

SQuInT 2026

Poster Session — Program and Abstracts

Location: Salt River Ballroom 5

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Abstracts

1. Learning Low-Energy Subspace Overlaps in Many-Body Systems with Measurement-Based and Coherent Quantum Strategies

Shamminuj Aktar — *Los Alamos National Laboratory*

Co-authors: Rishabh Bhardwaj (LANL), Tanmoy Bhattacharya (LANL), Stephan Eidenbenz (LANL)

<https://arxiv.org/pdf/2607.00235>

Predicting the overlap of quantum states with specified low-energy subspaces is a key diagnostic for quantum many-body dynamics, with direct applications in state preparation, subspace-based algorithms, and the study of thermalization. We study the supervised prediction of subspace overlaps O_K between time-evolved states and K -dimensional low-energy eigenspaces of a 10-qubit Heisenberg spin chain following a local perturbation. We compare two quantum information extraction strategies: measurement-based learning, in which classical shadow features are processed by convolutional neural networks, and coherent quantum learning, in which quantum convolutional neural networks process the state directly. We further introduce physics-informed variants for both approaches, including Hamiltonian-aware shadows and QCNN gates aligned with the Heisenberg exchange structure.

Across five dataset configurations spanning weak, moderate, and strong quench regimes, physics-informed QCNNs achieve stable performance, with mean test-set R -squared values of 0.753 to 0.846. Shadow-based methods show stronger regime dependence: they outperform QCNNs in the moderate-quench regime, reaching an R -squared value

of 0.886, but underperform in weak and strong quenches at default shot budgets, where the best shadow results are 0.615 and 0.672, respectively. Hardware validation using Quantinuum and IBM noise models shows that arbitrary state preparation is the dominant limitation, requiring approximately 2,044 two-qubit gates and causing near-complete depolarization before inference. These results identify a regime-dependent tradeoff between measurement-based and coherent quantum learning, with shadow methods excelling when the target remains locally accessible and physics-informed QCNs providing more robust performance across dynamical regimes.

2. Learning Near-Optimal Trotter Orderings with Structure-Aware and Physics-Aware Transformers

Shamminuj Aktar — *Los Alamos National Laboratory*

Co-authors: Reuben Tate (LANL), Stephan Eidenbenz (LANL)

<https://arxiv.org/abs/2604.27171>

Trotterization approximates quantum time evolution by sequentially applying exponentials of individual Hamiltonian terms. When these terms do not commute, their ordering affects the simulation fidelity, making the selection of an effective ordering a combinatorial problem over a factorial search space. Evaluating many candidate orderings through classical simulation becomes increasingly expensive as the system size grows. We investigate learning-based approaches that predict high-fidelity Trotter orderings directly from Hamiltonian structure and generalize to systems larger than those used during training.

We first formulate ordering selection as classification over 24 structured candidates derived from commutation-graph colorings and permutations of the resulting commuting groups. A structure-aware transformer trained on one-dimensional XXZ Heisenberg chains with 3 to 14 qubits achieves a mean test fidelity gap of 0.00115 relative to the best of the 24 structured candidates on unseen systems with 16 to 20 qubits, without evaluating candidate fidelities at inference time.

Building on this approach, we remove the fixed candidate-space restriction and formulate Trotter ordering as a direct ranking problem. A physics-aware transformer assigns a scalar score to each Pauli term and constructs an ordering by sorting the scores. Anticommutation structure is incorporated through commutator-biased attention and an anticommutation-weighted ranking loss, with simulated-annealing orderings used as training references. Separate models for first- and second-order Trotterization are trained jointly on one-dimensional chains with up to 14 qubits and two-dimensional lattices with up to 12 qubits. They are evaluated on unseen chains with 16 to 20 qubits and lattices with 16 and 20 qubits. For first-order Trotterization, the median fidelity gap is 0.0000 on chains, 0.0144 and 0.0088 on triangular lattices, and 0.0948 and 0.0823 on rectangular lattices with 16 and 20 qubits, respectively. For second-order Trotterization, the corresponding gaps are 0.0114 on chains, 0.0364 and 0.0244 on triangular lattices, and 0.1348 and 0.1239 on rectangular lattices. The predicted ordering exceeds the simulated-annealing reference on 34 percent of first-order and 8 percent of second-order chain instances. These results demonstrate strong generalization on chains and triangular lattices, while rectangular lattices remain the most challenging geometry and motivate more geometry-preserving representations.

3. Faster Randomized Dynamically Corrected Gates

Kevin Baca — *University of New Mexico*

Co-authors: Leeseok Kim (UNM), Milad Marvian (UNM), Alicia Magann (Sandia)

Dynamically corrected gates (DCGs) implement a target unitary while canceling specified error terms, enabling high-fidelity quantum operations in practice. Although many DCG constructions have been developed, most achieve only low-order error suppression, since higher-order DCGs are often costly or difficult to realize under realistic bounded-control constraints. In this work, we introduce randomized DCG constructions that improve the suppression order by randomizing over corresponding lower-order gate designs. Specifically, we focus on two existing DCG frameworks: Eulerian DCGs and space-curve DCGs. For both methods, we derive a general condition and provide an explicit construction showing that randomization over two first-order robust DCGs can entirely suppress the leading error,

yielding full second-order robustness. The resulting randomized sequences are significantly shorter than deterministic DCGs of the same order. For Eulerian DCGs, we further extend the framework to upgrade an arbitrary-order construction by an additional order.

4. Adaptive fast-feedback protocol for drift compensation in quantum gates

Mayank Bhatia — *Sandia National Laboratories*

Co-authors: Kristin Beck (LLNL), Yujin Cho (LLNL), Michael McKerns (LANL)

We introduce an adaptive calibration strategy for stabilizing quantum gates in the presence of underlying parameter drift. The strategy is designed to be platform agnostic and compatible with complex and nonstationary drift processes. It operates by executing simple quantum circuits with known, target outcome distributions, and conditioning control parameter updates on their outcomes in real time. To maximize performance, the approach adaptively alternates between indefinite- and definite-outcome quantum circuits, with adaptive steps triggered when a change in the character of the drift process is detected. We numerically study the performance of this adaptive drift compensation protocol in the same single-qubit gate calibration setting for tracking drift in single-qubit gates. Here, we consider a variety of drift processes including processes that combine slow, continuous drift dynamics with rapid, discontinuous jumps. We then discuss an FPGA implementation of the protocol and present experimental results showing its performance for drift tracking on a superconducting qubit.

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5. Reducing Losses in Hyperfine State Detection of Alkali Atoms in Optical Tweezers via Alternating Counter-Propagating Probe Beams

Jessica Blevins — *Miami University*

Co-authors: Jose Roberto Fabre Segundo (Miami), Eduardo Mejia-Pretto (Miami), Sukhraj Singh (Miami)

Rapid, low-loss measurement of the hyperfine state of atomic qubits remains an

important challenge in neutral atom quantum computing. We analyze a recent experiment [“High-fidelity, low-loss state detection of alkali-metal atoms in optical tweezer traps”, M. Chow, B. Little, and Y-Y. Jau, PRA 108, 032407 (2023)] in which two important sources of state-detection error are suppressed: eviction of trapped atoms due to probe photon recoils, and state information loss induced by trap and probe light depumping. In their experiment, the probe beam is retroreflected to mitigate atom loss induced by photon recoil. We investigate

prospects for further suppression of the above losses, by alternating the counter-propagating probe beams along the lines of L. Su, et al., Nat. Comm. 16(1), 1017 (2025).

6. Development of a Multimodal Confocal Imaging Platform for Diamond-Based Biological Quantum Sensing

David Boone — *Arizona State University*

Co-authors: Mouzhe Xie (ASU), and others

Despite two decades of substantial progress, diamond quantum sensing based on optically addressable nitrogen-vacancy (NV) qubits has yet to make transformative impacts in biological and biomedical research. While advances in hardware performance, materials engineering, and metrological methods have pushed NV sensitivity and spectral resolution increasingly close to their physical limits, far less attention has been directed toward sample-sensor interfacing, operational biocompatibility, and measurement practicality. Moreover, NV sensing is typically implemented as a standalone technique on specialized, single-purpose optical setups, with limited integration into established imaging modalities that could provide orthogonal yet complementary biological information. Addressing

these practical and integration challenges will be essential for moving quantum sensing beyond proof-of-concept studies toward meaningful biological discovery.

Here, we custom-build an instrumental platform based on a commercial Nikon-PicoQuant fluorescence microscopy system that integrates three core functional modalities to study samples of interest in the same field of view. First, multicolor confocal imaging enabled by eight different laser wavelengths can generate diffraction-limited images with spectrally resolved fluorophores to simultaneously reveal molecular and subcellular features of interest. Second, time-resolved experiments such as fluorescence lifetime imaging (FLIM) and time-correlated single photon counting (TCSPC) provide unique photophysical information about biochemical changes and molecular interactions. Third, our implementation of synchronized laser and GHz microwave pulses enables robust NV-based quantum sensing of highly localized biological magnetic signals or in-cell temperature through optically detected magnetic resonance (ODMR), Ramsey, T1 and T2 relaxometry, and potentially nanoscale EPR/NMR experiments. In addition, we develop microfluidic quantum sensor devices leveraging ultrathin (10-500 nm) NV-containing single-crystal diamond membranes for precise sample handling and environment control. Together, these efforts have established new opportunities to interrogate cells and tissues by the synergistic use of advanced imaging and quantum sensing techniques within the same microscopy platform, paving the way for biomedical discoveries inaccessible to any single modality alone.

7. On the Complexity of Finding Decoherence Free Subspaces

Evan Borras — *University of New Mexico*

The open quantum system admits a diverse range of both interesting and useful steady-state structure, one which being a decoherence free subspace. Decoherence free subspaces are a steady-state structure of the open quantum system which preserves quantum coherence between the states lying within it and thus has found a variety of applications throughout quantum information science and technology. In this paper we study the computational complexity of deciding whether an open quantum system admits a decoherence free subspace or not. More specifically we study this problem within the context of Markovian open quantum systems governed by the time-independent Lindblad master equation. To make headway towards this goal, we consider the simpler problem of deciding whether a given Lindbladian admits a pure steady-state, or equivalently, a one-dimensional decoherence free subspace. Along the way we introduce the k -Local Lindbladian problem, which captures the difficulty of computing purity decay rates of Lindbladian dynamics. We show that our one-dimensional decoherence free subspace problem can be reduced to this k -Local Lindbladian problem under perfect completeness which we proceed to show is QMA1-Hard for $k = O(\log(n))$. In addition, we also show the general k -Local Lindbladian problem is QMA-Complete for $k = O(\log(n))$. Our hardness construction generalizes Kitaev's clock Hamiltonian construction to the open quantum system setting by encoding the execution of a quantum circuit into the steady subspace of a Lindbladian containing both pure and mixed history states. This subspace is then mixed depending on the output of the encoded circuit. Our results suggest that deciding whether a generic open quantum system admits a decoherence free subspace is intractable even for quantum computation.

8. Quantum Noise is the New Signal: Sensing and characterizing stochastic processes with quantum systems

Anthony Brady — *IonQ*

<https://arxiv.org/abs/2510.09521>; <https://arxiv.org/abs/2603.15742>; <https://arxiv.org/abs/2604.14298>

Many signals of physical interest are intrinsically stochastic. Fluctuations—and correlations among those fluctuations—reveal properties of noisy quantum devices, many-body systems and complex materials, biological samples, and possible new physics. To a quantum sensor, however, these signals appear as decoherence. This poses a natural question: How can quantum resources best be used to extract the information in the statistics and correlations of these stochastic signals?

In this talk, I will discuss the broad framework of quantum noise metrology—the estimation and learning of stochastic processes with quantum systems—as well as recent results from our work in this direction. I will first describe the

general paradigm of multi-parameter Markovian noise metrology, and use it to understand when quantum resources can improve our ability to estimate stochastic Markovian signals.

I will then illustrate this framework in quantum sensor networks. For an array of spin sensors undergoing spatially correlated dephasing with a power-law form, entanglement provides a metrological advantage when the noise correlations are sufficiently long ranged. Temporal correlations, i.e., memory effects, modify this advantage and require interrogation and control sequences matched to the noise spectrum. In a similar guise, I will discuss how entangled sensing strategies can greatly outperform separable sensing strategies in specially engineered noise models—even admitting an exponential separation under particular resource assumptions. These results point toward entanglement-enhanced measurements of correlation functions and stochastic dynamics in complex quantum systems as an exciting frontier for networked quantum metrology.

Complementary examples arise in quantum optical imaging. Spatially varying absorption and fluorescence profiles imprint themselves on structured light through photon loss and gain. I will discuss how spatially structured “twin-beam echoes” can separate these processes into distinguishable measurement outcomes. For the toy problem of resolving two weak subdiffraction absorbers, I further show how quantum-optical probes retain finite information about the absorbers' separation as the separation tends to zero. This contrasts the vanishing of the separation information when probing the absorptive scene with semi-classical probes—the famous “Rayleigh curse.”

If time permits, I will close with ongoing work on in situ error characterization. This uses quantum-error-correcting codes to not only suppress errors, but to simultaneously learn coherent and stochastic error processes while leaving the encoded logical degrees of freedom approximately undisturbed.

Taken together, these results highlight the richness of quantum noise metrology and point toward the exciting frontiers of sensing, learning, and characterization of (and with) complex quantum systems and environments.

