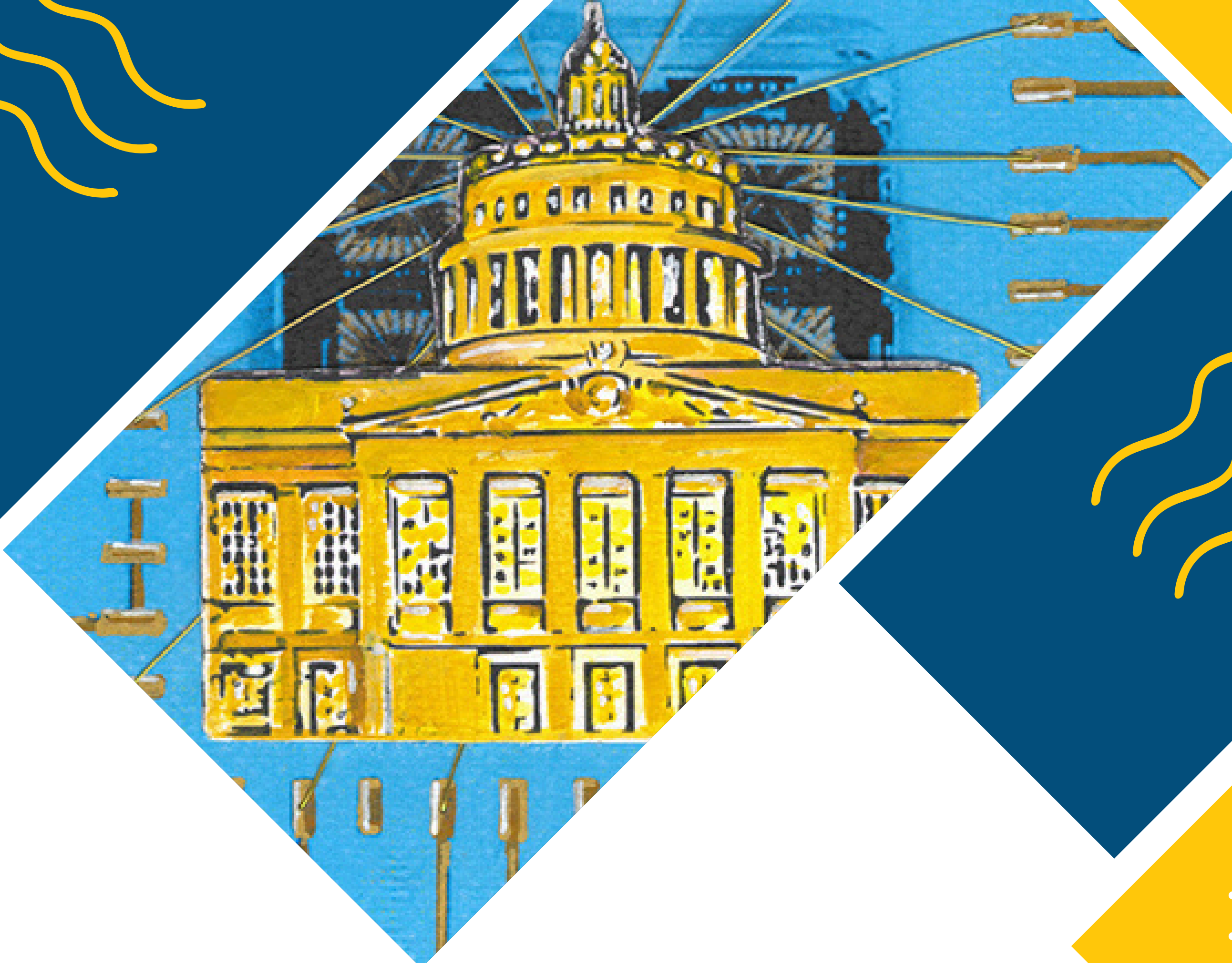

CQS - 12

Rochester Conference on Coherence and Quantum Science

JUNE 22 - 26, 2025

GORDON AND BETTY MOORE FOUNDATION

INTERNATIONAL YEAR OF Quantum Science and Technology

UNIVERSITY of ROCHESTER

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH, UNITED STATES AIR FORCE

Contents

Sunday

15:00

Registration
Munnerlyn Atrium in Goergen Hall

17:00

Welcome reception sponsored by the Institute of Optics
Munnerlyn Atrium in Goergen Hall

20:00

Monday

07:00 **Check-in & Breakfast**
Hirst Lounge in Wilson Commons

08:30 **Opening Remarks**
Hoyt Hall

09:00 **Donna Strickland**
Hoyt Hall
Chair: Machiel Blok

10:00 **Coffee Break**
Munnerlyn Atrium in Goergen Hall

	Coherence Sloan Auditorium *Chair: Lorenza Viola*	***Quantum Optics*** Wegmans Hall *Chair: Mohammad Mirhosseini*
10:30	Peter Milonni	Marina Radulaski
11:00	Gerd Leuchs	Stephen Walborn
11:30	Sultan Abdul Wadood	Ben Sussman
12:00	Songbo Xie	Benjamin Nussbaum

12:15 **Lunch**
Hirst Lounge in Wilson Commons

14:00 **Klaus Mølmer**
Hoyt Hall
Chair: Gabriel Landi

14:45 **Discussion/Break**
Munnerlyn Atrium in Goergen Hall

	Quantum Foundations Sloan Auditorium *Chair: Klaus Mølmer*	***Optomechanics*** Wegmans Hall *Chair: Marina Radulaski*
15:15	Andrew Jordan	Andrew Geraci
15:45	Akram Touil	Mohammad Mirhosseini
16:15	Elinor K. Twyeffort	Jack C. Sankey
16:45	Regina Demina	Pablo Postigo

17:00 **Reception/Poster session**
May Room & Bridge Lounge in Wilson Commons

18:00 **Dinner**
Hirst Lounge in Wilson Commons

19:30

Tuesday

07:00 **Breakfast**
Hirst Lounge in Wilson Commons

08:30 **Lieven M. K. Vandersypen**
Hoyt Hall
Chair: John Nichol

09:30 **Coffee Break**
Munnerlyn Atrium in Goergen Hall

	Quantum Information Sloan Auditorium *Chair: Iman Marvian*	***Quantum Noise & Control*** Wegmans Hall *Chair: Ignacio Franco*
10:00	Michelle Y. Simons	Lorenza Viola
10:30	Sophia Economou	Robin Blume-Kohout
11:00	Julian Kelly	Edwin Barnes
11:30	Kenji Ohmori	Nicholas Bigelow Feiyang Ye
12:00	Ka Wa Yip	Robert Czupryniak

12:15 **Lunch**
Hirst Lounge in Wilson Commons

14:00 **Christopher Monroe**
Hoyt Hall
Chair: Machiel Blok

14:45 **Discussion/Break**
Munnerlyn Atrium in Goergen Hall

	Improving Quantum Processors Sloan Auditorium *Chair: Aziza Almanakly*	***Super-semi*** Wegmans Hall *Chair: Robin Blume-Kohout*
15:15	Robert W. Boyd	Valla Fatemi
15:45	Kevin Patrick O'Brien	Sankar Das Sarma
16:15	Justyna P. Zwolak	Roman Lutchyn
16:45	Zihao Wang	Juzar Thingna

17:00 **Reception/Poster session**
May Room & Bridge Lounge in Wilson Commons

18:00 **Dinner**
Hirst Lounge in Wilson Commons

19:30

Wednesday

07:00 Breakfast
Hirst Lounge in Wilson Commons

08:30 Mikhail Lukin
Hoyt Hall
Chair: Kevin Patrick O'Brien

09:30 Coffee Break
Munnerlyn Atrium in Goergen Hall

	Cavity QED Sloan Auditorium *Chair: Edwin Barnes*	***Quantum Sensing*** Wegmans Hall *Chair: Andrew Jordan*
10:00	Alexandre Blais	John Howell
10:30	Aziza Almanakly	Kanu Sinha
11:00	Aashish Clerk	Xiao-Feng Qian
11:30	Dominik Schneble	Ting Yu
12:00	Tathagata Karmakar	Tanjung Krisnanda

12:15 Lunch
Hirst Lounge in Wilson Commons

13:45 Carlos Stroud
14:00 Jun Ye
Hoyt Hall
Chair: Michael Raymer

14:45 Discussion/Break
Munnerlyn Atrium in Goergen Hall

	Quantum Photonics & Cold Atoms Sloan Auditorium *Chair: Nicholas Bigelow*	***Light/Matter & Chemistry*** Wegmans Hall *Chair: Natalia Ares*
15:15	Michael Raymer	Gregory D. Scholes
15:45	Anand Kumar Jha	Paul Brumer
16:15	Margoth Córdova-Castro Pranta Saha	Jianshu Cao
16:45	Elisha Haber	Tao E. Li

17:00 Free time

17:30 Shuttle to Strong Museum of Play

18:00 Banquet
Strong Museum of Play

21:00 Return

Thursday

07:00 Breakfast
Hirst Lounge in Wilson Commons

08:30 Pedram Roushan
Hoyt Hall
Chair: Chaitanya Murthy

09:30 Coffee Break
Munnerlyn Atrium in Goergen Hall

	Quantum Simulation Sloan Auditorium *Chair: Dominik Schneble*	***Many-body Physics*** Wegmans Hall *Chair: Akram Touil*
10:00	Susanne Yelin	Aurélia Chenu
10:30	Zlatko Minev	Norman Yao
11:00	Iman Marvian	Aashish Clerk
11:30	Ceren B. Dag	Ignacio Gustin Jakub Garwola
12:00	Alex Rubin	Nanako Shitara

12:15 Lunch
Hirst Lounge in Wilson Commons

14:00 Nicole Yunger Halpern
Hoyt Hall
Chair: Ceren Dag

14:45 Discussion/Break
Munnerlyn Atrium in Goergen Hall

	Solid State Devices Sloan Auditorium *Chair: Valla Fatemi*	**Qudits** Wegmans Hall *Chair: Machiel Blok*
15:15	Pasquale Scarlino	Martin Ringbauer
15:45	Natalia Ares	Fernando Luis
16:15	Xuedong Hu	Benjamin Brock
16:45	Abhaya S. Hegde	Elizabeth Champion

17:00 Pizza Reception
Munnerlyn Atrium in Goergen Hall

19:00 Public Lecture - Nicole Yunger Halpern
Hoyt Hall

20:00

About

The 12$^{\text{th}}$ Rochester Conference on Coherence and Quantum Science (CQS-12), formerly known as the Rochester Conference on Coherence and Quantum Optics (CQO), has been held every six years since the inception in 1960—coinciding with the first observation of lasing. The conference is rooted on Rochester's legacy as the birthplace of quantum optics and key elements of quantum coherence. Leonard Mandel and Emil Wolf established the six-year cycle to provide a periodic snapshot of major advances in the field. Key topics presented at the conference have included an outline of quantum optics by Roy Glauber, the first comprehensive quantum theoretical analysis of the laser (then known as the optical maser), and the first experimental demonstration of a two-qubit entangling gate.

CQS-12 is dedicated to Joseph H. Eberly (1935 - 2025). Joe was both the Andrew Carnegie Professor of Physics and a Professor of Optics at the University of Rochester, where he spent nearly six decades on the faculty.

Joe was, first and last, a physicist—a pioneering theorist in quantum optics whose ideas reshaped the field. He loved the discipline with a rare purity and gave his life to it with enthusiasm and delight. He published more than 400 peer-reviewed papers over the course of his career, co-authored three graduate textbooks, cofounded the open-access journal Optics Express, and made seminal contributions to quantum entanglement, spontaneous collapse and revival phenomena, and the behavior of non-diffracting light beams.

We would like to pay tribute to Joe for his significant contributions to quantum optics and, in particular, to the Rochester Conferences, which he helped organize over the past decades—including this very edition. His influence is deeply embedded in this year's program, and we hope participants will take a moment during the conference to reflect on and appreciate Joe's enduring legacy.

Contact information

Contact: Christine Confer <`cqs12@mail.pas.rochester.edu`>
Website: `www.sas.rochester.edu/quantum/cqs`
Public safety: Call or text at (+1) 585-275-3333. Blue Light phones are available across campus and will immediately connect you with a security officer.

Local Organizing Committee

Machiel Blok	Nick Bigelow	Joe Eberly	Ignacio Franco
Gabriel Landi	John Nichol	Nick Vamivakas	

We thank Anny Ostau De Lafont for designing the conference logo.

Advisory Board Members

Useful Information

Sunday activities: Registration opens 3 pm at the Munnerlyn Atrium in Goergen Hall. A **welcome reception**, sponsored by the *Institute of Optics*, will be held in the same location between 5-8 p.m.

Speakers are encouraged to use their own laptops for the presentations, and test their setup in advance. Additional computers and flash drives will also be available in the presentation rooms. Tutorials are 45 minutes + 15 minutes of questions, invited talks 25+5 and contributed talks are 10+5.

Poster sessions will take place on Monday and Tuesday evenings at Wilson Commons. Participants can set up their posters starting Monday morning, and they will be available for viewing and discussion until Thursday at noon. Poster dimensions should not exceed 4ft x 4ft.

Volunteers can be recognized by yellow lanyards. Please feel free to reach out to them for assistance with any issues that might arise.

Parking is available in the **Library Lot** (see map). To enter, use the code 493511# (make sure to press the # key at the end).

WiFi: `UR_RC_Guest` is available throughout the campus, and can be joined without a password. Access to `eduroam` is also available.

The **conference banquet** will be held on Wednesday evening at the Strong Museum of Play, 1 Manhattan Square Dr, Rochester, NY. A shuttle is arranged from the back of Rush Rhees library. Buses will depart between 5:30 pm and 6:00 pm.

Program Timetable

Monday, June 23

7:00	Check-in and Breakfast	*Hirst Lounge in Wilson Commons*
8:30	Opening Remarks by Machiel Blok and Provost Nicole Sampson	*Hoyt Hall*

Keynote Session

Chair: Machiel Blok — *Room: Hoyt Hall*

9:00 **Donna Strickland**, *University of Waterloo*
Lasers – they are quantum and coherent

10:00 Coffee Break — *Munnerlyn Atrium in Goergen Hall*

Parallel Sessions

	Coherence	Quantum Optics
	Chair: Lorenza Viola *Room: Sloan Auditorium*	*Chair: Mohammad Mirhosseini* *Room: Wegmans Hall*
10:30	**Peter Milonni** Invited *University of Rochester* A quantum radar with undetected photons	**Marina Radulaski** Invited *UC Davis* Wafer-scale silicon carbide quantum photonics development guided by DOE testbed simulations of cavity QED
11:00	**Gerd Leuchs** Invited *Universität Erlangen-Nürnberg/MPL* Coherence in spontaneous emission of a single atom	**Stephen Walborn** Invited *University of Concepción* Multicore optical fiber devices for quantum optics and information
11:30	**Sultan Abdul Wadood** Invited *Princeton University* Classically informed quantum limits in superresolution	**Ben Sussman** Invited *University of Ottawa* Ultrafast quantum photonics: Beating decoherence with fast light pulses
12:00	**Songbo Xie** Contributed *North Carolina State University* Modulator-assisted local control of quantum battery via Zeno effect	**Benjamin Nussbaum** Contributed *University of Illinois Urbana-Champaign* Post-selected entanglement from GaAs quantum dots

12:15	Lunch	*Hirst Lounge in Wilson Commons*

Tutorial session

Chair: Gabriel Landi — *Room: Hoyt Hall*

14:00 **Klaus Mølmer**, *Niels Bohr Institute, Copenhagen University*
The state of a monitored quantum system – more than meets the eye

14:45 Discussion/Break — *Munnerlyn Atrium in Goergen Hall*

Parallel Sessions

	Quantum Foundations	Optomechanics
	Chair: Klaus Mølmer *Room: Sloan Auditorium*	*Chair: Marina Radulaski* *Room: Wegmans Hall*
15:15	**Andrew Jordan** Invited *Chapman University/University of Rochester* Catching a tunneling particle in the act: Fundamental lessons and energetic consequences	**Andrew Geraci** Invited *Northwestern University* Precision sensing and fundamental physics with levitated optomechanics
15:45	**Akram Touil** Invited *Los Alamos National Laboratory* It from bit	**Mohammad Mirhosseini** Invited *Caltech* A mechanical quantum memory for microwave photons
16:15	**Elinor K. Twyeffort** Invited *University of Southampton* Exploring the quantum-to-semiclassical transition in the Rabi model	**Jack C. Sankey** Invited *McGill University* Corralling phonons with radiation pressure
16:45	**Regina Demina** Contributed *University of Rochester* Quantum information observables in the system of top and antitop quarks at LHC	**Pablo Postigo** Contributed *University of Rochester* Pursuing ground state of on-chip optomechanical resonators at room temperature enabled by machine learning

17:00	Reception/Poster Session	*May Room & Bridge Lounge in Wilson Commons*
18:00	Dinner	*Hirst Lounge in Wilson Commons*

Tuesday, June 24

7:00 Breakfast — *Hirst Lounge in Wilson Commons*

Tutorial Session

Chair: John Nichol — *Room: Hoyt Hall*

8:30 **Lieven M.K. Vandersypen**, *QuTech, Delft University of Technology*
Quantum computing with spins – past, present and future

9:30 Coffee Break — *Munnerlyn Atrium in Goergen Hall*

Parallel Sessions

	Quantum Information	Quantum Noise & Control
	Chair: Iman Marvian *Room: Sloan Auditorium*	*Chair: Ignacio Franco* *Room: Wegmans Hall*
10:00	**Michelle Y. Simmons** Invited *Silicon Quantum Computing* Engineering high quality qubits in silicon with atomic precision	**Lorenza Viola** Invited *Dartmouth College* Implications of correlated nonclassical noise for gate-error virtualization and quantum error correction
10:30	**Sophia Economou** Invited *Virginia Tech* Controlling entanglement of nuclear spin memories in defect-based quantum networks	**Robin Blume-Kohout** Invited *Sandia National Laboratories* Multiscale modeling of quantum computing registers
11:00	**Julian Kelly** Invited *Google* Willow and quantum computing below the surface code threshold	**Edwin Barnes** Invited *Virginia Tech* Quantum control: Geometric space curves, error mitigation, and quantum simulation
11:30	**Kenji Ohmori** Invited *Institute for Molecular Sciences* Ultrafast quantum computing with ultracold atom arrays at quantum speed limit	**Nicholas Bigelow** Contributed *University of Rochester* Quantum sensing and control in space
11:45		**Feiyang Ye** Contributed *University of Rochester* Towards understanding and mitigating charge noise in Si/SiGe quantum dots
12:00	**Ka Wa Yip** Contributed *Northeastern University* Variational quantum annealing for quantum chemistry	**Robert Czupryniak** Contributed *University of Rochester* Artificially intelligent Maxwell's demon for optimal control of open quantum systems

12:15	Lunch	*Hirst Lounge in Wilson Commons*

Tutorial session

Chair: Machiel Blok — *Room: Hoyt Hall*

14:00 **Christopher Monroe**, *Duke University and IonQ*
Quantum computing with atoms and photons

14:45 Discussion/Break — *Munnerlyn Atrium in Goergen Hall*

Parallel Sessions

Improving Quantum Processors

Chair: Aziza Almanakly
Room: Sloan Auditorium

15:15 **Robert W. Boyd** — Invited
University of Rochester
Nonlinear optics and photon-based quantum information

15:45 **Kevin Patrick O'Brien** — Invited
MIT
High-efficiency, low-loss Floquet-mode traveling wave parametric amplifiers

16:15 **Justyna P. Zwolak** — Invited
NIST
Smart calibration of quantum dot devices

16:45 **Zihao Wang** — Contributed
University of Rochester
Probing excited-state dynamics of transmon ionization

Super-semi

Chair: Robin Blume-Kohout
Room: Wegmans Hall

15:15 **Valla Fatemi** — Invited
Cornell University
Physics and applications of Andreev spin qubits

15:45 **Sankar Das Sarma** — Invited
University of Maryland
Majorana zero modes and topological quantum computation: What, why, how, when?

