used in adiabatic versions of oracular quantum algorithms using only the oracle operators assumed known in their gate based versions. These algorithms include: Grover, Deutsch-Jozsa and Bernstein-Vazirani algorithms respectively. The main Reason for using operators of gate based quantum computing to construct the final Hamiltonians of the adiabatic versions of the above algorithms is that, the knowledge of the solution subspace is not assumed.

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Mapping the Levin Wen model to the Kitaev Quantum Double model for the Hopf algebra case.