9. Quantum Crash

Noah Bray-Ali — *Science Synergy*

In 2026 IonQ reported a significant gap between the entanglement of a pair of logical qubits observed with 16 trapped-ion qubits and the entanglement predicted within the standard decoherence paradigm of quantum information. Similarly, in 2025 Google Quantum AI observed a logical qubit error rate thousands of times larger than expected using 72 superconducting qubits operating below the threshold for fault-tolerant quantum error-correction. We suggest that the quantum error-correction algorithm itself induces a condensation, or quantum crash, into the “dual” quantum code (e.g. the Z basis quantum repetition code algorithm leads to condensation into a X basis code state), and we argue that this condensation leads to a correlated burst of error event detection probability across the device that persists for the coherent lifetime of the logical qubit, potentially explaining the puzzling IonQ and Google Quantum AI results.

10. Circuit Depth and Pulse-Rate Tradeoffs in Multi-Qubit Dynamical Decoupling

Amy Brown — *University of Southern California*

Co-authors: Daniel Lidar (USC)

Dynamical decoupling (DD) is a time-tested method for mitigating decoherence and crosstalk in quantum systems. General multi-qubit DD has historically focused on orthogonal arrays with sequences whose circuit depth scales linearly with the number of qubits. Chromatic-Hadamard Dynamical Decoupling (CHaDD) streamlined these methods by properly coloring the hardware graph and assigning to each color a decoupling sequence based on Hadamard matrices, resulting in sequences whose circuit depth scales linearly with the number of colors, which can be as low as the chromatic number of the graph. Here, we explore the tradeoff between efficiency in circuit depth scaling with the number of colors and pulse repetition rate (PRR), the average rate at which qubits experience decoupling pulses, and the impact on sequence performance. We introduce two sequences based on binary and Gray matrices, which are special cases of non-minimum-depth CHaDD sequences, whose circuit depths scale exponentially with the number of colors but whose performance, measured as the average ability to preserve the initial state over a number of

preparation state settings, is superior due to a lower PRR. This advantage disappears when robust versions are introduced, which mitigate the error contribution from coherent pulse errors, suggesting that the PRR serves as a proxy for accumulated coherent control error. Broadly speaking, aggregate state preservation performance of a host of chromatic DD sequences can be adequately predicted by the PRR. We present a number of sequence variations and group their experimental performance according to predictions based on the sequences' PRRs.

11. Single-Photon Storage Protocol in a Delayed Waveguide-QED System

Miguel Castillo-Celeita — *National Autonomous University of Mexico*

Co-authors: Jose Luis Meza Cabañas (UNAM), Pablo Barberis Blostein (UNAM)

We study a single-photon storage protocol in a waveguide coupled to two spatially separated Λ -type atoms. The atoms are also driven by a transverse classical control field.

In this configuration, the input single photon is prepared as a localized wave packet. While the photon interacts with the atoms, the control mode is switched off. This allows part of the photon excitation to be transferred to the metastable atomic states. After a chosen storage time, the control fields are switched on again to retrieve the excitation.

The analysis of the metastable-state probability and correlations provides evidence of partial storage of the incident photon in the two-atom system. In this work, we characterize how the interatomic distance, the pulse width, and the initial wave-packet parameters influence the storage process.

Our results show that a few-emitter waveguide-QED system can reproduce some features of electromagnetically induced transparency light storage. At the same time, this system allows us to study the role of propagation delay and non-Markovian effects in a simple quantum memory setup.

12. Which observables should a quantum reservoir computer measure?

Efe Kurtulus Celep — *Carleton College, Physics*

Co-authors: Arjendu Pattanayak (Carleton)

Quantum reservoir computing extracts computational value from a driven quantum system using a linear map from measured observables. We report here on the dependence on the choice of measured observables, as well as on how information is encoded into the system using the paradigmatic case of two coupled superconducting oscillators [Dudas et al., npj QI 9, 64 (2023)]. While holding all other factors constant, we (A) compare Husimi-Q coherent-state projections as observables (measurable by routine heterodyne detection) to the standard Fock-state populations and (B) encode the input in the phase instead of the amplitude of the drive. If we take an equal number of observables, the Husimi readout is never worse: slightly better when the input is amplitude-encoded, and significantly better when it is phase-encoded. Specifically, the Husimi readout yields a far better conditioned feature space and equal or greater information processing capacity at every measurement budget tested, and at every nonlinearity degree in the exact-measurement limit. However, the encoding choice is a trade-off: Amplitude encoding holds more capacity when expectation values are exact and reaches deeper into the input history but this capacity lives in weakly represented directions of the feature space relative to phase-encoding: for example, when each observable is estimated from 10^3 repetitions of the experiment, it retains 21% of its exact limit capacity, against 61% for phase encoding (using in both cases the Husimi readout). In particular for trajectory prediction in the chaotic regime of the Mackey–Glass equation, phase encoding with the Husimi readout gives the lowest error across the full range of measurement budgets examined.

13. Efficient Magic State Cultivation for $\sqrt{T}$ gate

I-Chi Chen — *Los Alamos National Lab*

Co-authors: Matheus da Silva Fonseca, Andrew Sornborger

<https://arxiv.org/abs/2606.10430>

Recently, experimental and theoretical quantum error correction methodology has seen remarkable breakthroughs. In particular, magic state cultivation has been shown to simplify magic-state preparation and make it feasible for near-term devices. However, recent research on magic state cultivation has focused primarily on the cultivation of $T|+\rangle$. Only a few other magic state cultivation methods beyond have been investigated. Here, we generalize phase kickback checks for magic states at arbitrary Clifford hierarchy levels in specific codes. We provide an example of cultivation of $\sqrt{T}|+\rangle$ in the doubled color code and the corresponding escape strategy using lattice surgery from the color code to large rotated surface codes. Using state vector simulation for un-grown cultivation, we observe a strong consistence between $\sqrt{T}|+\rangle$ and $S|+\rangle$ cultivation's performance on the doubled color code. Finally, we discuss the application of the corresponding $\sqrt{T}|+\rangle$ cultivation, incorporating the STAR architecture and $\sqrt{T}$ gates, for early fault-tolerant quantum computing and its potential to shorten gate synthesis in the fully fault-tolerant quantum computing era.

14. Susceptibility of qudit-qudit entanglement to quantum noise: insights from the negativity rank

Matthew Chen — *Duke University*

Co-authors: Natalie Klco (Duke)

Significant complexity of quantum many-body systems resides in their ability to exhibit entanglement, i.e., uniquely quantum correlations that are a key resource in quantum computation. To quantitatively explore the diminishing effect of quantum noise on entanglement, we focus on the negativity witnesses, an entanglement measure based on local time reversal transformations that has been observed to be a perfect witness in simple physical contexts such as spacelike vacuum regions of free scalar fields. Beyond basic calculation of the negativity, we analyze the associated eigenvalue spectra of partially transposed density matrices subject to various forms of quantum noise for qudit-qudit bipartitions of arbitrary local dimension. By extending the maximum number of separable states that can be arbitrarily mixed into an entangled pure state while retaining negativity partial transpose (NPT) to be exactly equal to the negativity rank, we show that higher rank provides greater(reduced) robustness to targeted(global) noise. Furthermore, we report an intuitive relationship between completely depolarizing noise and the Absolutely Positive Partial Transpose (APPT) subspace, which defines the noise boundary beyond which no unitary operator is capable of generating forms of entanglement typically considered operationally useful (NPT). Additionally, an analytic purity constraint for the APPT subspace is derived which may be useful in the search for APPT entanglement.

15. Color Codes in a Permutohedral Lattice

Lucas Daguerre — *Yale University*

Co-authors: Isaac Kim (UC Davis), Joon Lee (Leiden)

Color codes are a class of topological quantum error-correcting (QEC) codes known for their transversal gate set and their connection with universal fault-tolerant quantum computation. While existing research has established ways of constructing the primal lattice of color codes, for three-dimensions onwards, the standard construction complexifies due to the use of a dual lattice. In this work, we develop a straightforward lattice-generating method without resorting to using the dual lattice. Our method extrapolates the 2D hexagonal and 3D tetrahedral color codes families to arbitrary dimensions. The key insight is that the bulk of the primal lattice is tessellated by the permutohedron, a D -dimensional polytope that geometrically represents the symmetric group S_{D+1} . The associated permutohedral lattice is defined on a hyperplane subspace isometric to the D -dimensional real space, where the boundary of a regular D -simplex is carved out. This construction method allows not only to algebraically define the primal lattice, but also provides a mathematical framework to derive properties of color codes in a permutohedral

lattice. We conclude by discussing applications and potential experimental realizations on near-term quantum devices with all-to-all connectivity, such as trapped-ions or neutral atoms.

16. Benchmarking Quantum Simulations of the Lipkin-Meshkov- Glick Model Using Large Tensor Networks

Rushil Dandamudi — *WISER; University of Maryland, College Park*

Co-authors: Maggie Bao (WISER/MIT), Jeremiah Wright (WISER), Joan Arrow (Naval Nuclear Lab)

By running DMRG on the NERSC Perlmutter supercomputer, we provide one of the largest LMG ground-state energy datasets in the literature, containing accurate ground-state energies for systems of up to 1400 particles. We compare these results with VQE and SQD implementations on an IBM Eagle quantum computer. VQE achieved results within 1-percent error for 6 particles, while exceeding that threshold for all other values. SQD extended that range to 17 particles, suggesting that, in a Noisy Intermediate-Scale Quantum era, subspace-based approaches may strike the best balance between accuracy, circuit depth, and noise resilience.

17. Entanglement Dynamics and State Protection in Asymmetric Giant-and-Small Emitter Interfaces

Arushi Deb — *Miami University*

Co-authors: Imran Mirza (Miami)

This poster presents a theoretical framework investigating the transient and steady-state entanglement dynamics within a highly asymmetric waveguide QED architecture. We model a heterogeneous emitter pair consisting of a single multi-point giant atom and a standard point-like small atom coupled to a shared one-dimensional waveguide continuum. Utilizing a Markovian master equation approach, our study details the analytical derivation of collective decay rates and waveguide-mediated exchange interactions. We focus on how the non-local quantum interference pathways unique to the giant atom configuration can be engineered to isolate the combined bipartite system into a phase-dependent dark state. The presentation outlines the theoretical bounds required to leverage these non-local interference loops for decoherence protection and state engineering, offering a simplified architectural design rule for hybrid-platform quantum networks and superconducting circuit interfaces.

18. Spacetime distance of dynamical Bacon-Shor codes

Ethan Egger — *Center for Quantum Information and Control, University of New Mexico*

Co-authors: Milad Marvian (UNM)

Dynamical quantum error correcting codes provide a generalization to the well-known stabilizer code paradigm. They are defined by a sequence of (not necessarily commuting) checks that project the quantum state into some dynamically defined logical subspace where information can be stored. This generalized setup provides more flexibility for syndrome extraction and logical operations for both subspace and subsystem codes, while also setting space and time on more even footing. Various constructions for spacetime codes have been proposed. For example, Alam and Rieffel introduced a Floquet-Bacon-Shor code that can encode on a $d \times d$ square lattice the usual Bacon-Shor logical qubit along with k dynamical logical qubits by modifying the measurement schedule of the original subsystem code. They argue that the distance of this construction is $\mathcal{O}(\frac{d}{\sqrt{k}})$.

However, analyzing the performance of dynamical codes can prove to be more subtle than subspace or subsystem constructions. For example, low weight spacetime errors can propagate to higher weight during some measurement schedules, making the notion of spacetime distance more complicated than the stabilizer code picture. Recently it has been shown by Blackwell and Haah that all Pauli errors acting trivially on the logical information of a dynamical code are generated by (i) Pauli operators that are elements of the current instantaneous stabilizer group (a stabilizer of the codespace at a specific time), and (ii) two identical Pauli operators inserted before and after a measurement they commute with (effectively "pushing" spacetime errors from one time step to another). These "benign" errors can be

used to define the notion of spacetime distance for dynamical codes: the minimum weight of an undetectable spacetime error that is not benign.

Motivated by this perspective, in this work we make two contributions. First, we introduce alternative constructions for Bacon-Shor inspired dynamical codes and analyze their properties. Second, we prove that the upper bound on distance for Alam and Rieffel's Floquet-Bacon-Shor code is tight for all $k \geq 1$.

These contributions make use of the results shown by Blackwell and Haah and generalize some of their findings. Crucially, they observe that any undetectable spacetime error is equivalent (up to benign generators) to a logical operator of the instantaneous stabilizer group at some point in time. This insight allows undetectable spacetime errors to be "pushed" into one time-step in the future. For the dynamical Bacon-Shor constructions considered, it is possible to perform this pushing without increasing the spacetime weight of the error. Then, the specific structure of the Bacon-Shor checks was used to prove a lower bound on the weight of dynamical logical operators, and hence, nontrivial undetectable spacetime errors. This in turn gives a lower bound for the code distance. For Alam and Rieffel's construction, this lower bound matches their upper bound, and for the alternative constructions introduced in our work, the bound is shown to be saturated by the weight of specific logical operators of the code.