16:15 **Roman Lutchyn** — Invited
Microsoft Quantum
Quantum computation using Majorana-based topological qubits

16:45 **Juzar Thingna** — Contributed
American Physical Society
All about PRX Quantum

17:00	Reception/Poster Session	*May Room & Bridge Lounge in Wilson Commons*
18:00	Dinner	*Hirst Lounge in Wilson Commons*

Wednesday, June 25

7:00	Breakfast	*Hirst Lounge in Wilson Commons*

Tutorial Session

Chair: Kevin Patrick O'Brien — *Room: Hoyt Hall*

8:30 **Mikhail Lukin**, *Harvard University and QuEra Computing*
Exploring quantum computing frontier with neutral atom systems

9:30 Coffee Break — *Munnerlyn Atrium in Goergen Hall*

Parallel Sessions

	Cavity QED	**Quantum Sensing**
	Chair: Edwin Barnes *Room: Sloan Auditorium*	*Chair: Andrew Jordan* *Room: Wegmans Hall*
10:00	**Alexandre Blais** (Invited) *Université de Sherbrooke* Unified picture of measurement-induced ionization in the transmon	**John Howell** (Invited) *Chapman University* Superfunction superradar
10:30	**Aziza Almanakly** (Invited) *MIT* Building superconducting quantum interconnects	**Kanu Sinha** (Invited) *University of Arizona* Collective atom-photon interactions in waveguide QED
11:00	**Aashish Clerk** (Invited) *University of Chicago* Non-Gaussian two-mode squeezing: Applications to multi-ensemble spin squeezing and beyond	**Xiao-Feng Qian** (Invited) *Stevens Institute of Technology* Parameter-decoupled superresolution: Breaking the diffraction barrier for passive sources
11:30	**Dominik Schneble** (Invited) *Stony Brook University* Quantum simulations with arrays of radiatively coupled matter-wave emitters	**Ting Yu** (Invited) *Stevens Institute of Technology* Quantum sensing and control in the presence of environmental noises
12:00	**Tathagata Karmakar** (Contributed) *UC Berkeley* Noise	**Nathan R. Gonzalez** (Contributed) *UC Davies* Cryogenic spectroscopy of NV centers in SiC nanopillars for scalable quantum photonics

12:15	Lunch	*Hirst Lounge in Wilson Commons*

Tutorial session

Chair: Michael Raymer — *Room: Hoyt Hall*

13:45 **Carlos Stroud**, *University of Rochester*
The Rochester coherence conferences: 65 years and counting

14:00 **Jun Ye**, *JILA, NIST and University of Colorado*
Quantum coherence and system scaling for clock and fundamental physics

14:45 Discussion/Break — *Munnerlyn Atrium in Goergen Hall*

Parallel Sessions

	Quantum Photonics & Cold Atoms	Light/Matter & Chemistry
	Chair: Kanu Sinha *Room: Sloan Auditorium*	*Chair: Natalia Ares* *Room: Wegmans Hall*
15:15	**Michael Raymer** Invited *University of Oregon* The Duan-Kimble quantum memory loading scheme revisited	**Gregory D. Scholes** Invited *Princeton University* Quantum-like states
15:45	**Anand Kumar Jha** Invited *IIT Kanpur* Partial optical coherence: Applications in high-dimensional quantum state measurement	**Paul Brumer** Invited *University of Toronto* Nonequilibrium steady state adventures with incoherent light
16:15	**Margoth Córdova-Castro** Contributed *University of Ottawa* Nanomaterials for spontaneous emission rate enhancement evidenced at single molecule level with nanometer resolution	**Jianshu Cao** Invited *MIT* Quantum control under strong light-matter interactions: Floquet dynamics and cavity polaritons
16:30	**Pranta Saha** Contributed *UC Davis* Scalable quantum nanophotonics with integrated color centers in Silicon Carbide	
16:45	**Elisha Haber** Contributed *University of Rochester* Shell-shaped Bose—Einstein condensates in toroidal optical traps	**Tao E. Li** Contributed *University of Delaware* Bridging electrodynamics and molecular dynamics in polariton simulations

17:00	Free time/Shuttle to Strong Museum of Play	*Behind Rush Rhees Library*
18:00	Banquet	*Strong Museum of Play*
21:00	Return	

Thursday, June 26

7:00	Breakfast	*Hirst Lounge in Wilson Commons*

Tutorial Session

Chair: Chaitanya Murthy — *Room: Hoyt Hall*

8:30 **Pedram Roushan**, *Google Quantum AI*
Novel quantum dynamics with superconducting qubits

9:30 Coffee Break — *Munnerlyn Atrium in Goergen Hall*

Parallel Sessions

	Quantum Simulation	Many-Body Physics
	Chair: Dominik Schneble *Room: Sloan Auditorium*	*Chair: Akram Touil* *Room: Wegmans Hall*
10:00	**Susanne Yelin** Invited *Harvard University* Resource-efficient, and robust: A unified toolkit for quantum characterization and probing	**Aurélia Chenu** Invited *University of Luxembourg* Spectral statistics of many-body systems: a refined measure of quantum chaos and two crossovers
10:30	**Zlatko Minev** Invited *Google Quantum AI* Quantum advantages in experiments: Computational & learning	**Norman Yao** Invited *Harvard University* Spin squeezed entanglement in dilute, dipolar systems
11:00	**Iman Marvian** Invited *Duke University* Learning and engineering multi-qubit interactions	**Aashish Clerk** Invited *University of Chicago* Exact insights into a driven-dissipative interacting spin chain
11:30	**Ceren B. Dag** Invited *Indiana University Bloomington/Harvard* Quantum simulations with neutral atoms	**Ignacio Gustin** Contributed *University of Rochester* Mapping electronic decoherence pathways in molecules
11:45		**Jakub Garwoła** Contributed *University of Toronto* Spin systems strongly interacting with bosonic baths via noncommuting coupling operators
12:00	**Alex Rubin** Contributed *UC Davis* Analog and digital quantum simulation of open many-body quantum optics	**Nanako Shitara** Contributed *University of Colorado Boulder* Variational quantum noise spectroscopy

12:15	Lunch	*Hirst Lounge in Wilson Commons*

Tutorial session

Chair: Ceren B. Dag — *Room: Hoyt Hall*

14:00 **Nicole Yunger Halpern**, *NIST and University of Maryland*
Useful autonomous quantum machines

14:45 Discussion/Break — *Munnerlyn Atrium in Goergen Hall*

Parallel Sessions

	Solid-State Devices	Qudits
	Chair: Valla Fatemi *Room: Sloan Auditorium*	*Chair: Machiel Blok* *Room: Wegmans Hall*
15:15	**Pasquale Scarlino** Invited *EPFL* High-kinetic-inductance resonators for hybrid quantum architectures and photonic metamaterials	**Martin Ringbauer** Invited *University of Innsbruck* Towards quantum simulation with trapped-ion qudits
15:45	**Natalia Ares** Invited *University of Oxford* The limits of control in semiconductor quantum devices	**Fernando Luis** Invited *Universidad de Zaragoza* Circuit QED with molecular spin qudits
15:45	**Xuedong Hu** Invited *University at Buffalo* On-chip spin qubit communications	**Benjamin Brock** Invited *Yale University* Quantum error correction of qudits beyond break-even
16:45	**Abhaya S Hegde** Contributed *University of Rochester* Time-resolved stochastic dynamics of quantum thermal machines	**Elizabeth Champion** Contributed *University of Rochester* Transmon qudit control and tomography via multi-frequency driving

17:00 Pizza reception — *Munnerlyn Atrium in Goergen Hall*

Public Lecture

19:00 **Nicole Yunger Halpern**, *University of Maryland* — *Hoyt Hall*
Quantum steampunk: The physics of yesterday's tomorrow

Talk abstracts

Monday morning, June 23

Lasers – they are quantum and coherent

Donna Strickland, University of Waterloo Keynote

In honor of the International Year of Quantum, I will discuss the quantum history of lasers. I also want to discuss the fact, that the coherence time of mode-locked laser trains or pulses must be much longer than the pulse duration. This fact seems to be misunderstood, but for there to be modes to lock, the coherence time must be longer than the cavity round trip time.

A quantum radar with undetected photons

Peter W. Milonni, University of Rochester Invited

We describe a quantum remote sensing framework with undetected photons based on quantum frequency combs with induced coherence by path identity. Unlike existing methods, the proposed scheme does not require a quantum memory to coherently store a single photon of an initially entangled pair.

D.A.R. Dalvit, T.J. Volkoff, Y.-S. Choi, A.K. Azad, H.-T. Chen, and P.W. Milonni, Phys. Rev. X 14, 041058 (2024)

Coherence in spontaneous emission of a single atom

Gerd Leuchs, Universität Erlangen-Nürnberg and Max Planck Institute for the Science of Light Invited

In classical optics a point source is spatially fully coherent. However, when a quantum system is put into an excited state, it decays back to the ground state through the process of spontaneous emission, which is ultimately responsible for most of the light around us. Spontaneous emission from a single emitter is a random process, rendering the phase of the emitted photon completely uncertain. This uncertainty raises the question of whether coherence exists between emissions in different spatial directions. After all, the vacuum fluctuations of the various plane waves tickling the atom are delta correlated. Furthermore, an atom has additional degrees of freedom and thus may conceivably decay into a superposition of states potentially entangling these different degrees. Our experimental results give a clear answer, confirming that such coherence does indeed exist.

Classically informed quantum limits in superresolution

Sultan Abdul Wadood, Princeton University Invited

Quantum-enhanced and quantum-inspired protocols have enabled superresolved measurements of phase and source separation. However, these protocols require classical resources whose costs need careful accounting. In this talk, we will discuss our recent work on classical strategies and the associated resource requirements for attaining the quantum limits of a) separation estimation of sub-Rayleigh sources and b) phase estimation with squeezed states.

Modulator-assisted local control of quantum battery via Zeno effect

Songbo Xie, North Carolina State University Contributed

Quantum batteries are quantum devices that store and deliver energy. In the charger-mediated protocol, energy is transferred between a charger and the battery through their interaction, which is controlled by global quenches requiring access to both systems. This approach becomes challenging for long-range charging, where the charger and battery are spatially separated. We propose a scheme to charge the battery using local controls on a third system, the modulator, which interacts only with the charger. The original interaction between the charger and the battery remains always on, with no direct or global control required during a charging cycle. Instead, by applying repeated unitary pulses to the modulator via Zeno effect, we dynamically modify the effective coupling between the charger and battery, thereby controlling the battery's charging speed. Our protocol enables remote, platform-independent local control of energy flow and offers a versatile tool for engineering interactions in spatially distributed quantum devices.

Wafer-scale silicon carbide quantum photonics development guided by DOE testbed simulations of cavity QED

Marina Radulaski, University of California, Davis Invited

Color center systems are among leading platforms in the development of quantum hardware due to their excellent spin, optical, and spin-photon properties. We integrate near infrared color centers in silicon carbide (SiC) with photonic devices for applications in quantum light sources, quantum repeaters and all-photonic quantum simulators at scale. Our angle-etching method produces close-to-uniform triangular cross-section devices across a 5-inch SiC wafer while maintaining the spectral properties of color centers. Next, we utilize nanopillars to enhance light collection and identify dipole polarization of nitrogen-vacancy (NV) centers in 4H-SiC and expand on the optical cryogenic characterization of this promising emitter with near-telecom emission and proposed spin-photon entangling processes.

Looking toward color center implementations of cavity QED, we explore Tavis-Cummings (TC) model in the open quantum system setting. Traditionally, numerical simulations of the TC model in an open quantum setting have been limited to small dimensions due to unfavorable scaling with the number of emitters. We study how quantum computers can help bridge this knowledge gap and propose and benchmark approaches for digital and analog quantum simulation of the TC model on superconducting and trapped ion systems offered by DOE testbeds. In this process, we demonstrate photon blockade in the Tavis-Cumming model for the first time.

[1] B. Marinelli, A. H. Rubin, V. A. Norman, S. Yang, R. Naik, B. M. Niedzielski, D. K. Kim, R. Das, M. Schwartz, D. I. Santiago, C. Spitzer, I. Siddiqi, M. Radulaski, "Observation of Photon Blockade in a Tavis-Cummings System," arXiv:2501.18751.
[2] V. A. Norman, S. Majety, A. H. Rubin, P. Saha, N. R. Gonzalez, J. Simo, B. Palomarez, L. Li, P. B. Curro, S. Dhuey, S. Virashawmy, M. Radulaski, "Sub-2 Kelvin characterization of nitrogen-vacancy centers in silicon carbide nanopillars," in press in ACS Photonics, arXiv:2401.10509.
[3] A. H. Rubin. B. Marinelli, V. A. Norman, Z. Rizvi, A. D. Burch, R. K. Naik, J. M. Kreikebaum, M. N. H. Chow, D. S. Lobser, M. C. Revelle, C. G. Yale, M. Ivory, D. I. Santiago, C. Spitzer, M. Krstic-Marinkovic, S. M. Clark, I. Siddiqi, M. Radulaski, "Digital Quantum Simulation of Cavity Quantum Electrodynamics: Insights from Superconducting and Trapped Ion Quantum Testbeds," arXiv:2404.03861.
[4] P. Saha, S. Majety, S. Dhuey, M. Radulaski, "Triangular cross-section grating couplers for integrated quantum nanophotonic hardware in silicon carbide," arXiv:2410.12150.
[5] S. Majety, V. A. Norman, P. Saha, A. H. Rubin, S. Dhuey, M. Radulaski, "Wafer-Scale Integration of Freestanding Photonic Devices with Color Centers in Silicon Carbide," npj Nanophotonics 2, 3 (2025), arXiv:2405.07498.
[6] A. N. Sims, D. Patel, A. Philip, A. H. Rubin, R. Bandyopadhyay, M. Radulaski, M. M. Wilde, "Digital Quantum Simulations of the Non-Resonant Open Tavis-Cummings Model," arXiv:2501.18522.

Multicore optical fiber devices for quantum optics and information

Stephen Walborn, University of Concepción Invited

Future quantum information networks will most likely need to be compatible with the telecommunications infrastructure. In this regard, the looming capacity crunch in optical fiber communication has fueled much interest in space division multiplexing technology. One promising candidate are multi-core optical fibers, which have multiple fiber cores within the same cladding. These fibers are particular interesting in the quantum regime, allowing for photonic path encoding with increased phase stability. Here I will present several recent results obtained at the University of Concepción that employ multi-core fiber devices for quantum optics and information processing. In particular, I will present several useful devices, including multi-core fiber beam splitters and their use in realizing generalized quantum measurements, point tomography, and quantum key distribution.

arXiv preprint arXiv:2412.14915
Nature Physics 19 (2), 190-195 (2023)

Ultrafast quantum photonics: Beating decoherence with fast light pulses

Ben Sussman, National Research Council of Canada & University of Ottawa Invited

Ultrafast optical pulses - femtoseconds to picoseconds in duration - are gaining interest for quantum processing due to their potential to encode information in brief time-bins, overcoming rapid decoherence.

The development of essential components for optical quantum technologies will be discussed, including a single photon switch based on the optical Kerr effect in single-mode fibres and a single photon memory based on fibre cavities. The switch controls single photon routing without adding noise, while the memory addresses a key scaling challenge by temporarily storing quantum states without loss of coherence, enabling quantum process synchronization.

Application of these components in photonic quantum processing and quantum sensing will be discussed, including random walks and more general processing, as well as quantum enhanced ranging and approaches to imaging and spectroscopy using correlated photons.

Post-selected entanglement from GaAs quantum dots

Benjamin Nussbaum, University of Illinois Urbana-Champaign Contributed

Bright, high-purity sources of entangled photons are critical for efficient quantum communication, quantum sensing, and quantum computing. Entanglement sources leveraging spontaneous parametric down-conversion (SPDC) been prominent in the field, but are limited by their probabilistic nature and the possibility of multi-pair events which. By starting with high purity single photons ($g^{(2)}(0) = 2.5\%$) from GaAs quantum dots, we demonstrate an entanglement source that has the potential to outperform SPDC for applications such as entanglement swapping within long-range quantum networks. We alternate the polarization of and delay every other photon, overlapping them on a non-polarizing beam splitter. For the cases where the photons exit different ports of the beam splitter, we report post-selected entanglement in the state $|\psi\rangle = |HV\rangle + |VH\rangle$ with a singlet fraction exceeding 96%.

The state of a monitored quantum system – more than meets the eye

Klaus Mølmer, Niels Bohr Institute, Copenhagen University Tutorial

The time evolution of a single quantum system that is subject to measurements is described by stochastic Schrödinger or master equations. While these approaches are derived from the usual rules of quantum mechanics and quantum measurements, their manifestation in different situations shed light back on the rules themselves. In the talk, I shall discuss recent theory that yield optimal analyses of measurement data for quantum sensing and metrology, while providing also foundational insights and new elements to our understanding of quantum states and quantum evolution.

Catching a tunneling particle in the act: Fundamental lessons and energetic consequences

Andrew Jordan, Chapman University and University of Rochester Invited

We address a foundational question in quantum mechanics: can a particle be directly found in a classically forbidden virtual state? We instantiate this conceptual question by investigating the traversal of electrons through a tunnel barrier, which we define in a triple quantum dot (TQD) system where the occupation of the central dot is energetically avoided. The motivation behind this setup is to answer whether the central dot is occupied or not during a virtual transition when it is being explicitly monitored. We investigate this problem in two different limits of continuous measurements: the stochastic quantum diffusion and the quantum jump. We find that, even though individual trajectories differ considerably across these limits, measuring leads to a higher occupation in the central dot on average. Our results demonstrate that the act of observation fundamentally reshapes tunneling dynamics, resolving the seeming paradox of detecting a particle in a classically forbidden region: weak measurements partially localize the particle, while strong measurements enforce a discontinuous either/or detection or no detection outcome. We also examine the thermodynamic consequences of this effect, and demonstrate how a quantum measurement engine can be designed around it.

arxiv:2503.10064

It from bit

Akram Touil, Los Alamos National Laboratory Invited

The mystery of how the classical world of our everyday experience emerges from a universe that is fundamentally quantum has intrigued physicists for over a century. Quantum Darwinism is a physical framework that addresses this quantum/classical divide. This framework builds on decoherence theory which focuses on the suppression of the quantumness and on the environment-induced superselection of preferred, so called, "pointer states." Quantum Darwinism goes beyond the decoherence paradigm by recognizing that the decohering environment also serves as a communication channel, carrying information about the state of the system of interest. By employing information-theoretic measures, we show that when distinct, independently accessible environmental fragments carry sufficient information about a system, all observers who access those fragments will attribute the same pointer state to it. This notion of consensus between observers addresses the question of the perception of a single outcome, which is all that is needed to explain the origin of our objective classical reality from unitary quantum mechanics without appealing to the collapse of the wave function. These findings elucidate the role of information in physical phenomena and how one arrives at "It From Bit".

arXiv preprint arXiv:2503.14791

Exploring the quantum-to-semiclassical transition in the Rabi model

Elinor K. Twyeffort, University of Southampton Invited

A driven two-level system undergoes dramatically different dynamics when the classical drive is replaced by an interaction with the most classical of quantum field states, a coherent state. This apparent lack of quantum-to-classical correspondence even in the limit of large photon numbers has been a long-standing puzzle in quantum optics. A recently developed formalism allows the semiclassical Rabi model to be derived directly from the corresponding quantum Hamiltonian [1]. This approach emphasises that vanishingly small single-photon coupling is the key ingredient for the semiclassical limit, combined with a large displacement of the field in phase space. Not only does this neatly resolve the correspondence issue, it also provides a mathematical framework for studying the transition to the semiclassical limit. To calculate quantum field corrections to the semiclassical dynamics, we introduce a technique called 'quantum-corrected Floquet dynamics' [2]. The first-order corrections to the state vector of the coupled quantum system can be solved analytically for arbitrary initial field states, providing a powerful yet surprisingly simple and physically insightful method for calculating short-time dynamics.

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Quantum information observables in the system of top and antitop quarks at LHC

Regina Demina, University of Rochester Invited

I will review the methodology and the results of the full spin correlation measurement in the system of top and antitop quarks at LHC. Using these results, we were able to demonstrate the system is entangled at the threshold of its production and in the high invariant mass regime. Using the full spin correlation coefficients we evaluated the von Neumann entropy, discord, magic and contextuality of the system. These measurements are performed in bins of the invariant mass and scattering angle. This is the first observation of entanglement using spin degrees of freedom in the system supported by strong interaction. I will discuss the prospects for the future QIS measurements in the top quark system, in particular decoherence due to strong force.