19. Vector magnetometry with continuous measurement and nonlinear dynamics

Alejandro Garcia — *CQUIC*

Co-authors: Jieqiu Shao (UNM), Noah Lordi (UNM), Ivan Deutsch (UNM)

We study a vector magnetometry protocol via continuous measurement of Faraday rotation of a laser probe passing through an ensemble of atomic spins in the presence of an unknown vector B-field and driven by additional known control fields. Through the use of control pulses, we implement random Larmor precession in the presence of nonlinear one-axis twisting on the spins, described by the Hamiltonian $\hat{H}(t) = \Omega (\cos\{\phi(t)\} \hat{J}_x + \sin\{\phi(t)\} \hat{J}_y) + \frac{\beta}{2} \hat{J}_z^2$. The combination of these leads to ergodic motion of the spin on the sphere which is used to probe the unknown vector field. We analyze the behavior of the strength of the nonlinearity quantified on the variance of our estimator, with a resolution set by the shot noise of the probe. Numerically we find that the presence of the nonlinearity improves the variance of our estimator and we identify a short time scale and long-time scale where the best improvement in the variance of the estimator differs depending on the choice of nonlinearity. We perform an analysis of the metrics that affect this behavior over these two time scales.

20. Quantum Optical Ground Station at the University of North Dakota

Corbin Giroux — *University of North Dakota*

Co-authors: Christopher Scott (UND), Ashley Vos (UND), Yamuna Thapa (UND)

Free space optical communication (FSOC) uses a laser to transmit information through free space in a direct path instead of the typical radio frequencies. There are many advantages to also implementing quantum hardware to perform this exchange of information; it will be more difficult to intercept, and both parties will be knowledgeable if a third-party attempts to listen. This makes FSOC a promising improvement upon traditional radio communication methods, larger data rates, cheaper installation, and quantum secured communication all contribute to its viability. It is particularly useful for satellite communication and has been demonstrated as a proof of concept; however, no one has integrated quantum optical hardware needed for satellite quantum key distribution (QKD) with standardized commercial optical ground stations (OGS) hardware. FSOC is a promising advancement in satellite communication but requires robust OGS for future scaling. Here, we report on an OGS that integrates quantum hardware for a satellite QKD with classical FSOC capability built to the Space Development Agency (SDA) 3.2.0 standard. We show a year long period of data characterizing the site conditions and quantum link capabilities. The OGS at the University of North Dakota is a state-funded facility meant to train optical link operators and support research and development for optical link hardware. It will also be used as a testing ground for quantum communication hardware that may be run in parallel with classical links. We show results from instrument data on atmospheric site conditions and satellite overpass duration. The average monthly cloud cover of Grand Forks, ND is 45.6% coverage over a year-long period.

This can then be used to accurately predict satellite overpass time. The average daily satellite time predicted for the OGS is dependent on the inclination of the satellite and peaks at 60 min for a 60° inclination. Next, atmospheric turbulence was characterized using seeing and the Fried parameter. Each were found to be consistent and predictable over a year-long period with an average seeing of 1.7 arcsec and an average Fried parameter of 7.0 cm. The atmospheric turbulence is specifically used to create an adaptive optics (AO) system for the OGS. The AO system can be run in a dual-wavelength mode where the AO system and pointing, acquisition, and tracking system are driven by a SDA-standard optical link. A quantum link may be run in parallel with the AO system, bypassing the AO system and fed directly through a narrowband spectral filter and a JPL Peacoq 32-element SNSPD array for high-rate photon counting.

21. Fault tolerant computation of the static structure factor and finite size effects

John Golden — *Los Alamos National Laboratory*

Co-authors: Rishabh Bhardwaj (Xanadu), Travis Jones (LANL), Alex Muñoz (LANL)

<https://arxiv.org/abs/2606.27734>

Fault-tolerant quantum algorithms offer a promising pathway for estimating the ground-state energies of periodic materials that are beyond the practical reach of classical electronic-structure methods. A remaining challenge is finite-size mitigation: quantum algorithms evaluate a finite supercell or finite Brillouin-zone mesh, while materials properties are defined in the thermodynamic limit. In this work we develop a quantum post-processing strategy for the leading two-body finite-size correction. After one-body shell effects are reduced by twist averaging, the dominant residual error is controlled by long-wavelength density fluctuations, which are encoded in the small-momentum static structure factor $S(q)$. We formulate the corresponding operator in a Bloch-orbital basis, construct its block encoding through the density operator, and estimate its ground-state expectation value using an amplified Hadamard test. We also introduce adaptive global and local binary search procedures for identifying the infrared fitting window used to reconstruct the two-body finite size error correction. The resulting cost remains subleading relative to the main ground-state energy estimation routine: the structure-factor correction has leading $\tilde{O}(N_b N_k)^3$ dependence on the Bloch-orbital basis size, avoids the large plane-wave prefactor of full Hamiltonian simulation, and requires only $\tilde{O}(N_b N_k)$ logical qubits. This provides a fault-tolerant alternative to down-sampling, replacing repeated energy calculations on larger cells with targeted measurements of the infrared density correlations that control the finite-size effects.

22. Out-of-control Hamiltonian Learning

Weiyan Gong — *Harvard University*

Co-authors: Sitan Chen (Harvard), Jordan Cotler (Harvard), Hsin-Yuan Huang (Oratomic/Caltech)

Learning the Hamiltonian of a many-body system from its dynamics is a central task in quantum science, yet the algorithms with the strongest provable guarantees assume some level of quantum control --- fast, arbitrary single-qubit gates interleaved with the evolution, and measurements in arbitrary bases --- that is beyond the capabilities of near-term analog quantum simulators.

Motivated by analog atom- and ion-based platforms such as Rydberg atom arrays and trapped ions, we study Hamiltonian learning under a minimal but experimentally realistic access model: only global uniform site-independent single-qubit, computational-basis, or even all-zero state preparation and measurements, and queries to constant time forward Hamiltonian evolution without interleaved controls.

For broad families of geometrically local Hamiltonians, we resolve both the algorithmic question and the identifiability question for the following cases:

1. Global uniform state preparation and measurements: We propose a protocol that can efficiently reconstruct every parameter of a nearest-neighbor Hamiltonian, with no unresolvable symmetry, on a large class of interaction graphs, including 1D, 2D, and 3D lattices, triangular, honeycomb, and kagome lattices, and next-nearest-neighbor chains—using only constant-time evolutions.

We further provide a broader criterion for the learnable graphs on which the nearest-neighbor Hamiltonian is defined.

2. Computational basis state preparation and measurements: We determine the exact group of unavoidable gauge symmetries.

As a warm-up, we show that even with all-zero state preparation and computational basis measurements, we are able to learn translation-invariant and rotation-invariant nearest-neighbor Hamiltonians on 1D, 2D, and potentially 3D lattices.

We then propose a series of algorithms that reconstruct 1D, 2D, and 3D translation-invariant nearest-neighbor and 1D three-local Hamiltonians and, most notably, general spatially varying nearest-neighbor Hamiltonians on 1D, 2D, and potentially 3D lattices.

Our algorithms combine a smoothed-analysis framework, tools from algebraic geometry, and robust estimation of short-time dynamics via Lieb–Robinson bounds, showing that robust Hamiltonian learning remains achievable under severely constrained, control-free access.

We also prove a lower bound showing that, with no interleaved control, even 1D nearest-neighbor Hamiltonians cannot be learned beyond the standard quantum limit, which matches the performance of our algorithms in various settings.

23. Towards Optimal Characterizations of Arbitrary Dynamics with a Few Pauli Measurements

Weiyuan Gong — *Harvard University*

Co-authors: Taiqi Zhou (CUHK)

<https://arxiv.org/abs/2606.19486>, <https://arxiv.org/abs/2607.23044>

Characterizing open and closed quantum systems serves as a fundamental subroutine of quantum device verification and calibration, signal sensing, and error correction.

For closed systems, recent works have proposed protocols achieving the optimal Heisenberg-limited scaling learning ansatz-free Hamiltonians from their real-time evolutions without fully specifying interaction structures. However, these protocols rely on both deep circuits with interleaving probes and control, and extremely short time resolution, making them difficult to implement on near- and intermediate-term in situ quantum experiments. In this work, we propose a computationally efficient, control-free, and ancilla-free algorithm that uses only Pauli product state preparation and measurement, and learns an ansatz-free Hamiltonian H with $\|H\| \leq \Lambda$ in total evolution time of $\Theta\left(\frac{\Lambda}{\epsilon^2} \log\left(\frac{\Lambda}{\epsilon}\right)\right)$. The evolution time cost of our algorithm is optimal for any control-free protocols as we further prove a lower bound of $\Omega\left(\frac{\Lambda}{\epsilon^2} \log\left(\frac{\Lambda}{\epsilon}\right)\right)$. Technically, our method introduces a randomized-sampling framework that combines band-limited kernel-based time sampling with a displacement sieve for Hamiltonian structure learning.

The characteristic probe time resolution depends only on Λ instead of ϵ , which makes our protocol especially appealing in the high-precision regime for sensing and calibration applications.

We also analyze the robustness of the algorithm against state-preparation-and-measurement (SPAM) errors, where we show that, by calibrating preparation and measurement errors, the algorithm maintains the same asymptotic total evolution time in the presence of SPAM noise when the Hamiltonian is local. Our results demonstrate the fundamental cost of experimentally friendly Hamiltonian learning and provide a practical route to rigorous in situ characterization of near-term quantum platforms.

For open systems, existing characterization protocols either assume prior knowledge of the interaction and noise structure, or demand ancillas, entangled probes, or mid-circuit control, or capture only the Pauli-diagonal part of the noise. Here, we present a protocol that reconstructs an arbitrary sparse Markovian generator, including every Hamiltonian together with the jump operator coefficients, using only product Pauli state preparation, single uninterrupted forward evolutions, and product Pauli measurements. Given a sparsity budget M and a strength bound Γ of the Lindbladian, every coefficient is learned to precision ϵ from $\widetilde{O}(\Gamma^2 M^2 / \epsilon^4)$ experiments and $\widetilde{O}(\Gamma M^2 / \epsilon^2)$ total

evolution time, with both supports identified from data without locality assumptions. The protocol runs at a logarithmic number of positive evolution times on a hardware clock lattice and is provably robust to calibrated state-preparation and measurement errors.

24. Learning Qubit Gate Dynamics in Open Quantum Systems by Fitting to the Nakajima-Mori-Zwanzig Equation

Samuel Goodwin — *University of New Mexico*

Co-authors: Brian McFarland (Sandia), Manuel H. Muñoz-Arias (Sandia), Edward Tortorici (Sandia)

<https://arxiv.org/abs/2601.07934>

Fault-tolerant quantum computing requires extremely precise knowledge and control of qubit dynamics during the application of a gate. Most existing quantum characterization protocols do not reveal the dynamics of a qubit during the application of a gate. We develop a data-driven learning protocol for quantum gates that builds off previous work on learning the Nakajima Mori Zwanzig (NMZ) formulation of open system dynamics from time series data, which allows for interpretation of the learned operators and comparison to expected dynamics. We show this learning technique can be applied to open quantum systems to learn the dynamics of a single-qubit quantum gate from simulation and experimental data. We focus on learning the Markov transition matrix, which captures the Markovian dynamics of our system, and the memory kernel, which indicates how far back in time we must look to be able to accurately predict future dynamics. We demonstrate this learning technique on three different systems: a simulation of a qubit whose dynamics are purely Markovian, a simulation of a driven qubit coupled to stochastic noise produced by an Ornstein-Uhlenbeck process, and trapped-ion experimental data of a driven qubit coupled to an environment whose noise is not characterized ahead of time. This technique is able to learn the generators, or the NMZ operators, in all three cases and can learn the timescale in which a continuously-driven qubit can no longer be accurately described by a purely Markovian model.

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25. The complexity of minimum-weight decoding of topological codes

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<https://arxiv.org/abs/2603.22064>, <https://arxiv.org/abs/2606.18145>

The decoding problem is one of the central algorithmic tasks in quantum error correction, and solving it efficiently is essential for scalable fault-tolerant quantum computing. A particularly important class of decoding algorithms is minimum-weight decoders. These decoders seek a minimum-weight recovery operator consistent with the measured syndrome, which often corresponds to the most likely error. Minimum-weight decoders remain among the most successful decoding algorithms, used widely in decoding algorithms for the surface code, the color code, and more general two-dimensional topological translationally invariant (2D TTI) codes.

This submission comprises two papers analyzing the complexity of the minimum-weight decoding problem. In the first, we prove that minimum-weight decoding is NP-hard in three quintessential settings: (i) the color code with Pauli Z errors, (ii) the surface code with Pauli X, Y, and Z errors, and (iii) the surface code with a transversal CNOT gate, Pauli Z and measurement bit-flip errors. In each case, we establish NP-hardness via a reduction from the three-dimensional matching problem, which is NP-complete. Our results show that computational intractability already arises in basic and practically relevant decoding problems central to both quantum memories and logical circuit implementations.

From the practical standpoint, however, one may care more about the complexity of solving the problem approximately. In the second paper, we prove that minimum-weight decoding of 2D TTI codes admits a polynomial-time approximation scheme (PTAS). That is, for any constant $\epsilon > 0$, a recovery operator of weight within a multiplicative factor of $1 + \epsilon$ of the minimum can be found in polynomial time. Our approach builds on Arora's PTAS for Euclidean problems, such as the traveling salesman problem, and applies when decoding can be cast in terms of point-like excitations connected by string-like errors. It therefore extends beyond two dimensions, covering certain

higher-dimensional topological codes and quantum memories, including the toric code with phenomenological or circuit-level noise. Our two results highlight a sharp computational complexity separation between minimum-weight decoding and its approximate realizations.

26. Bounding a Quantum Adversary in Relativistic Bit Commitment

Sarah Hagen — *University of Illinois Urbana-Champaign*

Co-authors: Shouvik Ghorai (UIUC), Kevin Thompson (Sandia)

Bit commitment is a cryptographic primitive in which one party first commits to a bit thus far unknown to a second party. In the reveal round a successful and secure protocol guarantees that the bit originally committed to is revealed and that the second party has not been able to previously access it. Bit commitment is used in protocols like secure coin flipping and zero-knowledge proofs; however, no unconditionally secure classical protocol to build bit commitment exists. In fact, both in the classical and quantum settings, bit commitment is impossible.

Nevertheless, since the commitment time needed for many applications is of a fixed length, it remains possible to focus on building secure bit commitment schemes whose security is guaranteed for a certain length of time. So-called relativistic bit commitment works by separating parties of the sender and receiver in order to leverage the duration it takes to send messages between them for bit commitment. The proposed scheme (see e.g. Lunghi et al. (2015)) is quantum in nature with the no-cloning theorem necessarily contributing to the security guarantee. Experimental demonstrations with small commitment times exist (Lunghi et al. (2013) and Liu et al. (2014)). Importantly, however, it has been shown by Chakraborty et al. (2015) that the realistic short commitment times resulting from the constraints of terrestrial geography can be overcome by adapting the quantum protocol to be arbitrarily long. Moreover, the increased resource overhead of the adapted protocol is primarily classical and therefore more easily achieved.

An important task in building such a bit commitment protocol, however, remains quantifying the security against quantum adversaries who try to cheat. The proposed protocols inherently prevent the second party from cheating. However, in the case of a dishonest committer, previous research has shown that the protocol's security essentially relies on two separate nonlocal games being hard to win for a quantum player represented at two distinct locations. For the second of these games, when the input size of both parties is the same, the success probability has been bounded rather tightly by Braverman and Shor (2015). It is the precise quantum cheating probability in the first game, upon which the protocol's security thus depends, which remains an open problem, despite previous work which has bounded the classical and quantum cheating probability (see e.g. Chakraborty et al. (2015) and Sikora et al. (2014)).

In our work, we consider the security of the protocol under the realistic assumption of quantum adversaries. The quantum-powered committer cheats successfully when they have won a variant of the general CHSH game, where one party's input is fixed to be of dimension 2 and the size of the other party's input is a prime integer. Sikora et al. (2014) studied this game for integers 2^n , applying an SDP relaxation for bounding the quantum value of this so-called unique game, as determined by Kempe et al. (2010), and conjecture a quantum value.

Our work shows that this conjecture does not hold generally. We use existing open-source tools for applying the NPA hierarchy to this nonlocal game setting and our own code which reduces the needed computational resources by exploiting symmetries specific to this problem. With these techniques, we upper bound the game's winning probability using the second level of the hierarchy for prime values $q \leq 7$.

Using the results we conjecture our own quantum bound for prime q . We can computationally show that the conjectured bound is tight for $q \leq 5$ by simultaneously lower bounding the quantum strategy using the success probability of proposed attacks. We also analytically determine the quantum value of such nonlocal games. We show that the first level of the NPA hierarchy is not sufficient in bounding the quantum value of the game for $q \geq 3$.

Ongoing work addresses the protocol's security definitively by proving that the security of the protocol rests solely on the security of the singular game we study and thus gives a tighter bound for the ϵ -binding parameter in relativistic bit commitment.

27. Quantum computer implementations of Riemannian gradient descent through randomization and Krylov subspace techniques

Ariq Haqq — *University of New Mexico*

Co-authors: Christian Arenz (ASU), Ojas Parekh (Sandia), Anastasiia Skurativska (Leiden)

Determining the ground state energy of a Hamiltonian is an important problem that quantum computers are well-suited to solve. There are various proposed methods to estimate the ground state energy on a quantum computer, namely variational quantum eigensolvers (VQEs). However, variational quantum algorithms suffer from two major problems: optimizing the parameters in VQEs can prove to be difficult, and the ansatz one picks does not necessarily guarantee preparing the ground state is possible. Riemannian gradient descent (RGD) is another technique of preparing the ground state that hopes to alleviate some of the problems that VQEs suffer from. Importantly, they are guaranteed to converge to the ground state for any given initial state (as long as the initial state has sufficient overlap with the ground state). However, implementing the full Riemannian gradient at each iteration of the algorithm is exponentially expensive. The objective of this research is to try to find efficient approximate implementations of RGD such that they maintain the convergence properties of the full RGD. One proposed method to efficiently implement RGD is instead of reconstructing the full Riemannian gradient, partially reconstruct it by using classical random sampling. We propose a different approach, inspired by techniques from Krylov quantum decomposition. One can show that by expressing RGD in the Krylov basis, it is possible to obtain an efficient approximate estimation of the ground state given that there is an oracle that gives moments of the energy $\langle H^k \rangle$ and that the dimension of the Krylov space does not grow too large for the given Hamiltonian.

28. Optimizing Polarization Squeezing in a Multipass Faraday Quantum Interface for Enhanced Magnetometry

Maggie Hausman — *Miami University*

Co-authors: Imran Mirza (Miami), Samir Bali (Miami), Thad Walker (Wisconsin)

We present a theoretical investigation of the squeezing spectrum of polarization-squeezed light generated through a multi-pass atomic Faraday interface. Building upon the two-cell, four-pass protocol introduced by Sherson and Mølmer [1], we model a linearly polarized laser interacting sequentially with two oppositely spin-polarized atomic ensembles under an applied magnetic field. Utilizing the quantum input-output formalism, we systematically track the joint evolution of the collective atomic spins and optical Stokes variables across all four passes. From this framework, we derive the full frequency-dependent squeezing spectrum to quantify the fundamental limits of quantum noise reduction. Developed in collaboration with ongoing experimental efforts by the Miami-Wisconsin collaboration, this model provides concrete parameter optimization for engineering bright polarization-squeezed light. Ultimately, these results offer a viable blueprint for bypassing standard quantum limits in optical atomic magnetometry, paving the way for magnetic field sensitivities that rival or exceed conventional SQUID and SERF sensors.

Reference: [1] J.F. Sherson and K. Mølmer, Polarization squeezing by optical Faraday rotation; Physical Review Letters, 97(14), 143602 (2006).

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29. Fundamental Limits for Thermodynamic Control with Quantum Feedback

Kaiyuan Ji — *Cornell University*

Co-authors: Gilad Gour (Technion), Mark M. Wilde (Cornell)

<https://arxiv.org/abs/2503.09012>

The study of feedback control inspired by Maxwell's demon has yielded fundamental insights into the relationship between thermodynamics and information. However, its fully quantum formulation, where the controller holds quantum side information that cannot be treated as a classical record, remains incomplete. In this paper, we establish

fundamental no-go limits for thermodynamic state conversion while allowing quantum side information to be fed back to the system coherently. From two basic operational principles respected by all physically admissible feedback-control schemes, we derive the tightest possible bounds on the single-shot work of formation and extractable work for arbitrary quantum systems conditioned on arbitrary quantum side information. In the asymptotic limit, these bounds yield a generalized second law of thermodynamics with quantum feedback, governed by a conditional free energy. We further show that this generalized second law is consistent with the traditional second law once the acquisition, processing, and reset of side information are accounted for. These results extend information thermodynamics to the fully quantum regime and provide precise thermodynamic meanings for the negativity of single-shot conditional entropies.

30. Quantum thermodynamics with imperfect Gibbs states

Luke Johns — *Los Alamos National Lab*

Co-authors: Luis Pedro Garcia Pintos (LANL), Joseph Lukens (Purdue), Christos Gagatsos (Arizona)

This presentation will show how fundamental principles of equilibrium quantum thermodynamics are qualitatively modified by imprecision in controlling a thermal state's Hamiltonian and temperature. Modeling thermodynamic processes as sequences of quenches and equilibrations, we will see that finite time and precision entail competing contributions to entropy production. As a result, reversibility is maximized neither by taking infinitely many steps nor by steering along a geodesic path of Gibbs states, unlike in noiseless thermodynamics. We will use concrete examples to relate these findings to the Landauer bound on quantum information erasure and the Carnot limit on quantum heat engines.

31. Measurement-Induced Entanglement Phases in Hyperbolic Gauge-Higgs Models

Cole Kelson-Packer — *University of New Mexico*

Co-authors: Hiroki Sueno (UNM), Akimasa Miyake (UNM)

Gauge theory and Higgs condensation lie at the heart of quantum many-body physics. On the other hand, non-Euclidean lattices are known to host novel phases of bond percolation models and underlie quantum error-correcting codes with intriguing properties. We study the entanglement phases of gauge-Higgs models on hyperbolic lattices described by measurement-only dynamics. We chart 2D phase diagrams employing topological entanglement entropy and a form of measurement-induced entanglement on the boundary. Our setting exhibits a phase absent in Euclidean space, wherein the bulk lattice hosts separated clusters of both intrinsic and symmetry-protected topological entanglement. Transitions between this "archipelago" phase and neighboring topological and trivial phases feature a critical exponent belonging to a mean-field universality class. We derive exact expressions for critical points on our phase diagrams' boundaries by employing a foliated resource state, mapping the spacetime "sponges" contained therein to classical percolation theory. Finally, we relate phases realized on different lattices via a Kramers-Wannier-type duality.

32. Randomized product formulas beyond optimal deterministic scaling

Leeseok Kim — *University of New Mexico*

Co-authors: Luis Pedro García-Pintos (LANL), Emanuel Knill (NIST)

<https://arxiv.org/pdf/2608.07720>

Product formulas, also known as Trotter formulas, are among the most widely used and practical methods for simulating quantum systems on quantum computers. Here we introduce two new classes of randomized product formulas for simulating Hamiltonians with separated energy scales, $H = A + \alpha B$, where α is small. In the standard access model, where one can implement exponentials of A and B separately, our randomized formulas achieve $\mathcal{O}(\alpha^2)$ error scaling at the cost of only doubling the gate depth of the corresponding deterministic formula. We further prove an $\Omega(\alpha)$ lower bound for deterministic product formulas. In a stronger access model, allowing exponentials of $A + \alpha B_{\ell}$ for $B = \sum_{\ell} B_{\ell}$, our randomized formula, based on

Trotter Heuristic Resource Improved Formulas for Time-dynamics (THRIFT) [J. L. Bosse et al., Nat. Commun. 16, 2673 (2025)], achieves $\mathcal{O}(\alpha^3)$ error scaling with only constant-factor expected gate overhead. We also establish an $\Omega(\alpha^2)$ lower bound for deterministic product formulas in this access model. Numerical simulations confirm gate-count reductions for simulating physically motivated systems.

33. Constructing simple models of noisy stabilizer QEC with leakage

Alex Kwiatkowski — *National Institute of Standards and Technology, Boulder*

As quantum error-correction experiments continue to improve, it will become increasingly important to develop characterization and benchmarking methods that can predict QEC performance from inferred error models or assess it directly in a black-box setting. Prior work by the author and collaborators [arXiv:2509.16887] showed that a stabilizer QEC cycle subject to Pauli noise can be represented as a classical Markov process over syndrome states, with a logical Pauli channel attached to each syndrome transition. Here, we extend this framework to systems in which each physical qubit experiences leakage. We develop the theory of Pauli twirling for leaked qubits and show how it can be used to simplify the error processes arising in stabilizer-code QEC cycles. We then show that a twirled noisy QEC cycle can be represented as a classical Markov process on a joint state space consisting of the syndrome and the data-leakage pattern, with a logical Pauli channel attached to each transition. Finally, we discuss how this formulation of a QEC cycle can guide the design of characterization and benchmarking experiments for stabilizer QEC in the presence of leakage.

34. Adiabatic Inspired Rydberg Gate

Tristan Larkin — *The University of New Mexico*

Co-authors: Ivan Deutsch (UNM), Vikas Buchemmavari (Atom Computing)

High-fidelity entangling gates are an essential component for any gate-based quantum computing platform. State-of-the-art time-optimal neutral-atom gates are designed to use large Rabi frequencies to run fast and counteract the finite Rydberg lifetime, yet their fidelities still fall just short of the threshold required for fault tolerance and are technically challenging to implement. Here we explore a family of gates inspired by adiabatic Rydberg gates whose shape resembles the original adiabatic gate, but takes half the time to implement with the same maximum Rabi frequency. These gates start and end with negligible light shift and their Rabi frequency and detuning functions are parameterized as continuously differentiable, piecewise-parabolic functions. The parameters are fit through numerical optimization of the gate fidelity. We find that, when embedded in a spin echo sequence, adiabatic-inspired gates are notably more robust than the fully adiabatic gate. Using realistic experimental parameters, we show that these gates can achieve fidelities between 0.99 and 0.999 in simulation.