Phys. Rev. D 110 (2024) 112016

Corralling Phonons with Radiation Pressure

Jack C. Sankey, McGill University Invited

Mechanical systems can achieve extraordinarily low noise and long coherence times by using phononic crystals as acoustic shielding from the environment. Until recently, these systems were built by embedding (carefully designed) structural defects that disrupt the crystal's periodicity, creating a localized, low mass mode in the band gap. Here we present a different paradigm, using the mechanical properties of light to disrupt the periodicity of an otherwise pristine crystal. This creates a single, optically programmable defect mode in the gap with highly adjustable mechanical properties. This enables smooth control over its spatial profile and inertial mass, notably transforming a vibration from one spanning the entire crystal to one gathered into just a few unit cells around the light. This speedy, reversible, all-optical control gives us a brand new way to engineer mechanical systems with on-the-fly reconfigurability. The concept naturally extends to programmable dimers, phononic waveguides, lattices, and more, vastly expanding the ways in which light can redirect mechanical motion. We also find a collective enhancement in this system that may provide new routes toward large-scale quantum motion.

Phys. Rev. Lett. 133, 226904 | arXiv:2403.08510 (2024)

Precision sensing and fundamental physics with levitated optomechanics

Andrew Geraci, Northwestern University Invited

In high vacuum, optically levitated particles can achieve excellent decoupling from their environment, making force sensing at the zeptonewton level (10-21 N) achievable. In this talk I will describe our experimental efforts employing dielectric particles suspended by radiation pressure as precision sensors for fundamental physics, including searching for quantum effects related to gravity, high-frequency gravitational waves, and Dark Matter.

A mechanical quantum memory for microwave photons

Mohammad Mirhosseini, Caltech Invited

Controlling mechanical oscillators in the quantum regime has implications for quantum information processing, precision sensing, and explorations of fundamental physics. In the gigahertz frequency band, superconducting qubits have emerged as a powerful tool for creating and measuring non-classical states in mechanical oscillators. Realizing these capabilities requires high-fidelity interfaces that can coherently transfer quantum states between electrical and mechanical domains. In this talk, we present an electromechanical interface that relies on electrostatic forces in nanoscale structures to achieve strong coupling between a transmon qubit and a nanomechanical oscillator. Utilizing quantum operations by the qubit, we investigate the microscopic origins of mechanical decoherence and demonstrate a phonon lifetime that exceeds the microwave photon lifetime in planar superconducting circuits by an order of magnitude. These results represent a key step towards employing mechanical oscillators as memory elements with practical advantages for quantum information processing. Furthermore, the material-agnostic nature of our approach offers a pathway to extending quantum control to long-lived phonons across abroad range of material platforms.

"A mechanical quantum memory for microwave photons", A. Bozkurt*, O. Golami*, Y. Yu, H. Tian, and M. Mirhosseini, arXiv:2412.08006, Dec 11, (2024).

Pursuing ground state of on-chip optomechanical resonators at room temperature enabled by machine learning

Pablo Postigo, University of Rochester Contributed

Optomechanics has brought the goal of room-temperature quantum experimentation and technology into reality through ultra-high mechanical-Q resonators, which are laser-cooled to their motional quantum ground states. Our work takes steps toward bringing quantum states to on-chip platforms via phononic crystal-shielded nanobeam photonic crystal resonators. Particularly difficult in this endeavor is the high optical-Q requirement to reach resolved-sideband cooling necessary for cooling to ground state without cryostats. Historically, this has necessitated the use of an external optical cavity. We develop a new shared-mode optimization technique and couple this with machine learning optimization to achieve the required optical Q-factor to bring the quantum optomechanical system on chip.

Tuesday morning, June 24

Quantum computing with spins – past, present and future

Lieven M.K. Vandersypen, QuTech, Delft University of Technology Invited

The long and winding road from the early quantum computing experiments to the major industry efforts today has been truly exciting. Over all these years, the state of a spin-1/2 particle not only served as the textbook example of a quantum bit, but also as a leading qubit implementation. In this tutorial, we will briefly survey past work and then focus on ongoing efforts and future directions towards a large-scale quantum computer.

Early explorations of quantum algorithms using liquid-state nuclear magnetic resonance relied on spin-1/2 nuclei in specially selected and synthesized molecules. These efforts culminated in the first implementation of Shor's celebrated factoring algorithm in 2001.

Since then, efforts have focused on electron and nuclear spins hosted in semiconductor quantum dots or color centers, for their potential for ultimate scalability. In this talk, I will present our vision of a large-scale spin-based quantum processor, and ongoing work to realize this vision.

Today, single-qubit gate fidelities with semiconductor spins are routinely above 99.9%, sometimes surpassing 99.99%. In small systems, two-qubit gates fidelities exceed 99.5%. Universal high-fidelity control, initialization and readout was shown with six qubits, including their operation in quantum algorithms. Meanwhile, quantum dot arrays of 16 dots have been demonstrated.

Whereas quantum dot spins usually sit just 100 nm apart during a two-qubit gate, we realized also two-qubit operations on spins 250 micron apart, mediated by microwave photons in a superconducting on-chip resonator. We also shuttled electrons across a device, covering an effective distance of 10 micron in less than 200 ns and with 99.5% fidelity. Moving electrons around, we can imagine bringing any two electrons close together for two-qubit operations, enabling arbitrary connectivity. Already, we realized a 99% fidelity two-qubit gate between mobile spins, and teleport a quantum state across the device.

When combined, the progress along these various fronts can lead the way to scalable networks of high-fidelity spin qubit registers for fault-tolerant quantum computation. The same quantum dot platform serves to simulate Fermi-Hubbard physics and spin models in two dimensions.

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Engineering high quality qubits in silicon with atomic precision

Michelle Y. Simmons, Silicon Quantum Computing, Sydney, Australia Invited

The realisation of a large-scale error corrected quantum computer relies on our ability to reproducibly manufacture qubits that are fast, highly coherent, controllable and stable. The promise of achieving this in a highly manufacturable platform such as silicon requires a deep understanding of the materials issues that impact device operation. In this talk I will demonstrate how we engineer every aspect of the processor using atom qubits in silicon for fast, controllable exchange coupling [1], fast, high fidelity qubit initialisation and read-out [2]; low noise all epitaxial gates for highly stable qubits [3,4]; and efficient, high fidelity qubit control [5,6] leading to the demonstration of the highest fidelity Grover's algorithm to date [7]. I will also discuss our latest results in quantum analogue processors. Here I will present an atomically engineered quantum feature generator in which we use quantum states to increase the accuracy of classical machine learning [8]. I will also show our latest results in analogue simulation [9,10] demonstrating the uniqueness of the atom in silicon system.

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Controlling entanglement of nuclear spin memories in defect-based quantum networks

Sophia Economou, Virginia Tech Invited

Entangled states of nuclear spins coupled to the spin of a defect can be used as quantum memories for quantum technology applications such as networks. I will discuss the dynamics of these systems and describe a new formalism we developed to efficiently design and characterize multi-qubit entangling gates and states for quantum error correction.

Willow and quantum computing below the surface code threshold

Julian Kelly, Google Invited

Quantum error correction provides a path to reach practical quantum computing by combining multiple physical qubits into a logical qubit, where the logical error rate is suppressed exponentially as more qubits are added. However, this exponential suppression only occurs if the physical error rate is below a critical threshold. In this talk, I will describe our new quantum chip “Willow” which meets this challenge, and demonstrates exponential suppression of error with a factor of $\Lambda = 2.14$ as a logical qubit is scaled up over code distances. We also use our Willow chip to repeat the Random Circuit Sampling benchmark and find the time to classically reproduce this result would be 10^{25} years.

https://www.nature.com/articles/s41586-024-08449-y

Ultrafast quantum computing with ultracold atom arrays at quantum speed limit

Kenji Ohmori, Institute for Molecular Science, National Institutes of Natural Sciences, Japan Invited

Understanding and controlling quantum many-body correlations is one of the central goals of modern science and technology. We pioneered a novel pathway towards this goal with nearby ultracold atoms excited simultaneously with an ultrashort laser pulse to a Rydberg state far beyond the Rydberg blockade regime [1-3]. This new approach is now applied to arbitrary atom arrays assembled with optical tweezers or optical lattices that develop into a pathbreaking platform for quantum computing and simulation on an ultrafast timescale [4-7].

In this ultrafast quantum computing, we have recently succeeded in executing a controlled-Z gate, a conditional two-qubit gate essential for quantum computing, in only 6.5 nanoseconds at quantum speed limit, where the gate speed is solely determined by the interaction strength between two qubits [5]. This is faster than any other two-qubit gates with cold-atom hardware by two orders of magnitude. It is also two orders of magnitude faster than the noise from the external environment and operating lasers, and thus can suppress those noise effects. Moreover, this two-qubit gate speed is comparable to that of the fast two-qubit gate demonstrated recently by "Google AI Quantum" with superconducting qubits [8]. This disruptive progress has been made possible not only by the ultrafast laser technologies, but also by our ultra-precise optical tweezers array and high-NA microscope technologies.

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Variational quantum annealing for quantum chemistry

Ka Wa Yip, Northeastern University Contributed

We introduce a variational quantum annealing (VarQA) algorithm for electronic structure theory, in which we use the quantum annealer as a sampler and prepare an ansatz state through its statistics. We also introduce a strategy called the "digitizer" for searching the space of variational parameters efficiently. We demonstrate the effectiveness of VarQA by evaluating the ground-state potential energy surface for molecules with up to 20 spin orbitals as well as an excited-state potential energy surface. This approach resembles the workings of the quantum Boltzmann Machines (QBMs), but is generalized to handle distributions beyond the Boltzmann distribution. In VarQA, with the number of required logical qubits equal to the number of spin orbitals, a fully connected Ising Hamiltonian can be readily implemented in a large-scale quantum annealer as a scalable ansatz for electronic structure calculations.

https://doi.org/10.48550/arXiv.2503.15473

Implications of correlated nonclassical noise for gate-error virtualization and quantum error correction

Lorenza Viola, Dartmouth College Invited

Correlated noise — spatial, temporal, or both — has long been recognized to be detrimental to quantum error correction (QEC). Additional challenges arise if, in addition, the noise stems from an intrinsically nonclassical environment, whose state is not directly controllable and can in principle undergo nontrivial evolution on its own. In this talk, I will focus on dephasing noise that is both spatio-temporally correlated and nonclassical, and is mitigated through the simultaneous use of QEC and dynamical decoupling (DD), subject to finite timing constraints. By first considering a minimal single-qubit model, I will show how the fidelity of a dynamically protected gate can depend strongly on the applied control history if temporal correlations remain significant across multiple circuit locations — even when the system-side error propagation is fully removed through perfect reset operations. I will then describe ongoing work on a logical qubit protected by a repetition code and DD, showing how the interplay between temporal correlations and non-classicality results in distinctive error behavior — even when the noise couples independently and identically to each qubit.

M. Burgelman, N. Wonglakhon, D. Bernal-Garcia, G. A. Paz-Silva, and L. Viola, "Limitations to gate-error virtualization from temporally correlated nonclassical noise," Physical Review X Quantum 6, 010323 (2025)

Multiscale modeling of quantum computing registers

Robin Blume-Kohout, Quantum Performance Lab, Sandia National Laboratories Invited

Knowledge is power. We theorize about physical systems not just out of curiosity, but to empower their control and manipulation to achieve useful ends. I propose that models of many-qubit quantum computers that can predict their behavior — i.e., the outcome probabilities of quantum circuits — to within, say, 0.01% per logic gate, would be extraordinarily useful. They would inform design, debugging, and architecture of prototype quantum computers. Conversely, our abject failure (as a field) to achieve this level of predictive modeling precision should spark furious curiosity. What hidden phenomena are we missing? To control such phenomena we must first detect, understand, and model them. In this talk, I will outline a vision and a framework for enabling high-precision "soup to nuts" multiscale modeling of many-qubit quantum processors, and I will discuss progress at Sandia's Quantum Performance Lab toward unlocking the power of knowing what's really going on inside the fridge.

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Quantum control: geometric space curves, error mitigation, and quantum simulation

Edwin Barnes, Virginia Tech Invited

Future technologies such as quantum computing, sensing and communication demand the ability to control microscopic quantum systems with unprecedented accuracy. Control errors and environmental noise are among the primary obstacles to realizing these applications. I will present a new theoretical framework for deriving control waveforms that dynamically combat errors and decoherence. This theory exploits a rich geometrical structure hidden within the time-dependent Schrödinger equation in which quantum evolution is mapped to geometric space curves. I will discuss the application of this technique to the design of gates for superconducting, semiconducting, and atomic qubits. I will also discuss control-based quantum simulation algorithms.

Quantum sensing and control in space

Nicholas Bigelow, University of Rochester Contributed

TBD

Towards understanding and mitigating charge noise in Si/SiGe quantum dots

Feiyang Ye, University of Rochester Contributed

Electron spins in silicon quantum dots are excellent qubits due to their long coherence times, scalability, and compatibility with advanced semiconductor technology. Even though single- and two-qubit gates with fidelities above the fault-tolerant threshold have been achieved in Si quantum dots, charge noise in the semiconductor environment still hinders gate fidelities, and key questions like what fluctuators cause charge noise, what affects them, and where they are in the device, remain unanswered. Here, we probe individual two-level fluctuators (TLFs) in Si/SiGe quantum dots via simple quantum-dot transport measurements. We find that the TLF switching rates depend sensitively on gate voltages. Furthermore, we demonstrate a class of feedback techniques to stabilize an individual charged TLF in a Si/SiGe quantum dot by leveraging sensitive gate-voltage dependence of the switching times. Altogether, our results make progress towards understanding and mitigating charge noise in semiconductor quantum dots.

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Artificially intelligent Maxwell's demon for optimal control of open quantum systems

Robert Czupryniak, University of Rochester Contributed

Feedback control of open quantum systems is of fundamental importance for practical applications in various contexts, ranging from quantum computation to quantum error correction and quantum metrology. Its use in the context of thermodynamics further enables the study of the interplay between information and energy. However, deriving optimal feedback control strategies is highly challenging, as it involves the optimal control of open quantum systems, the stochastic nature of quantum measurement, and the inclusion of policies that maximize a long-term time- and trajectory-averaged goal. In this work, we employ a reinforcement learning approach to automate and capture the role of a quantum Maxwell's demon: the agent takes the literal role of discovering optimal feedback control strategies in qubit-based systems that maximize a trade-off between measurement-powered cooling and measurement efficiency. Considering weak or projective quantum measurements, we explore different regimes based on the ordering between the thermalization, the measurement, and the unitary feedback timescales, finding different and highly non-intuitive, yet interpretable, strategies. In the thermalization-dominated regime, we find strategies with elaborate finite-time thermalization protocols conditioned on measurement outcomes. In the measurement-dominated regime, we find that optimal strategies involve adaptively measuring different qubit observables reflecting the acquired information, and repeating multiple weak measurements until the quantum state is 'sufficiently pure', leading to random walks in state space. Finally, we study the case when all timescales are comparable, finding new feedback control strategies that considerably outperform more intuitive ones. We discuss a two-qubit example where we explore the role of entanglement and conclude discussing the scaling of our results to quantum many-body systems.

https://doi.org/10.1088/2058-9565/adbccf

Tuesday afternoon, June 24

Quantum computing with atoms and photons

Christopher Monroe, Duke University and IonQ Invited

Quantum computers exploit the bizarre features of quantum physics – uncertainty, entanglement, and measurement – to perform tasks that are impossible using conventional means. These may include the computing and optimizing over ungodly amounts of data, breaking encryption standards, and simulating models of chemistry and materials. Tempering the hype is the fact that there are few use cases that can be proven. Despite this, many important problems known and unknown will likely never be solved until we have quantum computers. Another major challenge is the notorious difficulty in building and scaling quantum computer hardware. Qubits based on individual atoms and interactions/networks based on electromagnetic and optical fields may be the only way to scale without breakthroughs in physics or materials. I will discuss the state-of-the-art in quantum computing using individual atoms and photons, and discuss their scaling, which will be undertaken by an uneasy coalition of scientists and engineers from academia, industry, and government.

Nonlinear Optics and Photon-Based Quantum Information

Robert W. Boyd, University of Rochester Invited

Nonlinear optics (NLO) plays a key role in creating quantum states of light used in the field of light-based quantum information. A well-known example is the process of spontaneous parametric down-conversion (SPDC), which is routinely used to produce entangled photon pairs. In SPDC, an intense laser beam excites a second-order NLO crystal. Some fraction of the photons in the incident beam split into two photons of lower energy. These daughter photons constitute an entangled photon pair.

The relation between NLO and the creation of quantum states of light exists at a fundamental level. Most common light sources, such as sunlight, lasers, discharge lamps, and LEDs, produce classical light. Classical light cannot be transformed into quantum light by means of a linear transformation; only a nonlinear transformation can turn classical light into quantum light.

Quantum states of light lend themselves to applications not possible with classical light. The field of quantum sensing is concerned with developing precision measurements methods. One sort of quantum sensing is quantum imaging, which seeks to produce better images using quantum methods. The image can be better in that it might possess higher spatial resolution, a larger signal-to-noise ratio, or be obtained using a small number of photons.

Our group has recently developed a quantum-enhanced phase microscope. The motivation for this study is that many biological materials possess very small intensity contrast but show significant phase contrast. Also, many biological materials are optically fragile and cannot withstand a high-intensity light field. This problem is aggravated through use of short-wavelength illumination, which is normally required to obtain good resolution. These difficulties can be mitigated through use of quantum methods. We will display micrographs of biological materials imaged with the quantum microscope.

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High-efficiency, low-loss Floquet-mode traveling wave parametric amplifiers

Kevin Patrick O'Brien, MIT EECS Invited

Superconducting qubits are one of the leading quantum computing platforms in part due to the nonlinearity of the Josephson junction. High quantum efficiency broadband amplification is a key requirement for high fidelity qubit readout and thus implementing quantum error correction. We illustrate the modeling and design of high quantum efficiency broadband parametric amplifiers using our open source package JosephsonCircuits.jl [1]. These amplifiers are engineered to match the Floquet modes in the amplifier to the eigenmodes of the environment, eliminating a previously ubiquitous noise mechanism in broadband amplifiers [2]. We present the fabrication of such amplifiers using a high-Q qubit fabrication process with state of the art junction critical current uniformity. We detail the characterization of these amplifiers including the highest reported quantum efficiency for a traveling wave parametric amplifier [3] and future directions of on-chip integration and isolation.

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[2] K. Peng, M. Naghiloo, J. Wang, G. D. Cunningham, Y. Ye, and K. P. O'Brien "Floquet-Mode Traveling-Wave Parametric Amplifiers" PRX Quantum 3, 020306 (2022)
[3] J. Wang*, K. Peng*, J. M. Knecht, G. D. Cunningham, A. E. Lombo, A. Yen, D. A. Zaidenberg, M. Gingras, B. M. Niedzielski, H. Stickler, K. Sliwa, K. Serniak, M. E. Schwartz, W. D. Oliver, K. P. O'Brien "High-Efficiency, Low-Loss Floquet-Mode Traveling-Wave Parametric Amplifier" arxiv 2503.11812 (2025)

Smart calibration of quantum dot devices

Justyna P. Zwolak, National Institute of Standards and Technology Invited

Scalable quantum computation with semiconductor quantum dots (QDs) depends on precise and adaptive control of gate voltages that define and manipulate individual qubits. Yet, operating QD-based qubits reliably requires precise, continual adjustment of multiple gate voltages to control individual charge carriers to form quantum bits. The challenge is compounded by the dynamic nature of QDs: their behavior shifts with small changes in temperature, charge noise, and material imperfections, requiring near-continuous monitoring and recalibration. Manual tuning quickly becomes infeasible as systems scale to many qubits.

To address this, we have developed a modular, autonomous, and platform-agnostic system for QD device calibration. Our approach breaks the complex tuning task into multiple specialized stages: device initialization, virtual gate definition (virtualization), charge state tuning, and optimization of interdot tunnel couplings (controllability). Each stage employs machine learning, optimization techniques, and physical insights to automate the interpretation of experimental data and inform the next control action.

Our intelligent tuning framework has demonstrated robust performance across device architectures and materials, from overlapping gate silicon devices to 2D quantum dot arrays. It not only reduces the burden on human operators but also establishes a benchmark for reproducibility, scalability, and cross-platform deployment. More broadly, our work illustrates how AI and automation can transform experimental workflows in quantum device control and accelerate progress toward practical quantum computing.