35. Multi-image quantum encryption scheme using blocks of bit planes and images.

Claire Levallant — *Paris*

<https://arxiv.org/abs/2503.23268>

The field of quantum image encryption is only a decade or two old. The state of the art so far relies for the most part on the encryption of a single image, which is put into quantum representation as a superposition of various data encoding the image. A quantum circuit is applied, which scrambles and diffuses the image. In this talk, we rather tackle the encryption and decryption of multiple images, which are treated as a single entity called a multi-image. The goal is namely to encrypt all the images simultaneously, by taking advantage of the massive parallel processing allowed by quantum computers. In what follows, we will call bit plane a plane filled with values 0 or 1 at each pixel position. The intensity at a given pixel position is an integer called pixel value whose binary decomposition provides the bit values on the different bit planes. In multi-image quantum encryption, all the bit values of all the pixel values of all the images get scrambled all together at once. For doing so, we use the quantum baker map which operates on a discretized square, by shuffling in a bijective manner all of its integral points. We do a two-stage scrambling, following one of our previous schemes. First, we scramble the pixel positions. Second, we scramble the images and the bit

planes. For the latter scrambling, we must have an equal number of bit planes and images. In the case when we encrypt a large number of images, we thus need to add many bit planes that are filled with bit values 0. This results in adding extra qubits in the quantum representation for the multi-image. A new idea presented here in order to limit the width of the quantum circuit consists of forming blocks of images instead. Each block contains as many images as there are bit planes. Some qubits are used to represent the blocks, and other qubits are used to represent the position of an image inside a block. We thus save a number of qubits that is logarithmic in the number of images to encrypt. Another novelty of our work is to exhibit a general quantum circuit for the quantum baker map, which can be applied with any value of its parameters. It appears that the quantum circuit complexity is polynomial in the parameters of the quantum baker map. Applied to both cryptographic schemes (the previous one without blocks and the current one with blocks), our results allow for comparison between the depths of the quantum circuits used for the scrambling of the images in each case. For the most secure version of the schemes and in the case of a large number of images to encrypt, the depth of the quantum circuit of the previous scheme is significantly better. However, in the least secure version of the schemes, both the width and the depth of the quantum circuit are bettered with the new scheme. Consequently, the right balance in terms of security on one hand, and storage and computational complexity on the other hand, is yet to be determined and will be the purpose of a forthcoming analysis during a comparative cryptanalysis of both schemes, which will be made possible by running simulations on a classical computer using test images. Our new scheme presents many advantages over pre-existing schemes. A non-exhaustive list of these advantages is the following. The baker map has an easier quantum realization which uses SWAP gates and controlled SWAP gates, versus other geometric transformations, whose quantum implementations are based on quantum arithmetic. Moreover, it has a much longer scrambling period than the Arnold transform that is traditionally used for quantum image encryption. Our diffusion stage is based on generating pseudo-random bits that are derived from running a cascade of a 5D hyperchaotic discrete dynamical system, a sine chaotification of the latter system with an infinite choice of parameters preventing from brute-force attacks, and Chebyshev polynomials with some of their indices depending on the plaintext multi-image thus rendering the scheme robust against chosen plaintext attacks and chosen ciphertext attacks. Our quantum representation is partly inspired from a bit plane representation that was introduced by other authors: instead of using one qubit per bit value on each bit plane, they use qubits to represent the position of the bit plane and one extra qubit to represent the bit value on that bit plane. This quantum representation allows for accurate retrieval of the images by projective measurements. The two problems of finding efficient ways to go from quantum representation to classical representation on one hand, and of diffusing the images without having to use an exponential in the width of the quantum circuit number of controlled CNOT gates on the other hand, should be addressed by taking into account the specificity of each quantum computing approach.

36. Toward On-Chip Terahertz Readout of Molecular Spin Qubits

Junzhe Liu — *Vanderbilt University*

Molecular spin qubits offer atomically precise, chemically engineered spin Hamiltonians, making them attractive platforms for quantum sensing. A central obstacle is reading out these qubits when their operating transitions lie at terahertz frequencies, beyond the reach of standard microwave hardware. We are developing an on-chip cavity platform to detect — and ultimately coherently address — the 0.901 THz zero-field-splitting transition of the high-spin molecule $\text{CoCl}_2(\text{PPh}_3)_2$. Because this is a weak magnetic-dipole transition of a low-conductivity molecular flake, detection requires concentrating the terahertz field into a sub-wavelength coplanar-stripline gap and resonantly enhancing the response with a plasmonic cavity. We present electromagnetic simulations and an analytical cavity model that quantify the achievable enhancement, its quality-factor limits, and the feasibility of resolving the spin transition. These results establish the device parameters for resolving the collective spin response of a molecular flake — a necessary step toward single-spin addressability in the terahertz domain and high-frequency quantum sensing with chemically tunable spins. Fabrication and measurement are underway.

37. Measurement-Dependent Ensemble Averages in Nonlinear Open Systems

Isaac Lund — *Carleton College*

Co-authors: Alex Gran (UNM), Arjendu Pattanayak (Carleton), Raymond Simmonds (NIST/CU Boulder), Emanuel Knill (NIST)

Quantum backaction from weak measurement affects quantum dynamics, and it is possible to find a strong dependence on measurement choice for individual unravelings of various open system quantum trajectories. Furthermore, this dependence can be shown to exist even in ensemble averages over trajectories IFF the averaged quantities are nonlinear in the wavefunction (generically known as Quantum Trajectory Averaged Variances or QTAVs). In one such system, the post-processing choice of phase ϕ for a local oscillator (LO) laser used in the homodyne measurement changes the form of the energy dissipation via the nonclassical spread variables. This can significantly change the energy absorbed, the size of these spread variables, and hence alter or enhance quantum effects. We report on a study of the strong phase dependence of these ensemble averages, and comment on experimental implementations and implications.

38. Simultaneous Intensity and Frequency Control for Optical Waveform Generation using an Acousto Optic Modulator

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Co-authors: Shengzhi Wang (UNM), F. Elohim Becerra (UNM)

Precise control of optical fields is essential for diverse applications in optics [1], atomic physics [2] and quantum processing [3]. Acousto and electro-optic modulation provides a tool for high bandwidth control of power, frequency, phase, and spatial degrees of freedom of optical beams [4]. Specifically, acousto-optic modulators (AOMs) provide a simple solution for high bandwidth optical modulation with high optical damage thresholds [5]. We present a calibration method that enables precise simultaneous control of intensity and frequency of an optical field based on an AOM, without requiring a detailed physical model of the modulator response. As an initial step, the method characterizes the nonlinear optical response of the AOM by measuring the intensity of the first-order diffracted beam as a function of the applied radio-frequency (RF) signal. The frequency-dependent diffraction efficiency is then measured over the desired frequency tuning range, and a reciprocal correction waveform is generated and iteratively refined to correct for the nonlinear AOM's response.

Using standard laboratory components and direct optical-power measurements, we suppress the intensity variations that ordinarily accompany broad AOM frequency sweeps. In both single-pass and double-pass configurations, the method reduces the residual intensity variation to below 1% over a frequency range 50-100 MHz, with a relative standard deviation of approximately 0.2% after convergence.

Beyond constant-intensity frequency sweeps, our method for calibrating the AOM response enables the generation of programmable optical waveforms with prescribed temporal intensity and frequency profiles. The approach requires only standard equipment common in many laboratories in optics and photonics, and atomic physics, making it readily adaptable to existing experiments. This method provides an accessible route to reproducible optical waveform synthesis for quantum control, atomic spectroscopy, precision measurements, and other applications requiring high-accuracy simultaneous control of optical amplitude and frequency.

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39. Building an optimized optical coherent-state receiver based on photon counting at telecom wavelengths.

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Conventional Homodyne and Heterodyne measurements are bound by their specific Shannon Limit for classical information capacity. These limits impose an energy efficiency ceiling for information transmission. Optical communication schemes with coherent states based on optimized photon-counting receivers are a promising route for increasing rates of information transmission beyond the conventional Shannon limits of homodyne and heterodyne measurements [1,2,3]

High-efficiency Superconducting Nanowire Single-Photon Detectors (SNSPDs) and high-bandwidth FPGA real-time feedback and control can be leveraged for building high efficiency optimized non-Gaussian receivers allowing for optimized communication schemes. These receivers generally use high bandwidth amplitude and phase modulators to adaptively optimize information gain based on displacement operations conditioned on photon counting measurements. Optimized dynamical displacements are constructed via numerical optimization of a cost function relating to a target metric. For example, one can maximize mutual information for information capacity.

We are working on the development of an optimized receiver based on photon counting at 1550 nm using electro-optic modulators (EOMs), with custom electronics for high-bandwidth feedback, and with absolute optical powers traceable to NIST standards. (1) We use EOMs to modulate both phase and amplitude of an input signal and local oscillator for extremely precise control of optical displacements. (2) To drive the EOMs are custom high-bandwidth electronics built to process complex dynamical displacement operations. (3) For optical measurements, we use a high-efficiency SNSPD with a calibration traceable to NIST. These elements will enable a high-bandwidth photon-counting telecom receiver for a wide range of applications in quantum communications.

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40. Improving Experimental Designs in Trapped Ion Experiments

Marcel Mazur — *NIST Boulder, University of Colorado Boulder*

Co-authors: Manny Knill (NIST), Scott Glancy (NIST), Alex Kwiatkowski (NIST), Shawn Geller (NIST), Italo Bezerra (UECE)

The motional states of trapped ions can be used as resources for quantum information protocols. In such protocols, it is often necessary to estimate properties of the underlying motional states. In this work, we examine how C-optimal design theory can be used to improve the estimation of parameters of interest associated with trapped-ion motional states. In the experiments we consider, the ion's motional state is coupled to its internal spin state by applying laser pulses on the carrier, blue sideband, or red sideband. The probability of measuring the ion in the spin-up state after a laser pulse of a given duration depends on the Fock-state distribution of the motional state. Parameters of interest are inferred from the spin-up probability as a function of laser pulse duration. We show that applying C-optimal design theory to the selection of laser pulse durations can improve the estimation of Fock-state populations, parity, fidelity, and, for Gaussian motional states, Gaussian-state parameters.

41. Modifying a SERF magnetometer to act as a source of highly polarization-squeezed light

Blues McMahon — *Miami University*

Co-authors: Mercy Wesonga (Miami), Reese Tyra (Miami), Andy Zabinski (Miami)

Off-resonant Faraday rotation of atomic spins is frequently utilized as a means of measuring atomic spin polarizations in a dense vapor, with a detection-sensitivity limited only by photon shot noise. For optically thick samples, the achievable photon shot noise sensitivity can be below the fundamental limits set by quantum projection noise. By analyzing the relationship between photon shot noise and quantum projection noise, we show that projection noise limits are reached when many photons are produced for each measured spin, and that the photon shot noise exhibits Heisenberg scaling, $1/N$ with atom number N , despite the absence of entangled or squeezed atoms or photons. Further, by mapping the quantum polarization fluctuations of the light onto effective magnetic field fluctuations via the AC Stark effect, we show that we may create highly polarization-squeezed light in a narrow frequency band from near-dc to about 1 kHz [1], which is the frequency range where spin-exchange-relaxation-free (SERF) magnetometers operate. Experimental progress toward the twin goals of QND detection of the collective spin state and creation of a polarization-squeezed light beam is described.

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42. Delayed Quantum Dynamics of Three-Level Atoms Coupled to an Optical Nanofiber

Jose Luis Meza Cabañas — *Universidad Nacional Autonoma de Mexico*

Co-authors: Miguel Castillo-Celeita (UNAM), Pablo Barberis Blostein (UNAM), Ivan Deutsch (UNM)

Most theoretical descriptions of waveguide quantum electrodynamics rely on the Born and Markov approximations, neglecting the finite propagation time of photons between spatially separated emitters. However, these approximations

become inadequate when the propagation delay is comparable to the characteristic timescales of the atomic dynamics, giving rise to non-Markovian effects and retardation-induced correlations. In this work, we study the quantum dynamics of two three-level atoms coupled through the guided modes of an optical nanofiber within the single-excitation manifold. By explicitly incorporating the finite photon propagation time between the emitters into the Schrödinger equation, the resulting dynamics are governed by delay differential equations that describe photon-mediated interactions beyond the Born–Markov regime for open quantum systems.

This two three-level atoms system model provides a foundation for future investigations of retardation effects in multi-level waveguide QED, with potential applications to quantum memories and quantum information processing. Future extensions to the two-excitation manifold will enable the investigation of photon-mediated processes and more complex quantum information protocols.

43. An error-corrected single-qubit photonic quantum memory

Manuel H. Muñoz-Arias — *Sandia National Laboratories*

Co-authors: Kevin Randles (Sandia), Kevin Thompson (Sandia), Mohan Sarovar (Sandia)

Consecutive quantum teleportation steps can be used to construct single-qubit quantum memories. In this work we study their realization in discrete-variable photonic quantum information, where dual-rail qubits are the fundamental units of quantum information. Within this modality, at each protocol step a successful fusion measurement between the information qubit and one qubit of an entangled Bell pair teleports the quantum information to the remaining qubit. As photons are susceptible to loss and fusions are probabilistic, the successful operation of the memory for several teleportation steps is highly unlikely. We thus introduce a fully-encoded version of the memory, which is based on two separate innovations: 1. a streamlined protocol for the preparation of encoded Bell-states within the QEC code of our choice, and 2. the identification of perfect strategies for logical fusions for said code. Such perfect strategies lead to an exponential suppression of the logical fusion failure rate with the number of physical qubits in the code. Within a lumped loss model for all the optical components, we derive exact analytical expressions for three figures of merit: a. the success probability after k memory steps, b. the fidelity of the teleported state, and c. the average number of steps before encountering the first nonsuccess. In all three cases we explicitly delineate the parameter regime where the encoded protocol offers an improvement over the unencoded counterpart.