Ziegler, J. et al. (2023). Tuning arrays with rays: Physics-informed tuning of quantum dot charge states. Phys. Rev. Applied, 20(3), 034067.
Zwolak, J. P., & Taylor, J. M. (2023). Colloquium: Advances in automation of quantum dot devices control. Rev. Mod. Phys., 95(1), 011006.
Rao A. et al. (2025). Modular Autonomous Virtualization System for Two-Dimensional Semiconductor Quantum Dot Arrays. Phys. Rev. X 15(2), 021034.

Probing excited-state dynamics of transmon ionization

Zihao Wang, University of Rochester Contributed

The fidelity and quantum nondemolition character of the dispersive readout in circuit QED are limited by unwanted transitions to highly excited states at specific photon numbers in the readout resonator. This observation can be explained by multiphoton resonances between computational states and highly excited states in strongly driven nonlinear systems, analogous to multiphoton ionization in atoms and molecules. In this work, we utilize the multilevel nature of high-EJ/EC transmons to probe the excited-state dynamics induced by strong drives during readout. With up to 10 resolvable states, we quantify the critical photon number of ionization, the resulting state after ionization, and the fraction of the population transferred to highly excited states. Moreover, using pulse-shaping to control the photon number in the readout resonator in the high-power regime, we tune the adiabaticity of the transition and verify that transmon ionization is a Landau-Zener-type transition. Our experimental results agree well with the theoretical prediction from a semiclassical driven transmon model and may guide future exploration of strongly driven nonlinear oscillators.

arXiv:2505.00639

Physics and applications of Andreev spin qubits

Valla Fatemi, Cornell University Invited

Superconducting qubits and semiconducting qubits are two leading solid-state platforms for quantum computation, each coming with distinct strengths and challenges. Hybrid structures made of both semiconductors and superconductors aim to combine the best features of both platforms. One such hybrid structure is the Andreev spin qubit, which hosts a microscopic, fermionic spin degree of freedom inside a Josephson weak link. The key feature is the spin-dependent supercurrent – this physics enables long-range, quantum coherent interactions between spins despite their microscopic size, offering new architectural opportunities based on this hybrid system.

In this talk, I will first present an introduction to Andreev spin qubits and what is unique in relation to both quantum dot spin qubits and superconducting qubits (see also [1] for related perspectives). I will then describe a new insight as to how we can use Kramers' theorem to our advantage for designing error-correction modules [2], followed by our recent experiments developing the hardware to better understand coherence of Andreev spins hosted in InAs nanowires [3]. Finally, I will conclude with key future challenges and opportunities for this platform.

[1] A. M. Bozkurt and V. Fatemi, "Josephson tunnel junction arrays and Andreev weak links: what's the difference?," in Spintronics XVI, SPIE, Sep. 2023, pp. 35–43. doi: 10.1117/12.2678477.
[2] H. Lu, I. A. Day, A. R. Akhmerov, B. van Heck, and V. Fatemi, "Kramers-protected hardware-efficient error correction with Andreev spin qubits," Dec. 20, 2024, arXiv: arXiv:2412.16116. doi: 10.48550/arXiv.2412.16116.
[3] H. Lu et al., "Andreev spin relaxation time in a shadow-evaporated InAs weak link," Jan. 20, 2025, arXiv: arXiv:2501.11627. doi: 10.48550/arXiv.2501.11627.

Majorana zero modes and topological quantum computation: What, why, how, when?

Sankar Das Sarma, University of Maryland Invited

Topological quantum computing involves using non-Abelian Majorana zero modes for carrying out error-free fault-tolerant quantum computing. These Majorana zero modes are stable nonlocal topological excitations which are immune to all local noise, and hence are robust against quantum decoherence. Such low energy stable Majorana zero mode quasiparticles may emerge in low-dimensional topological superconductors, and they are their own antiparticles (hence, 'Majorana'). These quasiparticles are (SU2)2 anyons, obeying non-Abelian braiding statistics, and can be used for fault-tolerant quantum computation. I will discuss the current status of the search for non-Abelian Majorana zero modes in solid state systems, discussing both theory and experiment. I will also provide my personal prognosis on what the future holds for the subject.

Quantum computation using Majorana-based topological qubits

Roman Lutchyn, Microsoft Quantum Invited

Research in quantum computing has provided numerous new physical insights and the potential to exponentially increase computational power for solving significant problems in science and technology. The primary obstacle to building a scalable quantum computer is errors caused by decoherence. Topological quantum computing addresses this challenge by utilizing topological materials that inherently limit errors.

In this talk, I will discuss the engineering of topological superconductors that support Majorana zero-energy modes at the interface between a conventional superconductor (Aluminum) and a semiconductor with spin-orbit interaction (Indium Arsenide). I will present recent findings from the Microsoft Quantum team that indicate the emergence of topological superconductivity in proximitized semiconductor nanowires. Additionally, I will cover recent measurements of fermion parity, which represent a step towards the fusion of Majorana zero modes. Finally, I will outline a proposal for scalable quantum computing that involves topological qubits composed of superconducting islands in a Coulomb blockade regime, hosting aggregates of four or more Majorana zero modes.

Nature volume 638, pages 651–655 (2025)

All about PRX Quantum

Juzar Thingna, American Physical Society (PRX Quantum and Physical Review Applied) Contributed

In this talk, I will discuss PRX Quantum, a highly selective open-access journal in quantum science and technology, and highlight how our dedicated editorial team is committed to selecting the highest-quality research and providing a rigorous, constructive peer review process. Our goal is to enable researchers to share their most impactful work effectively, fostering progress and innovation within the quantum community.

Wednesday morning, June 25

Exploring quantum computing frontier with neutral atom systems

Mikhail Lukin, Harvard University and QuEra Computing Tutorial

We will discuss recent advances in realizing programmable quantum systems using neutral atom arrays excited into Rydberg states. These systems allow control over several hundred qubits in two dimensions and the exploration of quantum algorithms with encoded logical qubits and quantum error correction techniques. Recent experiments using neutral atom systems have redefined this exciting scientific frontier of quantum computing. They herald the advent of early error-corrected quantum computation and chart a path towards large-scale logical processors. Examples of emerging scientific directions, in areas ranging from many-body physics and quantum chemistry to quantum gravity will be discussed.

Unified picture of measurement-induced ionization in the transmon

Alexandre Blais, Université de Sherbrooke Invited

Circuit quantum electrodynamics (cQED) has emerged as a powerful platform for quantum computation and for the investigation of quantum optics at microwave frequencies. A critical part of all cQED experiments is qubit readout, which relies on microwave drives. In principle, higher drive amplitudes should lead to faster and more accurate readout. However, experiments have consistently shown that as the drive amplitude increases, the readout quality rapidly deteriorates, something that severely limits qubit readout in the laboratory. We begin by reviewing the basics of qubit measurement in circuit QED, followed by presenting numerical simulations that capture the dynamics of the readout process. Our findings reveal signatures of 'qubit ionization', where the qubit is brought to highly excited states by the readout drive, leading to a breakdown of the measurement fidelity. Building on previous theoretical and experimental advances, we present a comprehensive theoretical framework providing a physical picture of the origin of transmon ionization, together with a set of tools which can readily be used to predict its occurrence. We further discuss how this phenomenon is not limited to qubit readout but also manifests itself in strongly driven nonlinear circuits across various settings. Finally, we compare our results with recent experimental data.

Phys. Rev. X 14, 041023 (2024)

Building superconducting quantum interconnects

Aziza Almanakly, Massachusetts Institute of Technology Invited

Over the past twenty years, the field of quantum computing has progressed from the investigation of individual quantum systems towards the implementation of many-qubit processors. Quantum computation at scale will likely rely on networks that distribute entanglement via, for example, propagating photons throughout the computer. Systems of superconducting qubits strongly coupled to 1D coplanar waveguides, described by the field known as waveguide quantum electrodynamics (wQED), are a promising platform for such quantum communication networks. In this talk, we discuss a superconducting module which leverages quantum interference to emit microwave photons on-demand and in a user-specified propagation direction in a waveguide [1]. These microwave photons serve as carriers of quantum information. We then connect two of these modules to a common waveguide to demonstrate directional photon emission and absorption. We use this chiral (directional) quantum interconnect to generate remote entanglement as a resource for distributed quantum computing [2]. This quantum network architecture enables all-to-all connectivity between non-local processors for modular and extensible quantum computation.

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[2] A. Almanakly et al., "Deterministic Remote Entanglement using a Chiral Quantum Interconnect." arXiv:2408.05164 [quant-ph] (2024). Accepted by Nature Physics.

Non-Gaussian two-mode squeezing: applications to multi-ensemble spin squeezing and beyond

Aashish Clerk, University of Chicago Invited

Bosonic two-mode squeezed states are paradigmatic entangled Gaussian states that have wide utility in quantum information and metrology. In this talk, I'll discuss recent work showing that the basic structure of these states can be generalized to arbitrary bipartite quantum systems in a manner that allows simultaneous, Heisenberg-limited estimation of two independent parameters for finite-dimensional systems. Further, we show that these general states can always be stabilized by a relatively simple Markovian dissipative process. In the specific case where the two subsystems are ensembles of two-level atoms or spins, our generalized states define a notion of two-mode spin squeezing that is valid beyond the Gaussian limit and that enables true multi-parameter estimation. I'll discuss how these states can be dissipatively prepared using tools available in cavity QED setups .

Quantum simulations with arrays of radiatively coupled matter-wave emitters

Dominik Schneble, Stony Brook University Invited

Understanding and harnessing light-matter interactions in novel contexts is central to the development of modern quantum technologies. One example is the emerging field of waveguide QED, in which one or more quantum emitters are coupled to an engineered low-dimensional photonic bath. We explore fundamental questions in waveguide QED using a quantum simulation platform with ultracold atoms in an optical lattice, in which artificial quantum emitters undergo spontaneous decay by emitting single atoms, rather than single photons. I will discuss some of the features of matter-wave quantum emitters and present recent work on radiative collective and many-body effects in one-dimensional emitter arrays. [Work supported by NSF PHY-1912546/2208050]

Y. Kim, A. Lanuza, D. Schneble, Nature Physics 21, 70 (2025)
A. Lanuza, D. Schneble, Phys. Rev. Res. 6, 033196 (2024)

Noise

Tathagata Karmakar, University of California, Berkeley Contributed

In the presence of continuous monitoring, the conditional evolution of a quantum system is stochastic. A stochastic master equation can express the relevant dynamics. In certain instances, unitary feedback can negate the stochasticity due to conditional evolution, leading to deterministic dynamics. Our work looks at constructive methods to find such feedback for general quantum systems. For pure states, we express the resultant noise-cancelled dynamics in terms of a non-Hermitian Hamiltonian. We unify noise-cancelling feedback across several known examples of entanglement stabilization tasks and compare the dynamics against spectral properties of the associated non-Hermitian Hamiltonian. Our work is relevant for designing feedback protocols for state preparation and stabilization of continuously monitored quantum systems.

Superfunction superradar

John Howell, Chapman University Invited

Radar is used in a wide array of applications including archaeology, agriculture, transportation, navigation, law enforcement, noninvasive medical diagnostics, climate change monitoring, natural disaster mapping, defense etc. Range resolution in radar is the ability to determine the distance between two objects along the same line-of-sight when performing remote sensing. The prevailing thought is that radar range resolution is inextricably linked to the inverse bandwidth of a pulse or to the wavelength of the electromagnetic wave owing to the coherent nature of the interfering wavefronts. We quote, "Wave theory indicates that the best vertical resolution that can be achieved is one quarter of the dominant wavelength. Within that vertical distance any reflections will interfere in a constructive manner and result in a single, observed reflection" (originally stated in [1] and quoted in [2]). The desire for better range resolution has driven scientists and engineers to ever-higher frequencies radar. Unfortunately, propagation distance in the air, in the ground or in water decreases as the frequency of the radar increases. This means that using existing technologies an archaeologist can only peer a few centimeters below the surface to obtain sufficient resolution to observe a coin. Recently, we have explored novel techniques to improve range resolution far below the inverse bandwidth [3-5]. In this presentation, I will give an overview of radar, range resolution, and discuss a novel set of functions based on super oscillations that permit us measure and classify complex scattering distributions up to 100 times smaller than the inverse bandwidth of a pulse or the limit that has held for almost 100 years.

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[2] Adrian Neal, "Ground-penetrating radar and its use in sedimentology: principles, problems and progress," Earth-science reviews 66, 261–330 (2004).
[3] JC Howell, AN Jordan, B Šoda, A Kempf, "Super Interferometric Range Resolution", Physical Review Letters 131 (5), 053803
[4] AN Jordan, JC Howell "Fundamental Limits on Subwavelength Range Resolution", Physical Review Applied 20 (6), 064046 [5] AN Jordan, JC Howell, A Kempf, S Zhang, D White "The Best Radar Ranging Pulse to Resolve Two Reflectors", arXiv preprint arXiv:2405.09571

Collective atom-photon interactions in waveguide QED

Kanu Sinha, University of Arizona Invited

The interaction between a collection of atoms and light can be cooperatively modified via quantum correlations between the atoms. Such cooperative light-matter interaction can be understood as a constructive or destructive interference between the atomic dipoles and the emitted radiation, which manifests as an enhancement (superradiance) or suppression (subradiance) of the total spontaneous emission from the atomic ensemble. I will present an overview of collective atom-field interactions going from short inter-atomic separations to distances comparable to coherence length of the emitted photons, wherein the memory effects of the intermediary electromagnetic environment become pronounced. We demonstrate that such a system can exhibit surprisingly rich non-Markovian dynamics, with collective spontaneous emission rates exceeding those of Dicke superradiance ('superduperradiance'), formation of highly delocalized atom-photon bound states and spontaneous generation of emitter-emitter entanglement in the presence of delay. I will discuss the advantages of such non-Markovian dynamics towards sensing field distributions. As a spatially varying field influences the atoms (e.g., by inducing a relative frequency detuning in the atomic transitions), we demonstrate that time-delayed feedback can enhance the quantum Fisher information associated with field gradient sensing. Our results present a new avenue for atom-based gradiometric sensors, utilizing non-Markovian features of the electromagnetic environment.

[1] K. Sinha, P. Meystre, E. A. Goldschmidt, F. K. Fatemi, S. L. Rolston, and P. Solano, Phys. Rev. Lett. 124, 043603 (2020)
[2] K. Sinha, A. Gonzalez-Tudela, Y. Lu, and P. Solano, Phys. Rev. A 102, 043718 (2020)
[3] P. Solano, P. Barberis-Blostein and K. Sinha, Phys. Rev. A 107, 023723 (2023)
[4] K. Sinha, J. Parra-Contreras, A. Das, and P. Solano, N. J. Phys. 27 054101 (2025)
[5] W. Alvarez, P. Solano, K. Sinha, P. Barberis-Blostein, Phys. Rev. Research 6, 023213 (2024)

Parameter-Decoupled Superresolution: Breaking the Diffraction Barrier for Passive Sources

Xiao-Feng Qian, Stevens Institute of Technology Invited

The Abbe diffraction limit has long constrained resolution for two-point sources. While superresolution microscopy (SRM) techniques (e.g., STED, SIM, PALM) surpass this limit for controlled active sources (enhancing resolution from 200 nm to 10 nm), they fail for passive sources (e.g., stars, delicate biological units). Existing quantum demultiplexing methods for passive sources are restricted to idealized scenarios (equally bright, incoherent sources) and neglect practical challenges like partial coherence, brightness imbalance, noise, and misalignment.

We introduce a parameter-decoupled framework to estimate sub-wavelength separations of passive sources without prior knowledge or control. Our theory bypasses estimation of coherence, phase, brightness imbalance, and photon statistics, while a physics-informed machine learning model addresses noise, photon loss, and alignment errors. This integrated method achieves resolution $14\times$ below the diffraction limit (Ĩ3.5 nm in typical optical microscopy) with 82% fidelity on experimental data, rivaling state-of-the-art active-source techniques. Its robustness enables applications in astrophysics, live-cell imaging, and quantum metrology where source control is impossible.

Under review at Nature Communications

Quantum sensing and control in the presence of environmental noises

Ting Yu, Stevens Institute of Technology Invited

In this talk, we will tackle the problem of optimally controlled estimation of non-Markovian noise spectrum parameters as a dynamical process, inspired by recent advances in machine learning (ML). An operational challenge of this task is to determine the optimal time to make the measurement, such that the system has evolved long enough to acquire sufficient information on the environmental noises, but not too long for the information to be lost due to dissipation. Based on ML techniques, an optimized control scheme is designed to run over a representative ensemble and train a control field so that the optimal time for the measurement occurs at a prescribed runtime. This protocol demonstrates robustness to errors in the assumptions during the training process, while also enhancing measurement precision with non-Markovian memory effects. We show that the measurement uncertainty may approach the limits imposed by the Cramér-Rao bound.

Dawei Luo and Ting Yu, Learning Non-Markovian Noise Parameters Dynamically With Ensemble Optimal Control

Realization of versatile and effective quantum metrology using a single bosonic mode

Tanjung Krisnanda, National University of Singapore Invited

Quantum metrology offers the potential to surpass its classical counterpart, pushing the boundaries of measurement precision toward the ultimate Heisenberg limit. This enhanced precision is normally attained by utilizing large squeezed states or multiparticle entangled quantum states, both of which are often challenging to implement and prone to decoherence in real quantum devices. In this work, we present a versatile and on-demand protocol for deterministic parameter estimation that leverages two efficient state transfer operations on a single bosonic mode. Specifically, we demonstrate this protocol in the context of phase estimation using the superposition of coherent states in the bosonic circuit quantum electrodynamics (cQED) platform. With low average photon numbers of only up to 1.76, we achieve quantum enhanced precision approaching the Heisenberg scaling, reaching a metrological gain of 7.5(6) dB. Importantly, we show that the gain or sensitivity range can be further enhanced on the fly by tailoring the input states, with different superposition weights, based on specific system constraints. The realization of this versatile and efficient scheme affords a promising path toward practical quantum enhanced sensing, not only for bosonic cQED hardware but also readily extensible to other continuous-variable platforms.

PRX Quantum 6, 010304 (2025)

Quantum coherence and system scaling for clock and fundamental physics

Jun Ye, JILA, NIST and University of Colorado Invited

Scaling up quantum systems to long coherence and large system sizes promises to revolutionize the performance of atomic clocks and quantum sensors, giving opportunities for new discoveries. Quantum technology has brought tens of thousands of atoms to minute-long optical coherence, enabling the achievement of best measurement precision. Recent advances include engineering of a spin Hamiltonian for record clock accuracy, determination of the gravitational time dilation across a few hundred micrometers, and the use of spin entanglement for clock precision beyond the standard quantum limit at 1E-18. Meanwhile, the combination of ultrafast optics and precision metrology has given us new tools for nuclear physics, leading to the recent breakthrough of quantum-state-resolved laser spectroscopy of thorium-229 nuclear transition. The permeation of quantum metrology to all corners of physics sparks new ideas to probe the interface of gravity and quantum mechanics and search for new physics.

The Duan-Kimble quantum memory loading scheme revisited

Michael Raymer, University of Oregon Invited

We reexamine the Duan-Kimble memory-loading scheme, wherein the state of a single-photon qubit is entangled with a quantum memory consisting of a single-atom qubit in a strongly coupled optical cavity, providing the capability to load the photon's state into the memory.[1] We introduce an improved scheme—the push-pull configuration—where the photon and cavity are tuned at the midpoint between atomic resonances, [2] and show that it can outperform the original on-off configuration in which the photon and cavity are tuned exactly to one of the atomic resonances. The results play a role in dramatically increasing entanglement-distribution rates via a scheme called zero added-loss multiplexing (ZALM). [3]

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[2] Michael G. Raymer, Clark Embleton, and Jeffrey H. Shapiro. The Duan-Kimble cavity-atom quantum memory loading scheme revisited. Phys. Rev. Appl. 22 (2024): 044013 (2024)

[3] Jeffrey H. Shapiro, Michael G. Raymer, Clark Embleton, Franco N.C. Wong, and Brian J. Smith. Entanglement source and quantum memory analysis for zero-added-loss multiplexing. Phys. Rev. Appl. 22, 044014 (2024).

Partial optical coherence: applications in high-dimensional quantum state measurement

Anand Kumar Jha, IIT Kanpur, India Invited

The high-dimensional orbital angular momentum (OAM) states have several unique advantages for photonic quantum technologies compared to two-dimensional states. However, one of the major roadblocks in implementing OAM-based applications with their full potentials is the absence of an ideal OAM-mode detector. Despite numerous efforts in the last three decades, currently, there is no OAM detector that can detect a broad OAM-mode spectrum, has uniform detection-efficiency over all the modes, and measures the true spectrum of an arbitrary quantum state without the need for any prior information. In this talk, I will discuss how partial coherence properties could be utilized for efficient measurements of high-dimensional OAM quantum states, and present our last few years of efforts in this direction culminating in having a broadband, uniform-efficiency OAM detector that works with fidelities more than 98% and with dimensionalities up to 100 for arbitrary quantum states at both high-light and single-photon levels.

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3. Phys. Rev. Applied 13, 054077 (2020)
4. Science Advances 11, eadq7201 (2025).

Nanomaterials for spontaneous emission rate enhancement evidenced at single molecule level with nanometer resolution

Margoth Córdova-Castro, University of Ottawa Contributed

Understanding how to control the spontaneous emission of light, which determines how likely, how quickly, and where an excited emitter will release a photon, is a necessary part for new or advancing existing quantum technologies. The efficiency of a single-photon source can be significantly increased at room temperature by engineering the surrounding material/electromagnetic environment. The rate (Γ) at which an emitter can convert its excited-state energy into a photon increases as more photonic states are available to radiate into, Purcell-enhanced nanophotonic platforms have been used to demonstrate photon-efficient detection and control of quantum emitters, qubits, and quantum sensors. Yet, challenges in reproducibility and scalability persist.

We present different material platforms to enhance single emitter rate emission sources at room temperature demonstrating lifetime variations from ns to picosecond, observed at the single molecule and nanometer resolution. We implemented a new hollow nanocone metamaterial that behaves as a metamaterial in the near-IR and supports rich optical properties with angular illumination dependence and tunable dipolar and quadrupolar plasmonic resonances from visible to near-IR spectral range. The hollow geometry give rise to high field enhancement. We also demonstrate decay rate enhancement inside engineered hyperbolic metamaterials, previously proven to be highly efficient for a variety of sensing and nonlinear applications. Their optical properties can be described by an effective anisotropic permittivity tensor which can have real part of the diagonal components of opposite signs. In contrast to isotropic or anisotropic metamaterials operating in the elliptic regime of dispersion, hyperbolic metamaterials exhibit spectrally separated elliptical, epsilon-near-zero (ENZ) and hyperbolic regimes. The resulting extremely rich mode structure offers unique opportunities for local density of photonic states engineering.

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5. T. Stefaniuk, L. Nicholls, R. M. Córdova-Castro, M. Nasir, and A. V. Zayats, "Nonlocality-enabled pulse management in epsilon-near-zero metamaterials", Advanced Materials, 2107023, 2022

Scalable Quantum Nanophotonics with Integrated Color Centers in Silicon Carbide

Pranta Saha, University of California - Davis Contributed

We develop a wafer-scale process for quantum nanophotonics in silicon carbide (SiC), targeting scalable integration of color centers with photonic circuitry. Color centers in silicon carbide (SiC) are a promising platform for quantum information hardware, owing to their long spin coherence times and the ability to optically read out and entangle their spin states with NIR photons [1]. To fully leverage their capabilities, integration with photonic devices is essential for enhancing optical performance and scalability. Angle-etching has emerged as a prospective method for preserving color center quality, enabling suspended photonic structures with a triangular cross-section. Notably, chip-scale experiments have demonstrated well-preserved optical and spin coherence of SiC color centers integrated with triangular waveguides [2]. In this work, we introduce a distinct approach by realizing wafer-scale angle-etching on an arbitrary SiC substrate in a Reactive Ion Beam Etching system [3]. Our simulation results demonstrate that the triangular geometry in SiC supports single-mode waveguide propagation [4], high-Q optical resonances [4], photonic band gap engineering [5], scalable mesh photonics [6], and efficient integration with on-chip SNSPDs [7]. To complete the photonic interface, fishbone grating couplers designed for this geometry offer efficient free-space coupling of color center emission, enabling scalable readout and on-chip connectivity [8].

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[3] S. Majety, et al npj Nanophoton. 2, 3 (2025)
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Shell-shaped Bose—Einstein condensates in toroidal optical traps

Elisha Haber, University of Rochester Contributed

Bose—Einstein condensates (BECs) confined in curved, two-dimensional geometries exhibit unique properties that are absent in their flat counterparts due to their periodic boundary conditions and nonzero local curvature. In this work, we consider a shell-shaped 87Rb BEC confined to the surface of an anisotropic torus and discuss how this system could be realized in a microgravity environment with an optical trap. Using the Gross-Pitaevskii equation, we obtain the interaction energy of vortex pairs and study the dynamics a rotating BEC. Additionally, we introduce an optical lattice potential and show how the energy band structure varies by tuning the anisotropy and spatial curvature of the trap, which modify the vector potential felt by the atoms.

This work was supported by NASA/JPL RSA 1656126.

Quantum-like states

Gregory D. Scholes, Princeton University Invited

In this talk I will ask: Can a classical system mimic a quantum system? Or, in terms of a specific example, can we design a classical circuit that emulates a quantum computer? The advance of this work [1] is to demonstrate a way to construct complex classical networks that mimic the states and correlations—like entanglement—that are signatures of quantum systems. This tangible, physically realizable framework gives a new perspective on the quantum world. The work reported here uses a recent framework whereby a graph (in the mathematical sense) serves to connect a classical system to a state space that we call 'quantum-like' (QL). The graph plays a special dual role by directing design of the classical system and defining the state space, that comprises arbitrary superpositions of states in a tensor product basis. I will illustrate this with a specific example of a large, dynamical classical system—a system of coupled phase oscillators—that maps, via a graph, to the QL state space. In the limit of a strongly phase-locked classical network—that is, where couplings between phase oscillators are very large—the state space evolves according to unitary dynamics, whereas in the cases of weaker synchronization, the classical variables act as a hidden environment that promotes decoherence of superpositions.

1. Gregory D. Scholes and Graziano Amati, Quantum-like product states constructed from classical networks: Phys. Rev. Lett. 134, 060202 (2025).

Nonequilibrium steady state adventures with incoherent light

Paul Brumer, University of Toronto Invited

Many natural processes are driven by incoherent light, such as vision, energy transport and photosynthesis, and operate in the non-equilibrium steady state. Results will be described on the nature of the "dynamics" and role of coherences under such circumstances, including the counterintuitive Fano-Agarwal noise-induced coherences. Examples will be drawn from models of light-induced energy transport, vision, and rate laws.

Quantum control under strong light-matter interactions: Floquet dynamics and cavity polaritons

Jianshu Cao, MIT Invited

In the first half of the talk, I will introduce our work on Floquet dynamics and motivate the introduction of cavity polaritons as a new approach for quantum control. For a periodically driven dissipative quantum system, I will examine the condition for its thermalization to the Floquet-Gibbs distribution and discuss consequences of possible violations [1]. To probe the resulting Floquet dynamics, I will present the computed spectrum and analyze the signatures of dynamical symmetries [2]. Further, I'll compare Floquet dynamics under strong lasers and polariton dynamics in optical cavities and highlight potential advantages of cavity QED in quantum coherent control.

In the second half, I will first summarize the exciting progress in polariton chemistry and then focus on quantum transport of exciton-polaritons. In optical cavities, disordered molecules are coupled to cavity photons collectively, such that the cooperativity in the light-matter interaction can overcome the Anderson disorder and lead to a turnover in transport at an optimal level of static disorder.[3] Further, cavity photons can drastically enhance the coherent time scale of wave-packet motion and lead to noise-enhanced wave-packet spreading in the ballistic regime. [4]

(1) PRL 123, 120602 (2019) Discontinuities in driven spin-boson systems due to coherent destruction of tunneling: breakdown of the Floquet-Gibbs distribution
(2) PRL 126, 090601 (2021) Dynamical Symmetries and Symmetry-Protected Selection Rules in Periodically Driven Quantum Systems
(3) PRB 105(6), 064205 (2022), Unusual dynamical properties of disordered polaritons in microcavities
PRL. 130, 213602 (2023), Polariton localization and dispersion properties of disordered quantum emitters in multi-mode microcavities
(4) Nanophotonics, 13.14, 2575-2590 (2024)

Bridging electrodynamics and molecular dynamics in polariton simulations

Tao E. Li, University of Delaware Contributed

The formation of polaritons, hybrid light-matter states formed between molecular transitions and optical cavity modes, provides a novel means to alter chemical reaction pathways and energy transfer processes in the condensed phase. Understanding these intriguing polariton experiments requires to accurately account for both realistic cavity geometries and the interplay between polaritons and material dark modes arising from microscopic molecular interactions. Herein, we introduce two computational schemes for advancing our simulation capacity of polaritons in the condensed phase. The first approach, mesoscale cavity molecular dynamics (CavMD), can efficiently simulate vibrational strong coupling for a large ensemble of realistic molecules confined in a planar Fabry-Pérot cavity, in which all involved cavity photon modes are propagated in the normal mode basis. Equipped with this approach, we examine the necessary condition for inducing polariton-polariton scattering via atomistic simulations. The second approach, finite-difference time-domain method with auxiliary bath fields (FDTD-Bath), explicitly incorporates local bath degrees of freedom coupled to the material polarization to describe the dark-mode dynamics. With this explicit inclusion of the material bath modes, linear polariton spectra and Rabi-splitting-dependent polariton relaxation rates in planar Fabry-Pérot cavities are reproduced more accurately than those with the conventional FDTD approach. Given the parallelism efficiency of these two open-source computational approaches, a wide range of polariton phenomena involving realistic cavity geometries can be efficiently modeled in the near future.

1. Tao E. Li. "Mesoscale Molecular Simulations of Fabry-Pérot Vibrational Strong Coupling" J. Chem. Theory Comput., 20, 7016–7031 (2024)
2. Andres Felipe Bocanegra Vargas, Tao E. Li. "Polariton-Induced Purcell Effects via a Reduced Semiclassical Electrodynamics Approach" J. Chem. Phys., 162, 124104 (2025)
3. Xinwei Ji, Tao E. Li. "Selective Excitation of IR-Inactive Modes via Vibrational Polaritons: Insights from Atomistic Simulations" J. Phys. Chem. Lett., 16, 5034-5042 (2025)
4. Tao E. Li. "FDTD with Auxiliary Bath Fields for Condensed-Phase Polaritonics: Fundamentals and Implementation" arXiv:2505.23963 (2025)

Thursday morning, June 26

Novel quantum dynamics with superconducting qubits

Pedram Roushan, Google Quantum AI Tutorial

In recent years, superconducting qubits have emerged as a leading platform for quantum simulation, particularly for studying quantum dynamics on Noisy Intermediate-Scale Quantum (NISQ) processors. I will discuss some of our work within this broad area of research. In a recent study [1], we directly image the dynamics of charges and strings in (2+1)-dimensional lattice gauge theories. We identify two distinct regimes within the confining phase: in the weak confinement regime, the string exhibits strong transverse fluctuations, while in the strong confinement regime, these fluctuations are significantly suppressed. In another study [2], we observe a novel form of localization in quantum many-body systems in one and two dimensions. Despite the absence of disorder, energy perturbations do not spread, even when both the evolution operator and initial states are fully translationally invariant. These results demonstrate that NISQ processors—in the absence of fully developed quantum computers—are invaluable tools for probing non-equilibrium physics, offering critical insights into complex quantum dynamics.

[1] Cochran et al., Nature 642, 315–320 (2025)
[2] Gyawali et al., arxiv.org/abs/2410.06557

Resource-efficient, and robust: A unified toolkit for quantum characterization and probing

Susanne Yelin, Harvard University Invited

We introduce a toolkit of two resource-efficient protocols that share minimal assumptions, robust performance, and black-box or global control access to complex quantum systems. The first is an ansatz-free Hamiltonian learning algorithm achieving Heisenberg-limited precision with only black-box queries and minimal digital controls, while tolerating realistic SPAM errors. The second is a sample-efficient pairing-measurement scheme for fermionic quantum-gas microscopes, requiring only global pulses and site-resolved readout, robust to lattice inhomogeneities. By leveraging minimal structural assumptions and optimal scaling, these methods together enable precise characterization and probing of many-body interactions and correlations, advancing quantum simulation, sensing, and benchmarking across diverse platforms.

arXiv:2502.11900
arXiv:2412.13186

Quantum advantages in experiments: Computational & learning

Zlatko Minev, Google Quantum AI Invited

We present two complementary experimental advances on superconducting processors. First, we introduce a dynamical string-net preparation (DSNP) protocol that realizes Fibonacci string-net condensation and braids non-Abelian anyons to implement logical non-Clifford operations in proof-of-principle demonstrations of universal-gate primitives and in sampling chromatic polynomials at the golden ratio [1]. Although these experiments do not yet manifest full quantum advantage, they establish an interesting new pathway for topological state engineering and possible quantum advantages on graph problems. Second, we demonstrate genuine quantum advantage in process learning via an error-mitigated, entanglement-enhanced protocol for Pauli channels of in-context gats on real deviecs. By coupling system qubits to auxiliary noisy quantum memory and encoding all channel parameters into commuting observables, we achieve an exponential reduction in measurement complexity, realizing an overhead of 1.33 ± 0.05 per qubit, far below the fundamental conventional setting bounds, for processes on up to 64 qubits [2]. Together, these results offer new directions for experimentally implementable quantum advantage protocols in both learning and computational complexity problems.

[1] Z. K. Minev et al., Realizing string-net condensation: Fibonacci anyon braiding for universal gates and sampling chromatic polynomials, arXiv:2406.12820 (2024).
[2] A. Karamlou et al., Entanglement-enhanced learning of quantum processes at scale, arXiv:2408.03376 (2024).

Learning and engineering multi-qubit interactions

Iman Marvian, Duke University Invited

In this talk, I present new methods for characterizing and synthesizing multi-qubit interactions. In the first part, I discuss both theoretical and experimental results on a novel method for detecting n-body interactions in the presence of a global U(1) symmetry. In the second part, I describe a recent result on synthesizing multi-qubit, permutationally invariant gates, such as the Controlled-Z gate with an arbitrary number of controls, using the Jaynes-Cummings interaction with uniform coupling, also known as the Tavis-Cummings interaction.

Plato Deliyannis, Iman Marvian, arXiv:2506.03453 (https://arxiv.org/abs/2506.03453)
Liudmila A. Zhukas, Qingfeng Wang, Or Katz, Chris Monroe, IM, arXiv:2408.10475 (https://arxiv.org/abs/2408.10475)
Iman Marvian, Nature Physics volume 18, pages283–289 (2022)

Quantum simulations with neutral atoms

Ceren B. Dag, Indiana University Bloomington & Harvard University Invited

Unprecedented control on neutral atoms presents a unique opportunity to physicists to prepare fundamentally interesting and technologically useful quantum states of matter. This talk will be composed of two parts: (i) I will highlight a recent quantum simulation that we performed on publicly accessible Rydberg atom array of QuEra Computing. In this work, we experimentally investigate the far from equilibrium physics of transverse-field Ising model, a prototypical model in statistical mechanics, and uncover significant deviations from the theoretical predictions. We theoretically traced this discrepancy to atom motion which acts as an emergent natural disorder in Rydberg atom arrays and elucidated our observations with a minimal random spin model. (ii) I will present the observation of arguably the simplest example of topological matter in an analogue dipolar interacting Bose-Hubbard quantum simulator designed in Greiner Lab. This platform is ideal to study quantum criticality between topologically distinct phases which require nonlocal probes. We experimentally demonstrate that the observed topological matter can be trivialized once it is stacked with another copy, and it is robust against disorder due to the presence of average symmetry leading to the first quantum simulation of mixed-state order.

Analog and Digital Quantum Simulation of Open Many-Body Quantum Optics

Alex Rubin, University of California, Davis Contributed

Many-body cavity Quantum Electrodynamics (QED) exhibits collective phenomena which are of fundamental interest and promise to enable transformative quantum technologies including quantum networks, all-photonic quantum simulators, quantum memories, and novel computing paradigms based on photonic cluster states [1]. An important class of systems, a lossy cavity coupled to N emitters, is described by the open Tavis-Cummings model. We present analog and digital simulations of open TC physics on NISQ superconducting hardware. Our analog simulations take advantage of the close analogy between circuit and cavity QED, directly demonstrating photon blockade in open TC systems of up to 3 emitters via photon number-resolving spectroscopy [2]. Our digital simulations make use of recently developed theoretical methods for representing dissipative open TC dynamics using the unitary operations of a quantum processor with low overhead, allowing for efficient computation that avoids the exponential resource requirements of classical approaches [3,4]. These simulations can help understand the effect of emitter disorder on system behavior, which is particularly relevant since precise control of TC system parameters remains difficult in solid-state optical platforms. Our results show that quantum processors are emerging as powerful tools for studying and designing quantum optical technology in the near future as they continue to mature.

[1] - Majety, et al. J. Appl. Phys. 131, 130901 (2022)
[2] - Marinelli, et al. arXiv:2501.18751 (2025)
[3] - Rubin, et al. arXiv:2404.03861 (2024)
[4] - Sims, et al. arXiv:2501.18522 (2025)

Spectral statistics of many-body systems: a refined measure of quantum chaos and two crossovers

Aurelia Chenu, University of Luxembourg Invited

The spectral statistics of a many-body system indicates whether the system is integrable or chaotic. Different quantum chaotic systems share universal statistical laws, well described by random matrix theory. We first focus on isolated systems, described by Hermitian random matrices, and show a revised surmise that captures the correlation between eigenenergies at any spectral distance. This is a generalization of the well-known and very useful Wigner surmise. Such a tool can be viewed as a measure of quantum chaos; we illustrate how to use it to capture when and how a many-body spin chain deviates from the idealized model of integrable and chaotic random matrices.

However, quantum systems are never truly isolated but rather interact with their environment or a measuring device. So it worth asking what is the interplay between the loss of conserved quantities, captured by the crossover from integrability to chaos, and the openness of a system. Open systems require a complex non-Hermitian treatment. Using a spin chain with local random disorder as a toy model, we quantitatively show that two transitions happen as the disorder strength is increased. We find that Hermiticity is broken before integrability. The study of complex-spectral statistics we provide unveils the rich physics of a dissipative many-body system and pinpoints which regime is explored as the system becomes more and more open.

https://doi-org.proxy.bnl.lu/10.1103/PhysRevResearch.7.013098
https://arxiv.org/abs/2504.20134

Spin squeezed entanglement in dilute, dipolar systems

Norman Yao, Harvard University Invited

Quantum metrology makes use of structured entanglement to perform measurements with greater precision than would be possible with only classically correlated particles. A paradigmatic example of such entanglement is spin squeezing, which is known to be dynamically generated by the celebrated one-axis-twisting model, corresponding to an all-to-all coupled Ising Hamiltonian. Motivated by recent advances in a variety of quantum simulation platforms, there has been tremendous interest in the possibility of generating spin squeezing via Hamiltonians which do not require all-to-all interactions. In my talk, I will present evidence for the following conjecture, namely, that scalable spin squeezing can be realized in any model exhibiting finite-temperature, easy-plane ferromagnetism. This greatly expands upon the landscape of Hamiltonians that can be utilized to dynamically generate metrologically-useful entanglement. Finally, I will describe recent efforts in my group aimed at observing spin squeezing using strongly-interacting, atom-like impurity ensembles in the solid-state.

Non-Gaussian two-mode squeezing: applications to multi-ensemble spin squeezing and beyond

Aashish Clerk, University of Chicago Invited

Bosonic two-mode squeezed states are paradigmatic entangled Gaussian states that have wide utility in quantum information and metrology. In this talk, I'll discuss recent work showing that the basic structure of these states can be generalized to arbitrary bipartite quantum systems in a manner that allows simultaneous, Heisenberg-limited estimation of two independent parameters for finite-dimensional systems. Further, we show that these general states can always be stabilized by a relatively simple Markovian dissipative process. In the specific case where the two subsystems are ensembles of two-level atoms or spins, our generalized states define a notion of two-mode spin squeezing that is valid beyond the Gaussian limit and that enables true multi-parameter estimation. I'll discuss how these states can be dissipatively prepared using tools available in cavity QED setups .