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44. Flood of multipartite Rains entanglement

Hailey Murray — *Cornell University*

Co-authors: Sagnik Bhattacharya, Marco Cerezo (LANL), Liuke Lyu, Mark Wilde (Cornell)

<https://arxiv.org/abs/2608.11406>

Multipartite entanglement admits phenomena such as the activation of genuine multipartite entanglement (GME) and the existence of inequivalent classes of entanglement, and existing bipartite entanglement measures have no unique generalization to this regime. In this work, we define the Rains, monsoon, hurricane, and squall entanglement as generalizations of the bipartite Rains relative entropy, and we establish various properties of these entanglement measures. We also prove that the Rains entanglement is monotone under selective quantum operations that completely preserve the positivity of the partial transpose. We establish single-letter upper bounds on the one-shot and asymptotic rates at which a fixed pure state can be distilled from an arbitrary state in both the standard and probabilistic approximate distillation scenarios. Among the entanglement measures we define, the tightest upper bound on the one-shot pure-state distillation rate is in terms of the Rains entanglement. However, the activation of GME (or, equivalently, the tensor instability of biseparability) makes it unclear if the one-shot bound in terms of the Rains entanglement can be extended to a single-letter asymptotic bound. Instead, we establish upper bounds on the asymptotic pure-state distillation rate in terms of the hurricane and squall entanglement. Upper bounds on the GHZ- and W-distillable entanglement follow as a consequence. Additionally, we define the multipartite max-Rains entanglement, write it as a semidefinite program, and derive a dual program for it. Finally, we analyze these measures for quantum pairwise independent networks, and we establish a conditional gradient (Frank-Wolfe) algorithm for computing the Rains entanglement.

45. All Optical Control of Nuclear Spin Qudits in ^{87}Sr for Quantum Information Processing

Omar Ibna Nazim — *University of New Mexico*

Co-authors: Vikas Buchemmavari (Atom Computing), Enrique A. Segura Carrillo (LANL), Michael Martin (LANL), Scott Glancy (NIST), Emanuel Knill (NIST)

Qudits offer an alternative to qubit-based quantum information processing, providing higher information density and reduced circuit complexity along with potentially novel approaches to quantum error correction and fault tolerance. The nuclear spin in the ground state of ^{87}Sr has a ten-level nuclear spin with long coherence times, making it well-suited for encoding a ten-level qudit. In this work, we propose an all-optical control scheme using vector and tensor

light shifts on the ground manifold. The light shifts are induced by polarized optical fields coupling the ground manifold to the 3P1 manifold via the hyperfine interaction. Compared with previously proposed magnetic control, which is limited in speed by field strength and bandwidth, optical control enables fast manipulation of the full ten-level manifold. We establish controllability of the ground manifold, demonstrate state preparation and unitary synthesis using quantum optimal control methods, and examine the effect of decoherence on the achievable fidelity. We also derive analytical estimates of the quantum speed limit for state preparation using the Majorana stellar representation and validate the estimates numerically. Our results establish ^{87}Sr nuclear-spin qudits as a promising platform for neutral atom quantum information processing.

46. Estimating Green's functions with a robust quantum Arnoldi method

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Co-authors: Andrew Baczewski (Sandia), Niklas Mueller (UNM)

<https://arxiv.org/abs/2605.22920>

Many applications of Green's functions (GFs) require their evaluation over intervals or at multiple points, motivating quantum algorithms that return an efficiently computable functional representation rather than mere point estimates. We introduce a robust quantum Arnoldi method (ROQAM) that achieves this goal. Its robustness is derived from formulation in terms of orthogonal polynomials, which preserves the upper-Hessenberg structure of the projected matrices despite finiteprecision estimation. We also show that as the iteration depth increases, the precision required for matrix-element estimation can be reduced. Resource estimates for the spectral function of a quantum impurity model indicate that ROQAM outperforms pointwise estimation via quantum singular value transformation by multiple orders of magnitude. Finally, we show that the ROQAM can be used to estimate GFs at nonzero temperatures using only a single Krylov subspace.

47. Low-Depth Circuit Formulation for Projective Quantum Eigensolvers

Kayley Nielsen Arauz — *Cal Poly*

Co-authors: Nicholas H. Stair (Cal Poly)

Projective quantum eigensolvers (PQEs) determine molecular and material ground-state energies by solving the time-independent Schrödinger equation through iterative updates of parameters in a unitary circuit. Here, we formulate PQE using particle-number- and projected-spin-conserving circuits constructed from simple Givens rotations. These symmetry-preserving (SP) circuits have lower circuit depth than the unitary coupled-cluster (UCC) circuits considered in prior PQE studies. We derive parameter-update equations for the SP ansatz using Jacobi rotations within a set of two-determinant subspaces to satisfy the PQE residual conditions. For several small molecular systems, the resulting symmetry-preserving PQE method (SP-PQE) converges to chemically accurate ground-state energies comparable to those obtained with UCC-PQE. We further show that applying the Jacobi subspace-rotation update to UCC-PQE yields faster convergence than the quasi-Newton update introduced in prior work.

48. Efficient Quantum Error Mitigation for Unitary k-Designs

Ayush Pancholy — *University of California, Berkeley*

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<https://arxiv.org/abs/2606.03891>

Quantum circuit ensembles that have the properties of unitary k-designs represent applications where there is no obvious bias toward any particular Pauli support, as is the case in simulating systems exhibiting "quantum chaos," which range from quantum dynamics near black holes to gapless spin fluid analysis. However, noisy hardware makes quantum circuits prone to a myriad of error sources, of which depolarizing and coherent error can be particularly destructive. To combat depolarizing error, popular techniques typically involve circuit or gate folding, which can be time-intensive procedures due to increased circuit depth and shot overhead. Other tensor-network-based mitigation techniques suffer from intractability in high-entanglement regimes. In this work, we leverage the structure of unitary

k-design Pauli support distributions by introducing a technique we name "circuit balancing," along with gate benchmarking data, in order to estimate circuit-wide depolarization. We describe how to invert the diagnosed circuit depolarization even in the presence of coherent error, via Pauli twirling. We provide asymptotics to estimate the number of twirls needed to maintain a desired output fidelity. We test our method numerically in a variety of simulation settings and find that it can significantly reduce average random circuit infidelity. Further, we employ our methods to find significant infidelity reductions when running a random circuit ensemble on a contemporary superconducting quantum computer, IBM Fez. Overall, we show that the method effectively reduces gate-based error for unitary k-designs without incurring any two-qubit gate overhead.

49. Inversion Interferometry for quantum-inspired super-resolution in optical microscopy

Sujeet Pani — *University of New Mexico*

Co-authors: Sheng Liu (Clemson), Diane Lidke (UNM), Keith Lidke (UNM)

Resolving point sources with high precision is a central task in diverse fields including astronomy, biology, and microscopy. Recent works in optical imaging have shown that measurements based on modal imaging, in which the field is decomposed into an optimal set of spatial modes prior to detection, enable resolving point sources with a precision approaching the quantum limit, quantified by the Quantum Cramér-Rao Bound (QCRB) [1]. Super Localization via Image inVERsion interferometry (SLIVER) realizes a near-quantum optimal measurement through a spatial parity decomposition of the input field, effectively sorting the field into its symmetric and antisymmetric components. This simple measurement provides a practical method for resolving two incoherent point sources with precision approaching the QCRB in the limit of small separations [2]. This capability is important for single-molecule fluorescence microscopy, where this measurement could enable real-time tracking of protein-protein interactions in specific biological processes. Realizing this high-precision measurement for sources such as broadband fluorophores used as tags in optical microscopy, requires investigating the critical parameters that can limit the performance of such a near-optimal measurement. These parameters include the dipolar nature of fluorophore radiation and the interferometer stability required for real-time and continuous measurement.

We study the problem of super-resolution imaging of dipole sources by extending the previous idealized study of scalar sources [1] to a full vectorial description and find that the dipolar emission significantly degrades the precision of the ideal SLIVER measurement at small separations. To recover the measurement advantage, we introduce POLAR-SLIVER, a modification of the measurement scheme that uses a vortex wave plate to decouple the radial and azimuthal polarization components of the dipole field before interferometric sorting [3]. While this modified measurement does not saturate the QCRB associated with the vectorial state of the sources, which differs from that of idealized scalar fields, it provides non-divergent precision at any separation and remains robust under realistic experimental conditions. We also investigate the phase stability of the image inversion interferometer required for implementing this measurement with broadband, temporally incoherent sources. Such an implementation demands operation at or near zero optical path-length difference with high interference visibility. We demonstrate an image-based phase-locking scheme in which an auxiliary counter-propagating laser generates spatial interference fringes, and the interferometer phase is extracted in real time through Fourier-domain analysis of the recorded interferograms, allowing stabilization at any phase set point within $[0, 2\pi)$ [4]. Together, these advancements can provide a path towards achieving near-optimal precision in super-resolution microscopy for imaging biological samples. Our current work focuses on the integration of the SLIVER measurement with a single-molecule fluorescence microscope for real-time, near-quantum-limited imaging of fluorescent biological samples.

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50. Non-adiabatic Regimes of Continuous Qubit Measurement

Cory Panttaja — *Schmid College of Science and Technology, Chapman University*

We model the entangled state evolution of a monitored readout resonator coupled to a quantum bit (qubit) in a superconducting circuit subject to control and readout drives. Modern superconducting devices for quantum computation use driven microwave resonators to indirectly read out the states of neighboring qubits. For slow qubit dynamics compared to the resonator decay rate, the resonator pointer states adiabatically follow the qubit states. Using a stochastic non-Hermitian Hamiltonian approach, we numerically explore more challenging regimes that involve faster qubit dynamics and demonstrate several nontrivial non-adiabatic effects, such as a tilted measurement axis with reduced rate.

51. Three-Dimensional Neutral-Atom Architectures for Quantum Error Correction

Maxwell Parsons — *University of Washington*

Co-authors: Kevin Wu (UW), Ohik Kwon (UW), Aarjav Jain (UW)

We present early progress toward fault-tolerant quantum error correction using a native three-dimensional (3D) neutral-atom architecture. Fault-tolerant quantum computing is bottlenecked by the physical-qubit overhead of error correction. For stabilizer codes with geometrically local interactions in two dimensions, the Bravyi-Poulin-Terhal (BPT) bound forces a tradeoff between rate and distance ($kd^2 \leq O(n)$), pushing planar processors toward low-rate codes with thousands of physical qubits per logical qubit. A third spatial dimension relaxes this bound to $kd \leq O(n)$, offering a factor of $\sim d$ fewer physical qubits at fixed rate and distance — a saving that grows with the very distance needed for stronger protection. Beyond the BPT argument, we show that a third dimension also improves the physical implementation of a non-local code, by shortening the atom transport that nonlocal syndrome extraction requires. We illustrate this with the $[[144,12,12]]$ bivariate bicycle QLDPC code: comparing planar and native 3D embeddings on a common neutral-atom hardware and noise model, the 3D embedding achieves $\sim 4\times$ smaller planar logical qubit footprint and roughly halves the syndrome-extraction cycle time, with fewer movement operations and shorter transport distances.

Realizing these advantages requires controlling the geometry of a third dimension as cleanly as we control a plane. We also describe experimental progress toward three-dimensional trapping of neutral-atom registers in geometries optimized for error correction and prospects for holographic local gate control in 3D.

52. Onset of Melting in Finite Ion Crystals: The Role of Structural Isomerization

Boris Pashinskii — *University of Washington*

Co-authors: Boris Blinov (UW), Alex Kato (IonQ), Sourin Das (IISER Kolkata), Namit Anand (HPE)

We investigate the microscopic mechanism of melting in finite two-dimensional ion crystals confined in anisotropic traps. Building on our previous studies of melting probability as a function of temperature and anisotropy, we extend the analysis to crystal sizes ranging from $N=4$ to $N=101$ ions and examine how structural isomerization modifies melting pathways. Using molecular dynamics simulations together with Metropolis-Hastings equilibrium sampling, we analyze radial fluctuations, angular disorder, Lindemann parameters, and isomer-dependent energy landscapes. We find that crystals with identical particle number may exhibit substantially different melting behavior due to changes in shell structure and effective confinement geometry. Contrary to a simple soft-mode instability picture, the observed melting process is characterized by a gradual thermally driven accumulation of radial and angular disorder. Structural isomerization reshapes the fluctuation channels through which delocalization develops, leading to nonuniform melting probabilities across temperature and anisotropy space. These results provide a unified microscopic picture of melting in finite ion crystals and clarify the role of structural rearrangements in finite-size phase transitions.