Mapping electronic decoherence pathways in molecules

Ignacio Gustin, University of Rochester Contributed

Establishing the fundamental chemical principles that govern molecular electronic quantum decoherence has remained an outstanding challenge. Fundamental questions such as how solvent and intramolecular vibrations or chemical functionalization contribute to the decoherence remain unanswered and are beyond the reach of state-of-the art theoretical and experimental approaches. Here we address this challenge by developing a strategy to isolate electronic decoherence pathways for molecular chromophores immersed in condensed phase environments that enables elucidating how electronic quantum coherence is lost. For this, we first identify resonant Raman spectroscopy as a general experimental method to reconstruct molecular spectral densities with full chemical complexity at room temperature, in solvent, and for fluorescent and non-fluorescent molecules. We then show how to quantitatively capture the decoherence dynamics from the spectral density and identify decoherence pathways by decomposing the overall coherence loss into contributions due to individual molecular vibrations and solvent modes. We illustrate the utility of the strategy by analyzing the electronic decoherence pathways of the DNA base thymine in water. Its electronic coherences decay in 30 fs. The early-time decoherence is determined by intramolecular vibrations while the overall decay by solvent. Chemical substitution of thymine modulates the decoherence with hydrogen-bond interactions of the thymine ring with water leading to the fastest decoherence. Increasing temperature leads to faster decoherence as it enhances the importance of solvent contributions but leaves the early-time decoherence dynamics intact. The developed strategy opens key opportunities to establish the connection between molecular structure and quantum decoherence as needed to develop chemical strategies to rationally modulate it.

Spin systems strongly interacting with bosonic baths via noncummuting coupling operators

Jakub Garwola, University of Toronto Contributed

We present an analytic approach to treat open quantum systems strongly coupled to multiple environments via noncommuting system operators: a prime example is a qubit concurrently coupled to both decohering and dissipative baths. Our approach, which accommodates strong system-bath couplings, generalizes the recently developed reaction-coordinate polaron transform method [N. Anto-Sztrikacs et al., PRX Quantum 4, 020307 (2023)] to handle couplings to baths via noncommuting system operators. Our approach creates an effective Hamiltonian that reveals the cooperative effect of the baths on the system. For a spin impurity coupled to both dissipative and decohering environments, the effective Hamiltonian predicts the suppression of relaxation by decoherence, a phenomenon previously observed in simulations but lacking so far a theoretical foundation. We also apply the method to an ensemble of spins coupled to local baths through noncommuting operators, demonstrating the engineering of the Kitaev XY spin chain interaction. Noncommutativity is a feature of quantum systems; future prospects of our approach include the study of thermal machines that leverage such genuine quantum effects.

https://doi.org/10.1103/PhysRevB.110.174304

Variational quantum noise spectroscopy

Nanako Shitara, University of Colorado Boulder Contributed

Quantum noise spectroscopy protocols allow, in theory, the complete characterization of Gaussian, pure dephasing noise afflicting quantum systems, through reconstruction of its noise power spectrum. Yet, in practice, it remains difficult to obtain well-resolved spectral features, owing to the possibility of any two distinct noise spectra giving rise to similar dynamics under a given measurement sequence. In this poster I will present our recently developed variational quantum noise spectroscopy method, which overcomes this difficulty through variational optimization of the noise spectrum against multiple pulsed measurements simultaneously. This makes use of measurements that have been readily available but that have rarely been used to simultaneously constrain noise spectrum reconstructions. I demonstrate its success in reliably reconstructing complex noise spectra, even with input measurements afflicted by moderate measurement error. We further apply this method onto experimental measurements on near surface nitrogen-vacancy centers in diamond and show that it is able to recover a characteristic peak in the spectrum corresponding to the presence of hydrogen nuclei in its vicinity, a feature not recovered from the employed measurements using a method widely considered the standard in the field.

https://arxiv.org/abs/2411.17064

Thursday afternoon, June 26

Useful autonomous quantum machines

Nicole Yunger Halpern, National Institute of Standards and Technology Tutorial

Researchers have designed quantum thermal machines including quantum engines, refrigerators, and batteries. Some of these machines have been realized experimentally, yet most are not useful. For example, quantum engines operate at much lower powers than many macroscopic counterparts. Yet cooling a quantum engine, so that it behaves quantum mechanically, costs substantial work; and controlling the engine costs more resources. Autonomous quantum machines, which require no time-dependent classical control, offer greater hope for practicality. I will illustrate with an autonomous quantum refrigerator that can reset computational qubits in a superconducting-qubit quantum computer. In a proof-of-principle experiment, the refrigerator cooled an initially excited qubit to approximately 22 mK, lower than the temperatures achieved by state-of-the-art reset protocols. Also, I will propose criteria for useful autonomous quantum machines, inspired by DiVincenzo's for quantum computing. [1] Aamir, Jamet Suria, Marín Guzmàn, Castillo-Moreno, Epstein, NYH, and Gasparinetti, Nat. Phys. 21, 318–323 (2025). [2] Marín Guzmán, Erker, Gasparinetti, Huber, and NYH, Rep. Prog. Phys. 87, 12 (2024).

[1] Aamir, Jamet Suria, Marín Guzmàn, Castillo-Moreno, Epstein, NYH, and Gasparinetti, Nat. Phys. 21, 318–323 (2025).
[2] Marín Guzmán, Erker, Gasparinetti, Huber, and NYH, Rep. Prog. Phys. 87, 12 (2024).

High-kinetic-inductance resonators for hybrid quantum architectures and photonic metamaterials

Pasquale Scarlino, EPFL Invited

Semiconductor spin qubits offer a promising route to scalable quantum computing, but their inherently short-range coupling imposes stringent constraints on device architecture. To overcome this limitation, we draw inspiration from circuit QED and use high-impedance superconducting resonators to mediate long-distance interactions. We have recently demonstrated strong coupling between confined charges in GaAs [1] and Ge [2] quantum dots (QDs) and microwave photons. In particular, in the Ge platform, we recently achieved vacuum Rabi splittings up to 260 MHz and a cooperativity of 100 between a hole charge qubit in planar Ge and a frequency-tunable SQUID-array resonator ($Zr = 1.3\,k\Omega$), paving the way for coherent spin–spin coupling over extended distances.

An additional advantage of high kinetic inductance resonators is their extreme compactness. We exploit this feature to implement low-disorder coupled cavity arrays (CCAs) using NbN thin films, enabling 1D quantum metamaterials with engineered band structures and cosine-like dispersions [3]. We have fabricated arrays comprising up to 100 ultracompact resonators, studied topological edge states in SSH-type geometries, and assessed disorder resilience via frequency- and time-domain analyses. We are also exploring the superstrong multimode coupling regime [4] by embedding a superconducting 'giant' artificial atom coupled at multiple points of the ultracompact cavity array.

Together, these results highlight the exceptional versatility of high kinetic inductance devices. They serve both to enhance light–matter interaction in hybrid QD–cavity systems and to enable the design of complex quantum photonic environments [5], making them central to the development of next-generation hybrid quantum technologies.

[1] P.Scarlino et al., Phys. Rev. X 12, 031004 (2022)
[2] F. De Palma et al., Nat. Commun. 15, 10177 (2024)
[3] V. Jouanny et al., Nat. Commun. 16, 3396 (2025)
[4] R. Kuzmin et al., npj Quantum Information 5, 20 (2019)
[5] C.W. Kim et al., PRX Quantum 3, 040308 (2022)

The limits of control in semiconductor quantum devices

Natalia Ares, University of Oxford Invited

As the complexity of solid-state quantum circuits grows, fluctuations and disorder emerge as fundamental constraints limiting reproducibility and challenging control. I will discuss how advanced machine learning techniques can address these challenges. I will present algorithms that allow for autonomous tuning and characterisation of quantum devices, including the first fully automatic tuning of a spin qubit. These approaches not only enable scalability, but also provide access to otherwise inaccessible device parameters, offering deeper insights into their underlying physics. Building on this, I will present a complementary perspective: how the same fluctuations that hinder control can be used to uncover the intrinsic thermodynamic limits of quantum devices. In particular, I will show how nanoscale systems allow us to probe the fundamental energy costs of information processing. Together, these perspectives highlight both the constraints and emerging opportunities in the control of semiconductor quantum technologies.

J. Schuff, et al. arXiv:2402.03931
D.L. Craig et al. Phys. Rev. X 14, 011001 (2024)
K. Aggarwal et al. arXiv:2412.06916
V. Wadhia et al. arXiv:2502.00096.

On-chip spin qubit communications

Xuedong Hu, University at Buffalo Invited

The short-range nature of the exchange interaction, which underlies two-qubit gates for spin qubits in semiconductor nanostructures, means that longer distance communication remains a significant challenge for this qubit platform. One pathway toward a scalable quantum computing architecture for spin qubits is via electron shuttling. Among the variety of ways an electron can be transported, such as the bucket brigade or the conveyor belt approach, surface acoustic waves (SAW) is an intriguing possibility. Experimentally, it has been shown that SAW can indeed transport a single or multiple electrons from one quantum dot to another with high fidelity.

Here we present a comprehensive study of SAW and its utility in electron shuttling. After clarifying the different SAW modes in a piezoelectric material, we focus specifically on how an electron is picked up by an SAW from a fixed quantum dot. To maintain the integrity of the spin sector, this pick-up process should be adiabatic, so that the mixing between spin and orbital degrees of freedom is minimized. We study the electron transfer process by first setting up the problem in a reference frame that moves with the SAW dot, and numerically calculate the time-dependent electron wave function through the transfer process. Our results show that this process is decidedly nonadiabatic. We vary several system parameters, and find that the electron can indeed be picked up with high fidelity, albeit in a wave packet consisting of many excited orbital states. Keeping this high degree of excitation in mind, we calculate electron spin relaxation in excited orbital states, and find interesting features with respect to their dependence on the applied magnetic field, degree of orbital excitation, and moving velocity.

We acknowledge financial support by US ARO via grant W911NF2310018.

Time-resolved stochastic dynamics of quantum thermal machines

Abhaya S Hegde, University of Rochester Contributed

Steady-state quantum thermal machines are typically characterized by a continuous flow of heat between different reservoirs. However, at the level of discrete stochastic realizations, heat flow is unraveled as a series of abrupt quantum jumps, each representing an exchange of finite quanta with the environment. In this work, we present a framework that resolves the dynamics of quantum thermal machines into cycles classified as engine-like, cooling-like, or idle. We analyze the statistics of individual cycle types and their durations, enabling us to determine both the fraction of cycles useful for thermodynamic tasks and the average waiting time between cycles of a given type. Central to our analysis is the notion of intermittency, which captures the operational consistency of the machine by assessing the frequency and distribution of idle cycles. Our framework offers a novel approach to characterizing thermal machines with significant relevance to experiments involving mesoscopic transport through quantum dots.

Phys. Rev. Lett. 134, 150402 (2025)

Towards quantum simulation with trapped-ion qudits

Martin Ringbauer, University of Innsbruck Invited

Today's quantum computers and simulators are almost exclusively built for binary information processing. Yet nature rarely gives us two-level systems. Hence, not only do our quantum information carriers tend to have a multilevel structure that is artificially restricted to two levels, but also the problems we want to study using quantum devices share the same structure. Taking this insight seriously, I will discuss the opportunities and challenges in developing quantum computing hardware that natively operates with qudits, rather than qubits as the fundamental unit of information. The potential of this approach will be exemplified by key applications from optimal quantum measurements to native qudit quantum simulations.

Circuit QED with molecular spin qudits

Fernando Luis, Instituto de Nanociencia y Materiales de Aragón (INMA), CSIC-Universidad de Zaragoza Invited

Scaling up quantum processors remains very challenging, even for today's most successful platforms. Molecular complexes, synthesized by chemical methods, combine a perfect reproducibility with the ability to tune their properties. The latter property allows scaling up quantum resources within each molecule, e.g. by encoding multiple qubits or, in general, d-dimensional qudits in their electronic and nuclear spin states. A molecule can then can act as a small-scale quantum processor or even correct errors [1-4]. Exploiting these systems calls for a solid-state platform able to initialize, control and read-out the molecular spins, and of establishing the communication channels between remote spins that are needed for full scalability [5]. I'll discuss recent experiments aimed at achieving this goal by coupling molecular spins to chips hosting multiple LC superconducting resonators and transmission lines [6-8]. Results performed on molecular spin ensembles provide proof-of-concept implementations of the basic quantum operations. Also, we find that the circuit can mediate effective interactions between distinct spin ensembles located on separately addressable remote resonators. In the case of electronuclear spin qudits, high cooperativity coupling to electronic and even nuclear spins has been achieved [6], which provide the basis for a full control and detection of the multiple spin states. Finally, I'll discuss different strategies, based on the optimization of either the circuit [9] or the molecular integration [10], for extending this approach to address individual molecular spins.

G. Aromí, et al, Chem. Soc. Rev. 41, 537 (2012)
A. Gaita-Ariño et al, Nature Chem. 11, 301 (2019)
S. Carretta, et al, Appl. Phys. Lett. 118, 24050 (2021)
A. Chiesa et al, Reports Prog. Phys. 87, 034501 (2024)
A. Chiesa et al, Phys. Rev. Applied 19, 064060.(2023)
V. Rollano et al, Commun. Phys. 5, 246 (2022)
M. Rubín-Osanz, et al, Low Temp. Phys. 50, 520 (2024)
I. Gimeno et al, Phys. Rev. Appl. 20, 044070 (2024)
I. Gimeno et al, ACS Nano 14, 8707 (2020)
A. Urtizberea et al, Mater. Horiz.7, 885-897 (2020)

Quantum Error Correction of Qudits Beyond Break-even

Benjamin Brock, Yale University Invited

Hilbert space dimension is a key resource for quantum information processing. A large Hilbert space is not only an essential requirement for quantum error correction, but it can also be advantageous for realizing gates and algorithms more efficiently. There has thus been considerable experimental effort in recent years to develop quantum computing platforms using qudits (d-dimensional quantum systems with d>2) as the fundamental unit of quantum information. Just as with qubits, quantum error correction of these qudits will be necessary in the long run, but to date error correction of logical qudits has not been realized experimentally.

In this talk [1], I will present the first experimental demonstration of an error-corrected logical qutrit (d=3) and ququart (d=4), which we realize by employing the Gottesman-Kitaev-Preskill (GKP) bosonic code [2] in a superconducting circuit platform. Using a reinforcement learning agent [3], we optimize the GKP qutrit (ququart) as a ternary (quaternary) quantum memory and achieve beyond break-even error correction with a gain of 1.82 +/- 0.03 (1.87 +/- 0.03). This work represents a new way of leveraging the large Hilbert space of a harmonic oscillator for hardware-efficient quantum error correction.

Brock et al., arXiv:2409.15065, accepted to Nature.

Transmon qudit control and tomography via multi-frequency driving

Elizabeth Champion, University of Rochester Contributed

Qudits hold great promise for efficient quantum computation and the simulation of high-dimensional quantum systems. Most qudit experiments to date have relied on decompositions of SU(d) operations into series of qubit-like rotations between two-level subspaces of adjacent states. In this talk I will discuss recent experiments which employed simultaneous multi-frequency drives to generate rotations in an effective spin-7/2 system mapped onto the energy eigenstates of a superconducting circuit. We implement single-shot readout of the 8 states using multi-tone dispersive readout and exploit the strong nonlinearity in a high-EJ/EC transmon to simultaneously address each transition and realize a spin displacement operator. Combining the displacement operator with a virtual SNAP gate, we realize arbitrary single-qudit unitary operations in O(d) physical pulses. We extend this to a new scheme for qudit state tomography requiring only O(d) pulses to fully characterize a qudit state. Our approach to qudit control and measurement can be readily extended to other physical platforms that realize a multi-level system coupled to a cavity and can become a building block for efficient qudit-based quantum computation and simulation.

E. Champion, Z. Wang, R. W. Parker, M. S. Blok. Efficient control of a transmon qudit using effective spin-7/2 rotations. Phys. Rev. X (Accepted May 2025)

Globally driven superconducting quantum compute

Riccardo Aiudi, Planckian

Traditional quantum computing (QC) architectures necessitate addressing each qubit individually, resulting in an excessive number of control lines entering the quantum processor—a challenge known as the "wiring problem." Moreover, superconducting qubits typically experience an undesirable "residual" longitudinal ZZ interaction between neighboring qubits, leading to phase accumulations that must be managed during computation. To offer a solution to these daunting issues, we present [1] a universal superconducting QC architecture where, exploiting the presence of always-on ZZ coupling terms, local driving of each individual qubit is replaced by *global* pulses that control *collectively* a large collection of the memory registers of the model, hence drastically reducing the total number of wires necessary to run the computation. Nevertheless pioneering global schemes of QC have been proposed [2] so far, these failed to reach the readiness level necessary to be competitive with models based on local control. Our scheme is inspired by a recent disruptive advancement that was made by Cesa and Pichler [3], who presented a universal quantum computer based on globally-driven Rydberg atoms. In our work [1], we propose a generalization of such results to a solid-state, superconducting platform based on a 2D ladder hosting three different species of superconducting qubits with a total of three control lines. In stark contrast with the existing literature, our scheme exploits the always-on longitudinal ZZ coupling which combined with specific driving frequencies, enables the reach of a blockade regime emulating the Rydberg blockade, which plays a pivotal role in the computing scheme. In comparison with the model proposed by Ref. [3], our proposal markedly reduces the number of physical qubits required for universal computation and for the initialization process

[1] R. Menta, F. Cioni, R. Aiudi, M. Polini, and V. Giovannetti, arXiv:2407.01182
[2] S. Llyod, S. C. Benjamin, Phys. Rev. A 61, 020301
[3] F. Cesa, H. Pichler, Phys. Rev. Lett. 131, 170601

Optimal Control for Enhancing Entanglement in Continuously Monitored Two-Qubit Systems

Adithi Ajith, Chapman University

Controlling quantum entanglement in a robust and resource-efficient manner is essential for advancing quantum information processing. In this work, we develop an optimal control framework to manipulate entanglement in continuously monitored two-qubit systems. Our method combines the Chantasri-Dressel-Jordan (CDJ) stochastic path integral formalism with Pontryagin Maximum Principle (PMP) to derive optimal protocols that enhance entanglement. Specifically, we investigate the optimal strength of a tunable coupling Hamiltonian under two different diffusive measurement scenarios: local spin measurements and half-parity measurements. Within the CDJ-P framework, we show that the optimal control assumes a "bang-bang" structure. We quantify entanglement enhancement along the most likely quantum trajectories. This approach significantly enhances entanglement across a large set of stochastic trajectories. Our results demonstrate that the CDJ-Pontryagin framework is a powerful tool for controlling entanglement in continuously monitored quantum systems.

A. Ajith, T. Karmakar, A.N. Jordan, "Optimal Control for Entanglement Manipulation in Continuously Monitored Systems", in prep.

Broadband photonic structures to achieve high coupling efficiencies and Purcell factors with dark and interlayer excitons in 2D materials

Pierre-Louis de Assis, Universidade Estadual de Campinas

Near unity coupling between a dipole and a target optical mode, and Purcell factors higher than 10—leading to an improvement on emission rates of at least one order of magnitude, which mitigates spurious effects from the environment—are highly desirable features for photonic structures intended for use in single-photon sources. Slot waveguides—formed by a thin low-index dielectric sandwiched between two thicker high-index ones, such as silicon nitride/silica/silicon nitride, or silicon/silica/silicon—have been demonstrated as being capable of achieving such a performance when a dipole is embedded on the low-index region, albeit with a coupling lower than 60%, due to the random orientation of dipoles.

The energy in slot guided modes is tightly confined in the low-index region, a feature that leads to high Purcell factors. The nature of the constructive interference of evanescent waves that forms such modes, however, means that they are strongly polarized in the direction perpendicular to the interface between the different dielectrics that compose it. While this leads to a near unity coupling to dipoles oriented in that direction (out-of-plane, with respect to the waveguide), it means that in-plane dipoles will have near zero coupling to the guided mode, reducing the total effective coupling.

We show that dark excitons in 2D materials, which can be shown to be out-of-plane dipoles, and interlayer excitons in 2D heterostructures, which are also naturally out-of-plane, are ideally suited to be used with slot waveguides. The applications of such a structure can go beyond single photon sources and enable a new platform for the study of dark excitons, which are typically probed with near field technique.

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Decoherence of a Uniformly Accelerating Particle

Aaron Bartleson, University of Arizona

We show that a uniformly accelerating, spatially-superposed particle interacting with the Minkowski vacuum exhibits decoherence in the position basis. Such spatial decoherence arises from the transformed state of the field seen in the particle's frame, which we investigate for two specific cases: uniform linear acceleration and uniform circular motion. In the case of uniform linear acceleration, it is well-known that the particle observes a thermal field at the Davies-Unruh temperature T_{DU}—we demonstrate that the backaction of such a field leads to a spatial decoherence consistent with that of a stationary particle immersed in a thermal field at T_{DU}. On the other hand, a particle in uniform circular motion experiences a non-Planckian spectrum [1] which leads to decoherence dynamics qualitatively different from those of a particle in uniform linear acceleration. Since the particle's trajectory in Minkowski spacetime determines the apparent correlations created between the otherwise uncorrelated vacuum field modes, the choice of trajectory thus determines the rate of decoherence experienced by the particle. Our results are pertinent to recent studies of decoherence near black hole event horizons [2], and will help delineate the role of Killing horizons in engendering such decoherence.

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Dynamical Sweet and Sour Regions in Bichromatically Driven Floquet Qubits

D. Dominic Briseño-Colunga, Chapman University

Frequency-tunable qubit architectures allow for the engineering of tunable couplings and fast high-fidelity parametric gates through their frequency modulation, making them a leading candidate for scalable quantum computing. However, these same systems are subject to fast dephasing from ubiquitous 1/f noise, greatly limiting the utility of the frequency control. We show that driving the system with two periodic drives of distinct commensurate frequencies can suppress the impact of 1/f noise within a tunable continuous manifold of dynamically protected operating points, restoring the utility of the frequency control. We employ Floquet theory to analyze the spectral and lifetime characteristics of a bichromatically driven two-level system and highlight both regions of high coherence (dynamical sweet spots) and regions of extreme sensitivity to instrumentation noise (dynamical sour spots). Notably, we show that bichromatic drives allow for large, continuous regions in the drive frequency with double protection against instrumentation and 1/f noise (doubly sweet spots), in contrast to point-like sweet spots of the monochromatically driven case.

Poincaré beams in turbulent media for communications

Carlos Cardoso-Isidoro, Colgate University

Transverse spatial modes of Poincaré beams, which arise from superpositions of beams with orbital angular momentum (OAM), provide a unique way to visualize and distinguish states within the unbounded state space of these beams. This rich state space, alongside other notable properties, makes Pincaré beams particularly promising for free-space optical communications. However, practical experiments that differentiate these beams states often rely on complex optical setups or advanced classification algorithms. In this work, we explore the impact of turbulence on Poincaré beams, simulated using Noll Phase screens, and present a simplified detection method where beam states are identified through the rotation of the beam and the rotation of the detectors. By incorporating the rotation speed as a new degree of freedom, we can encode additional information. We conclude that this communication scheme not only offers robust encoding and decoding of mode information and angular velocity, but also enhances resistance to turbulence distortion, providing a potential solution for more reliable and efficient free-space communications.

Galvanically connected dc-SQUID as a tunable coupler for fluxonium qubits

Abhishek Chakraborty, University of Rochester

Tunable couplers enable the realization of efficient two-qubit gates with a high on/off coupling ratio and reduced crosstalk within a single design. In this work, we theoretically explore the possibility of using a dc-SQUID, galvanically connecting two superconducting fluxonium qubits, as a tunable coupler. We compare grounded and floating designs for fluxonium for this coupling scheme and examine the effects of fabrication uncertainty and decoherence. We numerically simulate gates from the f-Sim family using fast-flux control on the coupler and qubits.

Noise vs non-Hermiticity

Aurelia Chenu, University of Luxembourg

We study the quantum dynamics generated by a non-Hermitian Hamiltonian subject to stochastic perturbations in its anti-Hermitian part, describing fluctuating gains and losses. The dynamics averaged over the noise is described by an 'anti-dephasing' master equation—that is neither trace-preserving nor of Lindblad form. We characterize the resulting state evolution and analyze its purity. The properties of such dynamics are illustrated in a stochastic dissipative qubit. Our analytical results show that adding noise allows for a rich control of the dynamics, stabilizing the lossy state and making state purification possible to a greater variety of steady states.

https://arxiv.org/abs/2407.07746 (PRL in press)

Towards Matterwave Interferometry With Levitated Nanoparticles and Tests of Gravity at Short Distances

Andrew Mordechai Dana, Northwestern University

Optical levitation in ultra-high vacuum (UHV) and cryogenic environments provides a platform potentially capable of providing quantum coherences of tens to hundreds of milliseconds for objects such as silica nano-spheres. Demonstration of matter-wave interference with optically levitated nanospheres has the potential to extend the current limit on matter-wave interference by three to four orders of magnitude, pushing the experimental limits on matter-wave duality. This would provide pathways towards the realization of gravity-induced entanglement experiments and tests of decoherence and wave function collapse models. To preserve a coherence time of approximately 200ms, experimental challenges such as near ground state cooling of the particles center of mass motion, pressures below 10-13mbar, internal temperatures below 100K, and relative position stability on the order of tens of nanometers must be overcome. This apparatus additionally allows for ultra-sensitive measurements of short-range forces enabling tests of the Casimir-Polder force and possible corrections to Newtonian gravity in the sub-micron regime.

arXiv:2504.18389, Phys. Rev. D 92, 062002, Phys. Rev. A 93, 053801

Non-Markovian spontaneous emission in a tunable cavity formed by atomic mirrors

Annyun Das, Department of Physics and Wyant College of Optical Sciences, University of Arizona

We analyze the non-Markovian spontaneous emission dynamics of a two-level test atom placed in a cavity formed by two atomic arrays in a waveguide quantum electrodynamics (QED) setup. We demonstrate a crossover from single-mode to multimode strong coupling cavity QED as the cavity length d becomes comparable to the coherence length associated with collective spontaneous emission v/(N). The resulting non-Markovian dynamics of the test atom and the emergent spectral density of the field are analyzed as a function of various tunable atomic array parameters: number of atoms, length of the atomic cavity, and resonance frequency of the atoms forming the atomic mirrors. Our results show limitations to cooperatively enhanced light-matter coupling in the presence of time-delayed feedback. We further illustrate that the non-Markovian system dynamics can be efficiently approximated in terms of a few modes of the emergent spectral density of the field.

arXiv:2504.09281v2 (Non-Markovian spontaneous emission in a tunable cavity formed by atomic mirrors)

Light-Matter interaction beyond the dipole approximation

Rishabh Dora, University of Rochester

We present a general theoretical framework for light-matter interactions beyond the dipole approximation between a non-uniform field and extended systems without invoking any higher-order multipolar expansion by utilizing the Power-Zieneau-Woolley (PZW) Hamiltonian. We develop a computational scheme to capture full spatial structure of the interaction Hamiltonian in a localized Wannier functions basis, which interfaces straightforwardly with standard electronic structure codes. We illustrate the approach by modeling a simple Su-Schrieffer-Heeger (SSH) chain interacting with an ultrashort Gaussian laser beam. We investigated the effects of considering the full spatial profile of the field, as well as the validity of dipole approximation depending on the unit-cell size and the wavelength of incident light. We also investigate the light interactions when there is disorder in the system due to Stark shifts. We find that the uniform excitation within the dipole approximation shows a sharp contrast to the exact dynamics induced by partial illumination of the chain by a Gaussian beam; however, it remains remarkably accurate until the beam's spot size is comparable to the total length of the chain. The dipole approximation holds robust even when the unit-cell length becomes comparable to the wavelength, and in non-periodic systems. Our general approach to light-matter interactions provides new insights into the regimes where beyond-dipole effects become significant, and can be applicable to nanojunctions.

Counting observables and stochastic excursions

Guilherme Fiusa, University of Rochester

Understanding fluctuations of observables across stochastic trajectories is essential for various fields of research, from quantum thermal machines to biological motors. We introduce the notion of stochastic excursions as a framework to analyze sub-trajectories of processes far from equilibrium. Given a partition of state space in two phases, labeled active and inactive, an excursion starts with a transition into the active phase and ends upon returning to inactivity. By incorporating counting variables, our approach captures finite-time fluctuations and trajectory-level behavior, providing insights on thermodynamic trade-offs between energy expenditure, entropy production and dynamical activity. As our main result, we uncover a fundamental relation between fluctuations of counting observables at the single-excursion level and the steady state noise obtained from full counting statistics. We also show the existence of an exchange-type fluctuation theorem at the level of individual excursions. As an application, we explore how analyzing excursions yields additional insights into the operation of the three-qubit absorption refrigerator.

https://arxiv.org/abs/2505.06208

Laboratory measurements of gravitational lensing diffraction

Enrique J. Galvez, Colgate University

We have developed a platform to simulate gravitational lensing in the laboratory [1]. We do this by imaging the light deflected by a spatial light modulator programmed with the predictions of general relativity. The use of a coherent light source and laboratory alignments allow us to set up and measure the diffraction patterns produced by gravitational lensing. This has not been possible to obtain in astrophysical observations due to spatial and temporal coherence challenges. We report on the case study of lensing by a binary system, which is rich in structure, showing interference-modulated caustics. The diffraction patterns evolve in shape and structure as a function of the parameters of the problem. Comparisons with theoretical calculations and modeling are excellent. These laboratory measurements may inform gravitational-wave diffraction, which is expected to be observable.

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Coherence uncertainty of quantized light

Martti Hanhisalo, University of Eastern Finland

In quantum physics, a primary concept and major manifestation of quantum complementarity is the uncertainty principle. It states that quantum objects may have complementary observables whose values cannot be simultaneously known with ultimate precision. Light exhibits such quantum uncertainty via its several fundamental properties including amplitude, phase, spectrum, and polarization. These nonclassical features set fundamental boundaries for optical sensing, metrology, and polarimetry. However, they also offer opportunities for quantum-enhanced measurement techniques that can outperform classical methods.

Here, we introduce the concept of first-order coherence uncertainty of quantized light fields. We concentrate primarily on a single monochromatic plane wave; such light is classically fully coherent and shows no fluctuations in amplitude, phase, or polarization. For scalar light, we find that the underlying photon number fluctuations translate into coherence uncertainty. Hence, the coherence fluctuations vanish only for number states. For vector light, however, we discover that all quantum states lead to coherence uncertainty due to the inevitable polarization fluctuations of the field. We quantify these findings with a set of coherence uncertainty relations that depend on the polarization state and space-time coordinates. For both scalar light and vector light, we employ a phase-space representation to delineate the spatiotemporal coherence fluctuations.

Our work reveals that the assessment of optical coherence is fundamentally limited even for a single monochromatic plane wave. It also serves as a theoretical foundation for our current work, which examines coherence uncertainty in the seminal double-slit experiment. In this context, we investigate the notion of coherence-squeezed light (akin to squeezed light in amplitude, phase, or polarization) and show how such a novel type of nonclassical light may affect the sharpness of the intensity fringes.

M. Hanhisalo, M. S. Mirmoosa, T. Setälä, Ł. Rudnicki, and A. Norrman, "Quantum uncertainty of optical coherence," Physical Review A 110, 063702 (2024).

Beyond Single Photon Dissipation in Kerr Cat Qubits

Irwin Huang, University of Rochester and Chapman University

Kerr cat qubits is a superconducting qubit designed to be resistant against bit-flip errors. However, Kerr cat qubits are still susceptible to a myriad of dissipation, leading to lower bit-flip lifetimes. In this talk, we will present some strategies for increasing the bit-flip lifetime of the Kerr cat qubit beyond two photon driving. These strategies include detuning the driven Kerr cat Hamiltonian, multi-photon cooling, and colored dissipation as a cooling mechanism. We show that two photon and colored cooling was able to increase the bit-flip lifetime, while detuning can improve the bit-flip lifetime while maintaining the phase-flip lifetime.

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Driven-dissipative remote entanglement between cascaded superconducting qubits

Abdullah Irfan, University of Illinois Urbana-Champaign

Stabilization of entanglement between spatially separated qubits is interesting from both a fundamental and a practical point of view. First, it provides a playground for exploring the dynamics of open quantum systems and the limits of entanglement in noisy systems. Second, it is a useful resource for communication and computation in a quantum network. One possible approach uses quantum reservoir engineering: by coupling two driven qubits to a chiral transmission line, the system can autonomously relax into an entangled steady state that is independent of the separation between the qubits [1, 2]. However, implementing this protocol is experimentally challenging. First, a cascaded system with sufficiently low loss must be realized [3]. Second, characterizing the two-qubit state is difficult due to strong qubit-transmission line coupling, which causes the qubits to decay during the tomography process. We discuss our approach towards faithfully characterizing entanglement, and present data that indicates a degree of stabilized entanglement consistent with numerical simulations of the system. Our work opens an avenue for entanglement delivery in quantum networks, and for exploring the limits of entanglement in noisy, distributed systems.

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Experimental feasibility of characterizing quantum scars in a 87Rb spinor Bose-Einstein condensate

Jessica Jenick, University of Rochester

The precise relationship between states that are thermal or nonthermal and states that are quantum scarred or regular is unknown, and spinor Bose-Einstein condensates (BECs) are a useful platform to study this relationship. Here, we discuss an experimental protocol to use a spin-1 87Rb BEC in a far detuned optical harmonic trap to probe scarred and regular quantum states. We consider the regime where the internal spin dynamics can be decoupled from the external dynamics, and thus the population and relative phase of each spin component may be controlled via a uniform magnetic and RF field. The different dynamics of regular and scarred states will be studied by measuring the populations of each spin state over time, as well as the probabilities of quantum revivals, using a Stern-Gerlach technique.

Development of ultrafast localization photoacoustic microscopy for dynamic clotting and dissolving of target blood vessel

Mansik Jeon, Kyungpook National University

Photoacoustic microscopy (PAM) enables non-invasive, high-resolution imaging deep within tissues using ultrasonic signals from pulsed laser irradiation. Scanning mirrors speed up image acquisition, but impedance matching introduces resistance, causing scan angle mismatches. Additionally, its point-by-point method requires many measurements, leading to long acquisition times. Thrombus forms through blood coagulation, leading to conditions like stroke, myocardial infarction, and vascular occlusion, which can be fatal if untreated. Customized animal models are essential for developing treatments, but traditional models have high mortality, low reproducibility, and don't allow simultaneous observation of thrombus formation and dissolution. This project aims to develop a high-speed, high-precision PAM system using position feedback and deep learning for super-resolution imaging, enabling the generation, dissolution, and observation of thrombi in specific areas, offering a new approach for studying thrombus-related animal models. We developed a PAM system and performed performance evaluation by imaging mouse brain vasculature. We were able to acquire a comprehensive brain vasculature map and depth information. We developed a feedback loop-based scanning position correction method, where the current signal from the scanner's driver is fed back, compared to the input signal, and used to generate a corrected signal. The difference in images before and after applying this method demonstrates the effectiveness of the developed position compensation technique.

Target ischemic stroke model creation method using photoacoustic microscopy with simultaneous vessel monitoring and dynamic photothrombosis induction

Hybrid singlet-triplet qubits enable fault-tolerant single-pulse CNOT gate

Roman Korol, University of Rochester

Quantum computation requires the ability to initialize, transform, and read qubit states in a multiqubit device. Qubits hosted in gate-defined double quantum dots offer all-electrical quantum control; they are also relatively easy to initialize and read out. Modern silicon- and germanium-based devices are relatively straightforward to scale up and feature high (>99.9%) single-qubit gate fidelity. However, universal quantum computation requires at least one entangling two-qubit gate (such as CNOT). To date, the two-qubit gate fidelities remain low. Here, we propose a hybrid singlet-triplet qubit architecture and predict a novel xz interaction between them. Using a Fermi-Hubbard model Hamiltonian, we show that this interaction enables a single-pulse operation of the CNOT gate with a gate time of about 1 microsecond. We include static noise and predict >99% fidelity under the experimentally comfortable set of parameters.

https://doi.org/10.1103/RevModPhys.95.025003

Quantum chaos on the separatrix of the periodically perturbed Harper model

Abobakar Sediq Miakhel, University of Rochester

Our work explores the quantum equivalent of classical chaos through a detailed analysis of the perturbed Harper model. Building upon the canonical framework of quantum chaos, we investigate the correspondence between classical phase space husimi distributions of our quantum system and its energy spectra. By introducing a time-periodic perturbation to the integrable system, we find the emergence of chaos in the classical system and wigner statistics in the quantum regime. Using semi-classical approaches like Floquet states and wigner distributions, we demonstrate the localization properties of Floquest states and their correspondence with classical resonance and chaos.

Building upon this study, our recent research on the Drifted Harper model shows the wavefunction probabilities of chaotic states conform to the Porter-Thomas distribution which is an indication of quantum chaotic behavior and could be explained by random matrix theory.

Please refer to the following link and the references there in regarding our work: https://pubs.aip.org/avs/aqs/article-abstract/7/2/023803/3346214/Quantum-chaos-on-the-separatrix-of-the?redirectedFrom=fulltext

Noise-resilient imaging through coherence filtering

Pranay Mohta, Indian Institute of Technology Kanpur

Noise is a significant challenge in imaging. Conventional intensity-based techniques mitigate noise through various filtering methods, but they often require prior knowledge of noise characteristics and struggle, especially under low-light conditions and with spatially structured noise. Quantum illumination provides enhanced noise rejection by exploiting the differing quantum properties of entangled photons used for object illumination and classical light for noise. However, its applicability is limited and necessitates substantial modifications to existing imaging setups. To address these limitations, we introduce a new paradigm in noise-resilient imaging — temporal coherence filtering — where noise rejection emerges naturally from coherence properties. Unlike conventional approaches, we achieve image distillation by leveraging temporal coherence differences between the object and noise fields within an interferometric framework. Our method uniquely integrates spatial coherence imaging with temporal coherence filtering, allowing simultaneous image formation via spatial coherence and noise suppression using temporal coherence without requiring prior knowledge of noise properties or quantum correlations. We experimentally validate our approach by recovering objects (like QR code and grayscale wheel) obscured by spatially structured noise $20\times$ stronger than the signal, demonstrating superior performance over conventional optical spectral filtering. Operating effectively even at the single-photon level, this method is also suited for extreme low-light imaging. Additionally, its adaptability to standard imaging setups makes it a promising tool for optical communication, fluorescence microscopy, and biological imaging.

Application of quantum Yang-Baxter equation algorithm to electron spin dynamics in paramagnetic molecules

Daria D. Nakritskaia, University of Nevada, Reno

In the era of noisy intermediate-scale quantum (NISQ) devices, the engineering of quantum algorithms prioritizes noise mitigation. In the past years, many quantum time dynamics (QTD) algorithms for Heisenberg models have evolved to address challenges associated with quantum noise. We focus on the QTD of the XY model describing the exchange interaction between pairs of electron spins in a one-dimensional (1D) chain of N electron spins. Because the spatially adjacent exchange interactions do not commute, time propagation requires Trotterization. In a quantum circuit, each Trotter step counts as a new quantum gate layer of two non-commuting gate classes. The larger the number of steps, n, the more significant the gate noise, but the more accurate the Trotterization. The quantum Yang-Baxter equation (QuYBE) algorithm compresses the circuit from n to N/2 layers, thus reducing the gate noise with comparatively little loss of accuracy [1].

The 1D XY model can be used to describe electron spin interactions between N spins in paramagnetic molecules if these interactions are restricted to a plane. Criteria for such restriction are: 1) the spin centers are in the same plane, 2) the angle between each set of three spin centers is within the range 60º-180º, and 3) the molecular spin density is localized in the plane of spin centers. As a demonstration, we chose a trinuclear Cu(II) cryptate with a reported antiferromagnetic exchange coupling constant J that meets the criteria [2]. We mapped this coupling constant onto the Jx and Jy components and performed the QTD simulations of the Cu complex on a classical computer, a noise-free quantum simulator (closed and open system), and a NISQ device. Comparing the classical and quantum results provided insight into the effect of quantum gate noise on the QTD simulations of electron spins in paramagnetic molecules.

1. B. Peng, S. Gulania, Y. Alexeev, N. Govind, Quantum time dynamics employing the Yang-Baxter equation for circuit compression, Phys. Rev. A 106, 012412 (2022).
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Combining kinetic and thermodynamic uncertainty relations in quantum transport

Didrik Palmqvist, Chalmers University of Technology

The thermodynamics of nanoscale engines differ fundamentally from their macroscopic counterparts due to the influence of nonthermal resources, quantum effects, and significant fluctuations in quantities such as currents, heat flows, and power. The precision of thermodynamic processes is critical to its performance; a refrigerator with fluctuating cooling power may fail to perform its intended task, even if it on average operates efficiently.