53. Topological superconductivity in hetero-dimensional nanoscale metamaterials for Majorana-based quantum computing

Purna Paudel — *Department of Physics, The University of Texas at El Paso, El Paso, TX, USA*

Co-authors: François Léonard (Sandia), Joseph Cuzzo (UTEP)

Conventional qubits are susceptible to external noise, causing decoherence and loss of encoded quantum information. In recent years, topological superconducting heterostructures have shown promise as potential platforms for Majorana-based fault-tolerant quantum computation where information is protected by the topology of the system. However, these complex superconducting heterostructures rely on strong spin-orbit coupling (SOC), which is difficult to characterize and constrains the possible materials that can be used. This presents an outstanding challenge for control and scalability of Majorana-based qubits, making it desirable to develop design principles that reduce the reliance on strong SOC. In this talk, we will present robust topological superconductivity in Yu-Shiba-Rusinov (YSR) networks with arbitrarily small spin-orbit interactions. We will demonstrate that YSR networks can support a topological phase hosting chiral Majorana modes in a wide and tunable parameter regime while remaining robust against geometric disorder of the network. Lastly, we will highlight how our approach can lead to a more general experimental strategy leveraging the geometric assembly of nanomaterials to improve quantum devices relying on spin-orbit interactions.

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54. Robustness of Matrix Product State Simulations in Quantum Many-Body Dynamics

Srinidhi Pawar — *University of New Mexico*

The classical simulation of quantum many-body dynamics remains one of the central challenges in quantum computation due to the exponential growth of Hilbert space with system size. Matrix product state (MPS) methods provide an efficient framework for simulating one-dimensional systems. In this work, we investigate the relationship between the complexity of non-equilibrium quantum dynamics and the robustness of MPS truncation by performing quantum quenches in one-dimensional spin models spanning integrable and non-integrable regimes. Our results show that local observables remain remarkably robust well beyond the point at which the global state becomes inaccurate, while the choice of initial state strongly influences the numerical drift of conserved quantities and the overall performance of MPS simulations. Ongoing work investigates how symmetry and the drift of conserved quantities can provide a quantitative predictor for the long-time reliability of MPS simulations and explores connections with quantum thermalization through the Eigenstate Thermalization Hypothesis (ETH), and the Generalized Gibbs Ensemble (GGE), with the broader goal of identifying the boundary between classically tractable many-body dynamics and regimes where quantum advantage becomes necessary.

55. Evaluating the Limits of QAOA Parameter Transfer at High-Rounds on Sparse Ising Models With Geometrically Local Cubic Terms

Elijah Pelofske — *Los Alamos National Laboratory*

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<https://journals.aps.org/prresearch/abstract/10.1103/p2lg-z4kn>

The emergent practical applicability of the Quantum Approximate Optimization Algorithm (QAOA) for approximate combinatorial optimization is a subject of considerable interest. One of the primary limitations of QAOA is the task of finding a set of good parameters. Parameter transfer is a phenomenon where QAOA angles trained on problem instances that are self-similar tend to perform well for other problem instances from that similar class. This suggests a potentially highly efficient and scalable non-variational learning method for QAOA angle finding. We systematically study QAOA parameter transferability from small problems (16, 27 qubits) onto large problem instances (up to 156 qubits) for heavy-hex graph Ising models with geometrically local higher order terms using the Julia based QAOA

simulation tool JuiQAOA to perform classical angle finding for up to 49 QAOA layers. Parameter transfer of the fixed angles is validated using a combination of full statevector, Projected Entangled Pair States, Matrix Product State, and LOWESA numerical simulations. We find that the QAOA parameter transfer from single instances applied to unseen problem instances does not in general provide monotonically improving performance as a function of p - there are many cases where the performance temporarily decreases as a function of p - but despite this the transferred angles have a general trend of improved expectation value as the QAOA depth increases, in many cases converging close to the true ground-state energy of the 100+ qubit instances. We also sample the hardware-compatible Ising models using the ensemble of fixed QAOA angles on several superconducting qubit IBM Quantum processors with 127, 133, and 156 qubits. We find continuous solution quality improvement of the hardware-compatible QAOA circuits run on the IBM NISQ processors up to $p=5$ on `ibm_fez`, $p=9$ on `ibm_torino`, and $p=10$ on `ibm_pittsburgh`.

56. Shot-by-shot calibration of single- and two- qubit gates on a trapped-ion quantum testbed

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As quantum computers scale, methods for calibrating quantum gates to high fidelity that are fast, lightweight, and easy to implement are increasingly desirable. Here, we demonstrate a shot-by-shot protocol for rapid, multiparameter gate calibration and drift control on a trapped-ion quantum testbed. The protocol operates by executing simple quantum circuits whose measurement outcomes provide directional information about underlying control parameter miscalibrations. Control parameter updates are made after

each circuit execution, leading to stochastic dynamics that converge and stabilize, on average and under mild assumptions, to the target calibration point. We experimentally demonstrate this protocol for calibrating single- and two- qubit gates, with shot-by-shot feedback enabled by flexible and low-latency classical control. Results are presented showing the performance against native and injected miscalibration and drift, including for joint, multiparameter tuning of two-qubit Mølmer-Sørensen gates.

57. Gaussian Quantum-Enhanced Quickest Optical Phase Change Detection

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Quickest detection of optical phase changes is crucial for secure quantum communications and real-time calibration of quantum devices. This work investigates how Gaussian quantum-enhanced probes can reduce detection latency. By parameterizing the probe's classical displacement amplitude and two-mode squeezing strength through a single power allocation ratio, displaced two-mode squeezed states are shown to offer significant detection latency advantages compared to purely classical or two-mode squeezed vacuum probes. To realize this theoretical advantage, an approximate

nulling receiver is proposed that asymptotically achieves the fundamental lower bound in latency for the optimal probe. Its superior performance over standard transceivers is demonstrated through simulation of the Cumulative Sum (CUSUM) algorithm under finite power, thermal noise, and optical loss. These results present an end-to-end theoretical treatment of Gaussian quantum-enhanced quickest optical phase change detection, establishing both an optimal Gaussian probe and a receiver that asymptotically saturates its quantum latency bound.

58. Quantifying the Effects of Heralded Multi-Photon Impurities on Fusion-Based Architectures via Pauli Error Mapping

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Fusion-based quantum computation has positioned itself as the modern paradigm of discrete-variable photonic quantum computation (PQC). One of the central challenges in this modality of quantum computation is the production

of indistinguishable and highly pure single photons. State of the art heralded single photon sources, as constructed using spontaneous four-wave mixing, can generate highly indistinguishable single photons. However, imperfect detection on the idler mode will, unavoidably, lead to some level of multi-photon contamination on the heralded signal mode. We show that the effect of photon loss on these multi-photon contributions translates into effective Pauli errors in the dual-rail qubit subspace and leverage this mapping to characterize the relationship between loss and the resulting Pauli error magnitude on several fusion-based PQC primitives, namely, heralded Bell-state generation, memory idling, and type-II fusions.

59. Robust Negativity in the Quantum-to-Classical Transition of Kerr Dynamics

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We quantify the quantum-to-classical transition of the single-mode Kerr nonlinear dynamics in the presence of loss. We establish three time scales that govern the dynamics, each with distinct characteristics. For times short compared to the Ehrenfest time, the evolution is classical, characterized

by Gaussian dynamics. For sufficiently long times, as we increase the initial photon number, unitary Kerr evolution would generate macroscopic superpositions of coherent states (so-called kitten states). However, this is severely restricted in the presence of small photon loss and the expectation values of observables coincide with their classical values. The intermediate time scale, however, shows resilient quantum behavior in the macroscopic limit. We show that in the mean-field non-Gaussian regime, the Kerr Hamiltonian (with small photon loss) generates a significant amount of Wigner-negativity, and classical flow is recovered only if the loss rate grows with system size. Our results broaden the usual understanding of quantum-to-classical transitions and demonstrate the potential for creating robust nonclassical resources for continuous-variable quantum information processing in the presence of loss.

60. Influence of Random Scattering Media on Two-Photon Orbital Angular Momentum Correlations

Carrie Rodriguez — *Institute for Quantum Studies, Chapman University*

Quantum states of light consisting of exactly two photons, or biphoton states, are a fundamental tool for studies and applications in quantum optics, due to the manifestation of various non-classical correlations in all light's degrees of freedom: polarization, time-frequency, and spatial modes. We explore how measuring the spatial properties of biphotons can help us investigate inhomogeneous media interacting with quantum states. In particular, we investigate how Orbital Angular Momentum (OAM) correlations of two-photon states are affected after propagation through a scattering medium, showcasing the creation of realization-specific distributions, deemed "OAM-correlation speckles." We show experimentally and theoretically the effects of a scattering medium on nonclassical correlations in OAM.

61. Permutation-Based Quantum Simulation of Burgers' Equation and Nonlinear PDEs

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We develop a quantum algorithm for the viscous Burgers' equation by combining Carleman linearization with the Permutation Matrix Representation. The lifted generator is decomposed into diagonal operators and reversible arithmetic permutations, enabling its direct use within the Linear Combination of Hamiltonian Simulations framework. Unlike generic approaches whose cost depends on the full generator norm, our complexity scales with its off-diagonal norm, offering an advantage for diagonally dominant discretizations. The same construction extends to nonlinear PDEs with higher-order derivatives, multiple fields, and multiple spatial dimensions, positioning PMR as a broadly useful primitive for quantum simulation of nonlinear dynamics.

62. Efficient simulation of IQP circuits with amplitude-damping noise

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<https://arxiv.org/abs/2604.05036>

Efficient classical simulation of noisy intermediate-scale quantum (NISQ) circuits has been a topic of intense study over the past few years. The majority of results on efficient simulation assume that the circuits undergo some variant of `\textit{unital noise}` or involve sufficient `\textit{randomness}`. However, there are limited results for circuits undergoing non-unital noise in the absence of randomness. In this work, we present a polynomial-time classical algorithm to sample from the output distributions of amplitude-damped instantaneous quantum polynomial (IQP) circuits. Our algorithm works for circuits generated by arbitrary ℓ -local diagonal gates with depth $d = \Omega(\log(n))$, undergoing constant amplitude-damping noise.

63. Benchmarking QEC Rounds using Memory Experiments

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As quantum computing enters the early fault-tolerant era, quantum hardware platforms are beginning to realize error-corrected logical qubits. This progress creates a need for characterization and benchmarking methods that remain economical as systems scale. Characterizing every physical qubit individually becomes computationally infeasible at larger code sizes, motivating techniques that directly probe logical qubit performance.

We introduce an explicit procedure for directly characterizing logical qubits using memory experiments together with a robust analysis framework. We demonstrate the procedure on a small stabilizer code implemented with two distinct quantum error-correction schemes, both revealing decoder-dependent effects as well as illustrating its ability to extract effective logical error dynamics under different correction protocols.

We further show that, despite the presence of memory effects in the underlying dynamics, the resulting error process can be approximated by an effective Markovian channel acting only on the logical degrees of freedom. This representation avoids the need to explicitly model the additional syndrome degrees of freedom while retaining an accurate description of the logical-qubit evolution. These results provide a scalable framework for characterizing and benchmarking logical qubits as error-corrected quantum processors continue to grow in size and complexity.

64. An Analysis of Commutation-Based Trotter Ordering Strategies on Heisenberg-Style Hamiltonians

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The ordering of Hamiltonian terms can substantially affect the accuracy of product-formula quantum simulation. We study a structured family of Trotter orderings obtained by coloring a Pauli commutation graph, keeping each commuting color class contiguous, and permuting the resulting blocks. Although commuting-fragment product formulas are established in the Hamiltonian-partitioning literature, we focus on the ordering space induced by a fixed partition and compare block-contiguous orderings with term-interleaving, magnitude, lexicographic, and random baselines. We prove simple coloring results for non-mixed and one-dimensional Heisenberg-style Hamiltonians and evaluate first- and second-order formulas on one- and two-dimensional spin systems up to 20 qubits. The results show that the partition, block permutation, Trotter order, and lattice geometry jointly determine fidelity; minimizing the number of commuting groups alone is not sufficient. These results characterize a compact, physically structured candidate space for AI-assisted Trotter-order selection and explain why context-dependent learned selection can outperform a single fixed heuristic.

65. Stabilizer-Based Qudit Entanglement Distillation for Non-Prime Dimensions

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Co-authors: Theresa Lynn (Harvey Mudd)

A class of entanglement distillation protocols uses stabilizer code formalism to detect, and correct, specific groups of errors affecting a bipartite maximally entangled target state. Due to the reliance on underlying algebraic structure, these protocols are typically restricted to qudits whose dimension d is a prime or prime power. We present a multi-pair stabilizer-based entanglement distillation protocol for qudits of arbitrary dimension. Our protocol is an extension of the FIMAX distillation protocol developed by Popp et al. (2025) which corrects Bell-diagonal states. In the case of non-prime d , we rely on a restricted set of stabilizer generators which allow the construction of equidimensional codespaces with intuitive canonical encodings. This allows for the creation of a generalized entanglement distillation protocol for any set of Bell-diagonal states. We present theoretical performances of two-pair distillation schemes across a variety of different d . Additionally, we explore multi-pair schemes and how the achievable fidelity depends on both the number of the pairs and the number of stabilizer generators.

66. Complete Characterization of Optimal Fusion strategies and Genericity of Perfect Strategies

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Logical fusions are important for a variety of tasks in quantum information, including quantum error correction and quantum repeaters. In the photonic setting, one must contend with the fact that physical fusions are probabilistic: with probability one half, the associated qubits are measured in product bases. Depending on which fusions fail and on the corresponding measurement bases, these physical failures can induce a failure at the logical level. The choice of failure basis for each qubit is known as a fusion strategy, and identifying good fusion strategies is essential for optimizing the performance of fusion-based quantum computation.

Here, we provide a complete characterization for the case in which $k=1$ qubits are encoded. In particular, we characterize the codes and fusion strategies for which all but one physical fusion can fail while still yielding a successful logical fusion; we refer to these as *perfect fusion strategies*. In doing so, we recover previously known perfect fusion strategies and identify perfect fusion strategies for quantum parity-check codes, answering an open question. We further show that perfect fusion strategies are generic: random $[n,1,d]$ graph codes admit a perfect fusion strategy with probability exponentially close to one.

67. Amplification of bosonic interactions through squeezing in the presence of decoherence

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We consider the amplification of bosonic interactions through parametric control that implements squeezing along orthogonal quadratures. We show that bosonic interactions described by certain classes of quadratic and quartic Hamiltonians can be enhanced in this way while simultaneously overcoming noise and decoherence. In general, the amplification method enhances both desired and undesired interactions present in the system. Depending on the case, however, detrimental processes can be less amplified than the desired couplings. We leverage this observation to improve the fidelity for preparing Bell-type entangled states between two bosonic modes in the presence of noise and losses. We also investigate noise models for which the protocol either fails or partially achieves a noise-tolerant state preparation speedup. Our work facilitates faster preparation of complex quantum states and implementation of entangling gates in the presence of decoherence mechanisms.

68. Robustness-Runtime Tradeoff for Quantum State Transfer

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<https://arxiv.org/abs/2602.22312>

Quantum state transfer is the primitive of transporting an unknown state on one site of a lattice to another. Using power-law interactions, recent state transfer protocols achieve speedup by utilizing the intermediate ancilla sites. However, these protocols require the ancillas to be in a perfectly initialized state, which, due to noise or imperfect control, may not be the case. In this work we introduce the robustness of a state transfer protocol, which quantifies the protocol's tolerance to error in the initial ancilla state. In the Heisenberg picture, state transfer grows operators supported on the final site such that they no longer commute with all operators on the starting site. We prove that robustness tightly bounds the Schatten p -norms of these commutators between initial and final-site operators. This generalizes the known cases of infinite p and $p = 2$, which govern completely state-dependent and state-independent state transfer respectively, demonstrating that intermediate values of p govern partially state-dependent state transfer. In conjunction with existing power-law light cones, our result gives new minimum runtimes for partially state-dependent protocols which, in certain regimes, are parametrically better than existing bounds. We introduce new robust state transfer protocols, charting the landscape between complete state-dependence and state-independence.

69. Thin-Film Optical Coatings

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Thin-film optical coatings are stacked layers of materials with different refractive indices. They control how light interacts with a surface by reflecting light or transmitting light. Optical coatings improve performance in optical components such as telescopes, lenses, optical filters, electronics, lasers, and more, by reducing unwanted reflection, increasing necessary reflection, increasing light transmission, or blocking out certain wavelengths to get a specific optical response. Optical coatings are important for quantum optical systems. Specialized coatings are needed for non-standard wavelengths in the infrared, often with multiple wavelengths being used at a time. These systems have high transmittance requirements because any optical loss can be detrimental to quantum states. The high costs and large batch sizes of commercial coatings are troublesome for rapidly growing quantum optics research. Here, we show a deposition recipe for titanium dioxide and silicon dioxide layered thin-film coatings, which are popular for anti-reflection coatings and various lenses and filters with a large transparency window. On the other hand, highly reflective coatings formed with the recipe are useful for optical cavities, which are used to increase light interaction with nonlinear media used for photon pair sources. We use high-temperature electron beam deposition to deposit the coatings, which is a fast process suitable for small batches. Inside the deposition chamber, a beam of electrons is used to heat and evaporate the sample material, in a vacuum, at a high temperature before the evaporated atoms condense and form a thin-film coating on the substrate mounted inside the chamber. We characterize the coatings using ellipsometry. The ellipsometry data is used to model the coating's optical properties and calculate its reflectance. The layers are simulated and optimized. This allowed us to create test pieces for anti-reflective coatings showing high transmission - highly reflective mirrors and dichroic mirrors, which we now employ in our own quantum optics experiments. These thin-film optical coatings improve quantum information technology by improving optical components that in turn control how light is stored and moved.

70. Hamiltonian and double-bracket flow formulations of quantum measurements

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<https://iopscience.iop.org/article/10.1088/1361-6633/ae6fe9>

We introduce a framework that unifies quantum measurement dynamics, Hamiltonian dynamics, and double-bracket (DB) gradient flows. We do so by providing explicit expressions for stochastic Hamiltonians that produce state dynamics identical to those that happen during continuous quantum measurements. When such dynamical processes are integrated over sufficiently long time intervals, they yield the same results and statistics as during wavefunction collapse. That is, wavefunction collapse can be interpreted as coarse-grained (stochastic) Hamiltonian dynamics. Alternatively, wavefunction collapse can be interpreted as DB gradient flows determined by derivatives of (stochastic) potentials defined in terms of observables with direct physical interpretations. The gradient flows minimize the variance of the monitored observable. Our derivations hold for general monitoring described by non-Hermitian jump processes. We show that such reinterpretations of measurement dynamics facilitate the design of feedback processes. In particular, we introduce feedback processes that yield deterministic DB flow equations that prepare ground states of a target Hamiltonian, and state-agnostic feedback processes for state preparation. We apply the latter for entanglement stabilization of a two-qubit system considering a setup with imperfect measurements and feedback delay. We conclude by re-interpreting feedback processes as gradient flows with tilted fixed points.

71. A High-Optical-Depth Atomic Ensemble for Measurement-Backaction-Induced Spin Squeezing

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Atomic ensembles are a promising platform for quantum metrology. Their strong and light-matter interactions can enable the generation of collective atomic quantum states, such as spin squeezed states, enabling measurements beyond the standard quantum limit [1]. We are currently working on the development of an atomic physics platform based on a cold Cs atomic ensemble for the preparation of spin squeezing in the collective clock-state pseudospin in the ground-state manifold based on dispersive birefringent light-atom interactions [2]. Our platform is based on a high optical depth atomic ensemble to enhance the coupling strength between light and atoms [3]. We will use quantum measurement backaction to generate the spin squeezing, which will be implemented by measuring the phase shift experienced by an optical probe field interacting with the atoms via balanced homodyne polarimetry.

We are currently upgrading our experiment focusing on three key elements. (1) We will use a closed-loop feedback system to accurately control the quadrupole magnetic fields for laser cooling and atomic-ensemble compression with fast switching. (2) We are constructing a crossed far-off resonance optical dipole trap (FORT) to increase atomic density, reduce atomic motion, and extend atom-light interaction time. (3) We are developing an ultra-low phase-noise microwave source for the coherent manipulation of the atomic qubit. These upgrades will enhance the robustness and stability of our platform for the generation, control, and detection of spin-squeezed atomic states.

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72. Weighted Nested Commutators for Scalable Counterdiabatic State Preparation

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Co-authors: Jialiang Tang, Xi Chen

<https://arxiv.org/abs/2603.25625>

Counterdiabatic (CD) driving enables efficient quantum state preparation, but it requires implementing highly nonlocal adiabatic gauge potentials (AGP) that are impractical to compute and realize in large many-body systems. We introduce a weighted nested-commutator (WNC) ansatz to approximate AGP using local operators. The WNC ansatz generalizes the standard nested-commutator ansatz by assigning independent variational weights to commutators of local Hamiltonian terms, thereby enlarging the variational space while preserving a fixed operator range. We show that the WNC ansatz can be efficiently optimized using a local optimization scheme. Moreover, it systematically outperforms the nested-commutator ansatz in preparing one-dimensional matrix product states (MPS) and the ground state of a nonintegrable quantum Ising model. We

then numerically demonstrate that CD driving based on the WNC ansatz significantly accelerates the preparation of 1D MPS for system sizes up to $N = 1000$ qubits, as well as the two-dimensional Affleck-Kennedy-Lieb-Tasaki state on a hexagonal lattice with up to $N = 3 \times 10$ sites.

73. Playing Nonlocal Games with Little to No Shared Randomness

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<https://arxiv.org/abs/2608.07833>

Bell nonlocality reveals correlations that cannot be explained by classical models and plays a central role in quantum information theory. In this work, we investigate classical models of Bell nonlocality under restrictions on shared randomness. For bipartite scenarios with bounded shared randomness, the set of classical correlations becomes nonconvex. We characterize the correlations achievable without shared randomness through the simultaneous evaluation of multiple linear Bell functionals. We then extend our analysis to quantum networks by relaxing the standard assumption of source independence. In this setting, the feasibility constraints derived for the bipartite case can be used to certify source dependence, and we further construct nonlinear inequalities that distinguish classical models with correlated sources from correlations achievable in standard quantum networks. As an application, we show that these nonlinear network inequalities give rise to an entropic Bell inequality for bipartite scenarios with limited shared randomness.

74. Classical Verification of Quantum Advantage via Clifford Obfuscation

Bin Yan — *Visa Research*

Demonstrating quantum advantage in a manner that can be independently verified by classical means remains one of the most pressing open problems in quantum computing. Here we propose a new heuristic approach for constructing quantum circuits that are hard to classically simulate yet whose output distributions can be efficiently verified classically. Our approach is based on Clifford circuit obfuscation. This obfuscation scheme hides the Clifford structure and injects a controlled and rapidly growing non-stabilizer resources that resist known classical attack strategies including reverse engineering and direct simulation. Our protocol is heuristic but is supported by both numerical and theoretical evidence. This work provides a new avenue toward classically verifiable quantum advantage that avoids the stringent implementation requirements of known approaches.

75. Low-Weight Logical-Pattern Suppression for Quantum LDPC Code Discovery

Dayeon Yoo — *University of New Mexico*

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Quantum low-density parity-check (qLDPC) codes are promising candidates for scalable fault-tolerant quantum computation, but identifying finite-size codes with both large distance and low logical-error rate remains a challenging combinatorial optimization problem. Minimum distance alone does not fully characterize practical decoding performance, while repeated decoder-based evaluation of candidate codes can be computationally expensive. We introduce a search framework with two components: a low-weight pattern-suppression principle for guiding code modifications and a computationally inexpensive surrogate objective for screening candidate codes.

For hypergraph-product (HGP) codes, we formulate code discovery as an edge-modification problem on the Tanner graph of a classical LDPC parent code. Candidate edge modifications are targeted to make an identified low-weight undetectable pattern detectable without decreasing the current HGP distance. We rank candidates using an exponentially weighted truncated spectrum of low-weight undetectable parent-code patterns. This spectrum is evaluated exactly up to a prescribed weight cutoff using meet-in-the-middle syndrome matching, which splits the columns into two halves, tabulates partial syndromes by weight, and combines matching syndromes to count zero-syndrome patterns. This avoids repeated noise sampling and BP+OSD decoding during candidate screening. Across sampled candidates, lower scores generally correspond to lower logical-error rates, although final performance is independently verified by decoding.

Using greedy and beam-search strategies, we optimize four HGP code families and obtain codes with parameters $[[625,25,9]]$, $[[1225,49,11]]$, $[[1600,64,12]]$, and $[[2025,81,12]]$, improving previously reported distances of 8, 10, 10, and 10, respectively. Final logical-error rates are evaluated using BP+OSD with 5×10^6 Monte Carlo trials. In our implementation, median greedy-search wall-clock time is approximately 11–38 times shorter than the corresponding measured LER-guided beam-search runtime across the four families. Beam search more reliably reaches the best observed distance for the two smaller families, while both strategies consistently reach it for the two larger families.

We then test whether the same pattern-suppression principle extends to bivariate-bicycle (BB) codes. Each BB code is specified by two bivariate polynomials whose monomial terms define structured circulant matrices. We identify low-weight X- and Z-logical operators and construct structured polynomial-term modifications designed to make selected logical patterns detectable, while a multi-target search suppresses several low-weight patterns simultaneously. The search identifies a certified $[[196,18,8]]$ code together with additional larger candidates whose exact distances remain under certification. These results support low-weight pattern suppression as a transferable strategy for qLDPC code discovery and show that structural surrogate objectives can substantially reduce reliance on decoder-in-the-loop optimization.

76. Exotic Erbium Doped Compounds for Higher Emission Rates

Jada Young — *Argonne National Lab, Materials Science Division*

Quantum telecommunication and interconnects require transmitting information via single photons over long distances, but quantum signals cannot be copied or amplified the way classical ones are without destroying the encoded state. Quantum memories capable of capturing, storing, and re-emitting photons offer a solution, and erbium (Er^{3+}) is a promising candidate due to its long spin coherence time and optical transition within the telecom C-band. However, Er^{3+} is a relatively dim ion, with radiative emission rates typically limited to the Hz range, far below the MHz rates needed for practical use. This limitation can be addressed by synthesizing Er^{3+} -doped crystals selected through prior computational screening for their potential to increase Er^{3+} radiative rate. Host candidates were synthesized via direct powder combination and annealing, then characterized using photoluminescence excitation (PLE) spectroscopy to confirm Er^{3+} incorporation into the crystal lattice. Sharp spectral peaks in initial batches indicate successful site substitution, though measured T1 lifetimes consistently deviated from computational predictions, suggesting a need for further model refinement or investigation of material distortions. Ongoing work includes X-ray diffraction to confirm crystal structure and continued synthesis across a broader range of host candidates.