To understand the role of fluctuations in small-scale, out-of-equilibrium systems, various bounds on achievable precision have been developed in recent years. These include the thermodynamic and kinetic uncertainty relations as well as their combinations that constrain the precision by the entropy production, or so-called activity. These bounds not only set performance limits but also serve as inference tools, enabling us to estimate hard-to-measure quantities like entropy production from more easily accessible observables such as the particle-current fluctuations.

Initially derived for classical systems, these uncertainty relations have been the focus of recent research aimed at extending them to quantum systems. In this presentation, I will show how such bounds can be derived for fermionic and bosonic systems using scattering theory, which models quantum transport of noninteracting particles in multiterminal setups. I will discuss both the thermodynamic and kinetic uncertainty relations as well as their combination. Furthermore, I will show how the exchange statistics of bosonic and fermionic particles modify the classical bounds, either reducing or enhancing precision.

D. Palmqvist, L. Tesser, J. Splettstoesser: arXiv:2504.04980 (2025)
D. Palmqvist, L. Tesser, J. Splettstoesser: arXiv:2410.10793 (2024)

Generation of Long-distance Many-body Entangled States in Atoms Coupled to Waveguides.

Jennifer Pamela Parra-Contreras, University of Arizona

Generating entangled many-body states between macroscopically separated atoms is an essential resource for quantum information and quantum communication applications. In this work, we propose a probabilistic protocol to generate atomic entangled states in an array of atoms coupled to a waveguide, where the atoms are separated by a distance comparable to the coherence length of a spontaneously emitted photon. To this aim, we consider an initially uncorrelated ordered array of four-level atoms with a -level structure coupled to a waveguide, with one of the atoms being initially excited. We study the collective atomic and field dynamics and propose an optimal configuration for a photodetection measurement of the field to probabilistically herald a desired atomic state, specifically a Greenberger–Horne–Zeilinger (GHZ) state. We demonstrate that, once a desired state is post-selected, successive iterations improve the fidelity of the protocol for generating entangled atomic states.

Fabrication optimization for Nb superconducting films

Jadrien Paustian, Syracuse University

We discuss fabrication of Nb resonators and fluxonia, optimizing fabrication parameters and investigating quasiparticle dynamics. Through this work we successfully optimize sputter deposition, hydrofluoric acid treatment, and resist stripping. We also discuss anomalous temperature dependent measurements seemingly arising from compressive stress in Nb films. These films exhibit typical residual resistivity ratios and DC transport measurements, but when measured in the microwave regime, exhibit temperature dependent loss and frequency shift of a film with much lower critical temperature. Together, these provide a toolkit for enhanced coherence in superconducting devices.

Low-loss Nb on Si superconducting resonators from a dual-use spintronics deposition chamber and with acid-free post-processing arXiv:2503.13285v1, Windischmann, H. (1991).
Intrinsic stress in sputtered thin films. Journal of Vacuum Science & Technology A: Vacuum, Surfaces, and Films, 9(4), 2431–2436. https://doi.org/10.1116/1.577295

Polarization modulation and geometric phase in two-slit interference with multimode NOON states

Elvis Pillinen, University of Eastern Finland

Geometric phase is a universal concept in physics and describes a phase contribution stemming from the curvature of the underlying parameter space [1]. Its applications span across various fields including optics, astrophysics, fluid dynamics, and quantum computing, for instance. Concerning optical beams, as the polarization state changes, the field may receive a geometric (Pancharatnam–Berry) phase. The evolving polarization state can arise due to interference as has been studied for both classical and quantum light in the double-slit setup [2, 3]. The existence of a geometric phase in such an interferometric arrangement has been experimentally verified with classical light [4], and in the single-photon case the phase has been related to wave-particle duality [5].

The so-called NOON states, forming a special class of multi-photon states, can offer N times greater phase sensitivity in interferometry compared to coherent or single-photon states [6]. Their highly non-classical features can find important applications in quantum metrology, lithography, imaging, and sensing, among others. In this work, by introducing generalized Nth-order Stokes parameters to describe higher-order polarization and coherence effects, we show theoretically that a multimode NOON state provides N times faster polarization modulation and geometric phase accumulation in double-slit interference [7].

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Measuring radial coherence

Radhika Prasad, Indian Institute of Technology Kanpur

Coherence refers to correlations between field vibrations at two separate points in degrees of freedom such as space, time, and polarization. In the context of space, coherence theory has been formulated between two transverse positions, which can be described either in the Cartesian coordinates or in the cylindrical coordinates. When expressed in cylindrical coordinates, spatial coherence is described in terms of azimuthal and radial coordinates. The description of spatial coherence in radial degree of freedom has been formulated only recently in JOSA A 40, 411 (2023). In this work, we demonstrate an efficient experimental technique for measuring radial coherence, and we report measurement of radial coherence of two different types of radially partially coherent optical fields.

Radhika Prasad et al, "Experimental technique for measuring radial coherence," Optics Express 33, 11693 (2025).

Multiphoton excitation in a Schottky barrier driven by ultrashort bright-squeezed vacuum

David N Purschke, University of Rochester Laboratory for Laser Energetics

Bright-squeezed vacuum (BSV) has recently emerged as an enabling tool in the field of attosecond and nonlinear quantum optics. Here, we perform photocurrent imaging on low-temperature grown gallium arsenide (LT-GaAs) electrode structures excited by ultrashort BSV pulses. The Schottky barrier formed between at the GaAs/Au interface leads to a spontaneous photocurrent that can be measured on a shot-to-shot basis. We observe a non-trivial mapping between the photon statistics and current-pulse statistics. Correlations between the BSV and photocurrent pulses reveal three competing excitation pathways linked to the fluctuations of the BSV: one-photon ionization of mid-gap states, 2-photon band-to-band excitation, and saturation due to band-flattening. We discuss future directions of this work, towards coherent control of THz current pulses using nonlinear quantum interferometry.

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Adiabatic and diabatic limits on the quantized Harper (almost Mathieu) operator

Alice Quillen, University of Rochester

We study a quantized, discrete and drifting version of the Harper Hamiltonian, also called the finite almost Mathieu operator, which resembles the pendulum Hamiltonian but in phase space is confined to a torus. Spacing between pairs of eigenvalues of the operator spans many orders of magnitude, with nearly degenerate pairs of states at energies that are associated with circulating orbits in the associated classical system. When time dependent, both adiabatic and diabatic transitions can take place at drift rates that span many orders of magnitude. Only under an extremely negligible drift rate would all transitions into superposition states be suppressed. An advantage of studying a quantized system on the torus is that it is finite dimensional, facilitating numerical calculations and potential applications in quantum computing, applications involving simulation of spin systems and for implementing effective adiabatic quantum computation algorithms.

Feedback control for open quantum systems

Alberto Jonatas Bezerra Rosal, University of Rochester

Feedback control in open quantum dynamics is crucial for the advancement of various coherent platforms. For a proper theoretical description, however, most feedback schemes rely on stochastic trajectories, which require significant statistical sampling and completely looses any analytical insights. Currently, only a handful of deterministic feedback master equations exist in the literature. In this work we derive a set of deterministic equations for describing feedback schemes based on generic causal signals. Our formulation is phrased in terms of sequentially applied quantum instruments, and is therefore extremely general. To illustrate that, we show how it can be used to derive various known feedback equations in the literature. Next we specialize this to the case of quantum jumps and derive a master equation that allows for feedback based on the channel of the last jump, as well as the time since it occurred. We show how this allows for new kinds of feedback strategies for ground-state cooling, such as turning on a coherent drive only if some specific time has elapsed since the last jump.

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Transfer of entanglement in a system of two-level atoms coupled to whispering gallery mode cavities

José Antonio Roversi, University of Campinas

Microtoroidal optical resonators can sustain two whispering gallery modes (WGMs) propagating clockwise (CW) and counterclockwise (CCW), which can interact with each other via an exchange-type term and strongly couple to atoms located outside the cavity as well. The WGM cavities may additionally couple to fibers via evanescent waves, allowing the observation of the transmitted light. The high controllability of the optical fields on these platforms makes them suitable for use in the quantum domain. In this context, the ability to transfer quantum entanglement stands out as a key requirement for the development of quantum technologies, particularly for the realization of quantum networks. In a previous work (doi:10.1016/j.ijleo.2022.170016), we demonstrated the possibility of achieving high-fidelity entanglement transfer and the generation of entangled states of light in a system of two coupled WGM cavities, depending on the type of cavity-cavity coupling (via evanescent waves or a bridge qubit) and on the strength of the intracavity mode coupling. In this work, we present a theoretical investigation of a system composed of two pairs of two-level atoms that can be coupled to one or two WGM cavities and seek under which conditions the transfer of entanglement may occur. We consider a system of four atoms arranged into two pairs, exploring two configurations: (i) both pairs are coupled to a single optical cavity; (ii) each pair is coupled to a separate cavity, with the two cavities being directly coupled. In (i), for instance, we show the transfer of a maximally entangled state from a pair of atoms to the other pair, and also the generation of a quadripartite entangled state of the four atoms, having one atom initially prepared in its excited state. We also study how the coupling of the atoms with a WGM cavity modifies their collective photon emission, with particular emphasis on superradiance effects.

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d-dimensional quantum like resources from complex classical networks

Debadrita Saha, Princeton University

Recent work [1,2,3] has introduced the concept of quantum-like (QL) bits, along with their associated QL states and gate operations, which emerge from the dynamics of complex, synchronized networks. Building on this framework, the present study extends these ideas to multi-level QL resources—referred to as QL-dits—as higher-dimensional analogs of QL-bits. We construct QL-dits using systems of k-regular graphs, where the emergent eigenspectrum of the adjacency matrix defines the QL state space. We explore several coupling geometries between subgraphs and analyze their effect on the emergent spectrum to characterize the structure of the quantum resource. Furthermore, the tensor product structure of multiple QL-dits is realized through the Cartesian product of graphs. We further investigate the potential computational advantages of employing d-level quantum-like resources over QL bits, particularly regarding classical resource efficiency. Overall, this work generalizes the use of synchronized network dynamics to enable QL information processing with higher-dimensional QL resources.

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Observation of quantum Darwinism and the origin of classicality with superconducting circuits

Kiera Salice, University of Houston

The transition from quantum to classical behavior is a central question in modern physics. How can we rationalize everyday classical observations from an inherently quantum world? For instance, what makes two people, each absorbing an independent fraction of photons scattered from this screen or paper, agree on the observation of the text written here? Quantum Darwinism offers a compelling framework to explain this emergence of classicality by proposing that the environment redundantly encodes information about a quantum system, leading to the objective reality we perceive. Here, by leveraging cutting-edge superconducting quantum circuits, we observe the highly structured branching quantum states that support classicality and the saturation of quantum mutual information, establishing a robust verification of the foundational framework of quantum Darwinism and the accompanying underlying geometric structure of quantum states. Here, leveraging cutting-edge superconducting quantum circuits, we have established a robust verification of the foundational framework of quantum Darwinism. This is accomplished by measuring the relevant information-theoretical quantities and probing the underlying geometric structure of quantum states. Additionally, we propose a particular class of observables that can be used as a separate quantifier for classicality, originating a computationally and experimentally inexpensive method to probe quantum-to-classical transitions. Our investigation delves into how the quantum effects are inaccessible to observers, allowing only classical properties to be detected. It experimentally demonstrates the physical framework through which everyday classical observations emerge from underlying quantum principles and paves the way to settling the measurement problem.

arXiv:2504.00781

Inverse design of bullseye cavities using tandem neural networks

Martin Sanchez, Institute of Optics, University of Rochester

Circular Bragg Grating (Bullseye) cavities are widely used as the nanophotonic cavity in single photon sources due to their modestly high Purcell enhancement, and excellent emission directionality. The design of which, while relatively simple, requires computationally expensive validation simulations, time-consuming design iterations, and is limited in performance due to designer intuition. The inverse design of a Bullseye cavity would be ideal, where instead of cavity performance calculated as a function of geometry, geometry is calculated as a function of target cavity performance. Here, we demonstrate a Tandem Neural Network (TNN) architecture for the inverse design of Bullseye cavities, optimizing Purcell enhancement and collimation efficiency at target resonant wavelengths within a training dataset. We describe how to implement this approach for a Bullseye cavity with a resonant wavelength at 690 nm and obtain a design for a comparatively high Purcell enhancement of 32.6, with an extraction efficiency of 0.63. We also report measured cavity quality factors, Qs, for some TNN designed Bullseye cavities, demonstrate the generalizability of the technique to other materials and Bullseye geometries, and show how to implement fabrication constraints to tailor the design to minimum feature sizes and/or layer thickness. This technique not only dramatically reduces design and simulation time, while revealing new favorable geometries, for Bullseye cavities, we believe the technique could be applicable to other cavity systems.

Theory of temporal three-photon interference

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Recent advances in quantum technology have shifted focus from qubits to high-dimensional and multi-photon entangled states, offering enhanced system capacities and sensitivity. Significant efforts have been made to realize three-photon entangled states [1, 2]. In recent few years, several works has shown the utilization of different three-photon states as a superior candidate for lithography [3] , teleportation [4] and metrology [5]. As a result, grasping the complexities of three-photon interference has become increasingly relevant within the realm of quantum optics. Three-photon interference can be observed through cascaded parametric down conversion (CPDC) and third-order (χ^3) parametric down conversion (TOPDC).

We present a detailed exploration of three-photon interference within the frameworks of both CPDC and TOPDC, emphasizing on understanding the underlying mechanisms and conditions for observing interference effects. Under specific conditions, we predict one such effect called Hong-Ou-Mandel effect.

In the work by Jha et al. [6], it is demonstrated that temporal two-photon interference effects involving the signal and idler photons generated through parametric down-conversion can be comprehensively characterized using two key length parameters: the biphoton path-length difference and the biphoton path-asymmetry-length difference. Building upon this, we now demonstrate that although the setup itself involves eight tuneable time (or length) parameters, three-photon interference can be fully characterized by three distinct time (or length) parameters. One parameter governs interference effects determined by the pump's temporal coherence, and the other two parameters govern Hong-Ou-Mandel type effects determined by phase-matching. Our work can potentially shed light on the rich and complex correlations associated with three-particle entanglement.

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A whispering gallery mode cavity interacting with a vibrating molecule

Antonio Vidiella-Barranco, University of Campinas

Microtoroidal optical cavities, small structures that confine light via total internal reflections can use modest optical power in a very small volume with ultra-high quality factors. Such cavities can sustain two whispering gallery modes (WGM) propagating clockwise (CW) and counterclockwise (CCW), which can also interact with each other via an exchange-type term. The WGM cavities may additionally couple to fibers via evanescent waves, allowing the observation of the transmitted light. Besides, the light fields can interact with particles placed near the cavity, making these systems well-suited for sensing. For instance, an external particle, such as an atom or molecule, may modify the effective refractive index of the system, leading to a detectable shift in the resonance wavelength. While some of these effects can be treated classically, a fully quantum approach to the light fields and the external particle would provide deeper insight into the behavior of the system. In this work, we theoretically investigate a simple model of a two-level molecule interacting with a WGM cavity. We consider a molecule having one vibrational degree of freedom, described by the Holstein-Jaynes-Cummings model. In this multi-partite quantum system, the vibration of the molecule is coupled to the electronic levels, which in turn are coupled to the two field modes that can also interact with each other. Assuming the strong molecule–cavity coupling regime, we focus on the following aspects, both analytically (to some extent) and numerically: (i) the influence of molecular vibrations on the system's dynamics, e.g., on the quantum entanglement between the two cavity field states. We address in particular the role of thermal noise in the vibrational mode; (ii) the transmission spectrum of light in the presence of the vibrating molecule, which makes this study relevant to quantum technologies such as sensing, especially for detecting particles near the cavity.

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Roadmap towards third-order-spontaneous parametric down-conversion in the optical regime

Surendar Vijayakumar, University of Rochester

We present an integrated platform to observe third-order-spontaneous parametric down-conversion (TOSPDC), enabled by modal phase matching between a fundamental transverse mode in the telecom range and a high-order transverse mode in the visible wavelength range. We demonstrate third-harmonic generation at 532 nm in our platform and present a roadmap towards the first demonstration of TOSPDC in the optical regime.

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Integrated quantum dot emitters for scalable and deterministic photonic quantum processors

Maria Carolina França Volpato, National Institute of Standards & Technology

Building a universal quantum computer has long been the ultimate goal of quantum computing research. Significant progress has been made in photonic-based platforms for quantum information processing over the past decade. In order to perform useful quantum computations, at least hundreds of logical qubits are required, meaning thousands of physical qubits must be generated. Commercial sources rely on generating a stream of single photons using one emitter, to ensure indistinguishability. Multi-photon injection is achieved via demultiplexing. This strategy limits the repetition rate of photonic computers to the MHz range. The probabilistic nature of some quantum gates will lead to large times-to-solution when performing large computations. The objective of this work is to develop new solutions to this bottleneck, through hybrid integration of structures containing quantum dots that will be specifically designed to ensure that different emitters can be tuned so they emit indistinguishable photons in the same chip. In this work we optimize the integration of III-V heterostructures, containing single photon emitters, with optimized photonic nanostructures to enhance coupling efficiency and emission purity. The structures were designed in the way that the QDs can be spectrally tuned via Stark shift and mechanical strain, enabling spectral tuning to do quantum interference between independent sources in the same chip. By combining the advantages of III-V quantum emitters with scalable, low-loss photonic platforms, this work lays the groundwork for photonic quantum processors with multiple on-chip qubit sources, bringing us closer to practical quantum computing.

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Decoherence Effects in Quantum Spiking Neural Networks

Yuanheng Wang, Princeton University

As computing hardware approaches nanoscale dimensions, quantum effects become increasingly non-negligible. Artificial neural network systems that use such hardware to implement physical neurons and propagate information through neural dynamics may exhibit non-classical cognitive mechanisms influenced by quantum phenomena. In this work, we elucidate how quantum coherence and decoherence among neural activations affect the quantum neural dynamic, ultimately changing the perception of a quantum neural network. We develop a quantum spiking neural network that uses quantum neural dynamics for information propagation and employ the nearly exact time-dependent density matrix renormalization group method to simulate its dynamics and perception in a fruit classification task.

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High-fidelity spatial information transfer through dynamic scattering media by an epsilon-near-zero time-gate

Yang Xu, University of Rochester

Transparent conducting oxides (TCO) such as indium-tin-oxide (ITO) exhibit strong optical nonlinearity in the frequency range where their permittivities are near zero. We leverage this nonlinear optical response to realize a sub-picosecond time-gate based on upconversion (or sum-) four-wave mixing (FWM) between two ultrashort pulses centered at the epsilon-near-zero (ENZ) wavelength in a sub-micron-thick ITO film. The time-gate removes the effect of both static and dynamic scattering on the signal pulse by retaining only the ballistic photons of the pulse, that is, the photons that are not scattered. Thus, the spatial information encoded in either the intensity or the phase of the signal pulse can be preserved and transmitted with high fidelity through scattering media. Furthermore, in the presence of time-varying scattering, our time-gate can reduce the resulting scintillation by two orders of magnitude. In contrast to traditional bulk nonlinear materials, time gating by sum-FWM in a sub-wavelength-thick ENZ film can produce a scattering-free upconverted signal at a visible wavelength without sacrificing spatial resolution, which is usually limited by the phase-matching condition. Our proof-of-principle experiment can have implications for potential applications such as *in vivo* diagnostic imaging and free-space optical communication.

Flux-pumped symmetrically threaded SQUID Josephson parametric amplifier

Kagan Yanik, University of Rochester/Chapman University

Josephson parametric amplifiers (JPA) have many useful applications in superconducting qubit measurements and quantum feedback. Ideally, JPA's are supposed to perform as perfect quantum amplifiers. However, in practice their performance is limited by higher-order corrections such as Kerr nonlinearity. In our work, we design a flux-pumped symmetrically threaded SQUID (STS) JPA which allows us to eliminate the Kerr nonlinearity from the Hamiltonian. We find that this setup can yield a gain closer to the ideal Degenerate Parametric Amplifier gain compared to SQUID based flux-pumped JPA. We also investigate quadrature mixing as well as noise properties of the Kerr free amplifier.

This document, prepared by Abhaya S. Hegde and Annie Schwartz, adapts an open-source LaTeX template from `https://github.com/maximelucas/AMCOS_booklet`.

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