

Center for
Quantum Networks

NSF Engineering Research Center



Center for Quantum Networks

NSF Site Visit

October 21-24, 2025

University of Maryland, College Park MD

Funded by National Science Foundation Award #1941583



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MARYLAND

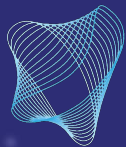
University of
Massachusetts
Amherst 1862 **RE REVOLUTIONARY**



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Center for Quantum Networks

NSF Engineering Research Center



Welcome and Introductions

Samuel Graham, Jr.

Dean, A. James Clark School of Engineering

University of Maryland, College Park

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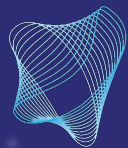
Land Acknowledgement

Every community owes its existence and strength to the generations before them, around the world, who contributed their hopes, dreams, and energy into making the history that led to this moment.

Truth and acknowledgement are critical in building mutual respect and connections across all barriers of heritage and difference.

So, we acknowledge the truth that is often buried: We are on the ancestral lands of the Piscataway People, who are the ancestral stewards of this sacred land. It is their historical responsibility to advocate for the four-legged, the winged, those that crawl and those that swim. They remind us that clean air and pristine waterways are essential to all life.

This Land Acknowledgement is a vocal reminder for each of us as two-leggeds to ensure our physical environment is in better condition than what we inherited, for the health and prosperity of future generations.



Center for Quantum Networks

NSF Engineering Research Center



University of Maryland Welcome

Dr. Gretchen Campbell

Associate Vice President, Quantum Research and Education

University of Maryland

Funded by National Science Foundation Award #1941583



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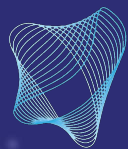
University of
Massachusetts
Amherst
1862 RE REVOLUTIONARY



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ARIZONA
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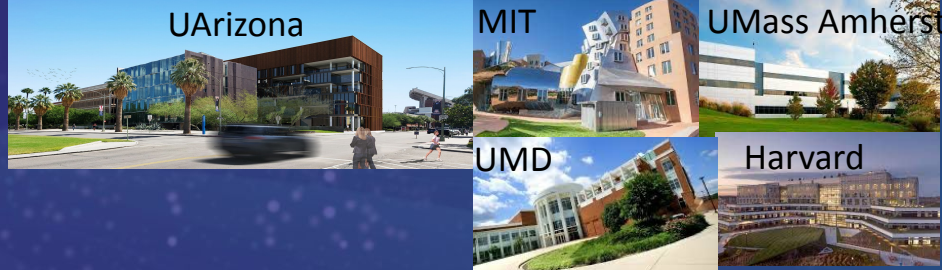


UNIVERSITY OF
OREGON



Center for Quantum Networks

NSF Engineering Research Center



Directors' Overview

Saikat Guha

Co-Director CQN & Co-PI

A. James Clark Endowed Chair Professor, ECE, University of Maryland, College Park MD

Adjunct Professor, Wyant College of Optical Sciences, University of Arizona, Tucson AZ

Affiliate Faculty, EECS, MIT, Cambridge MA



Funded by National Science Foundation Award #1941583



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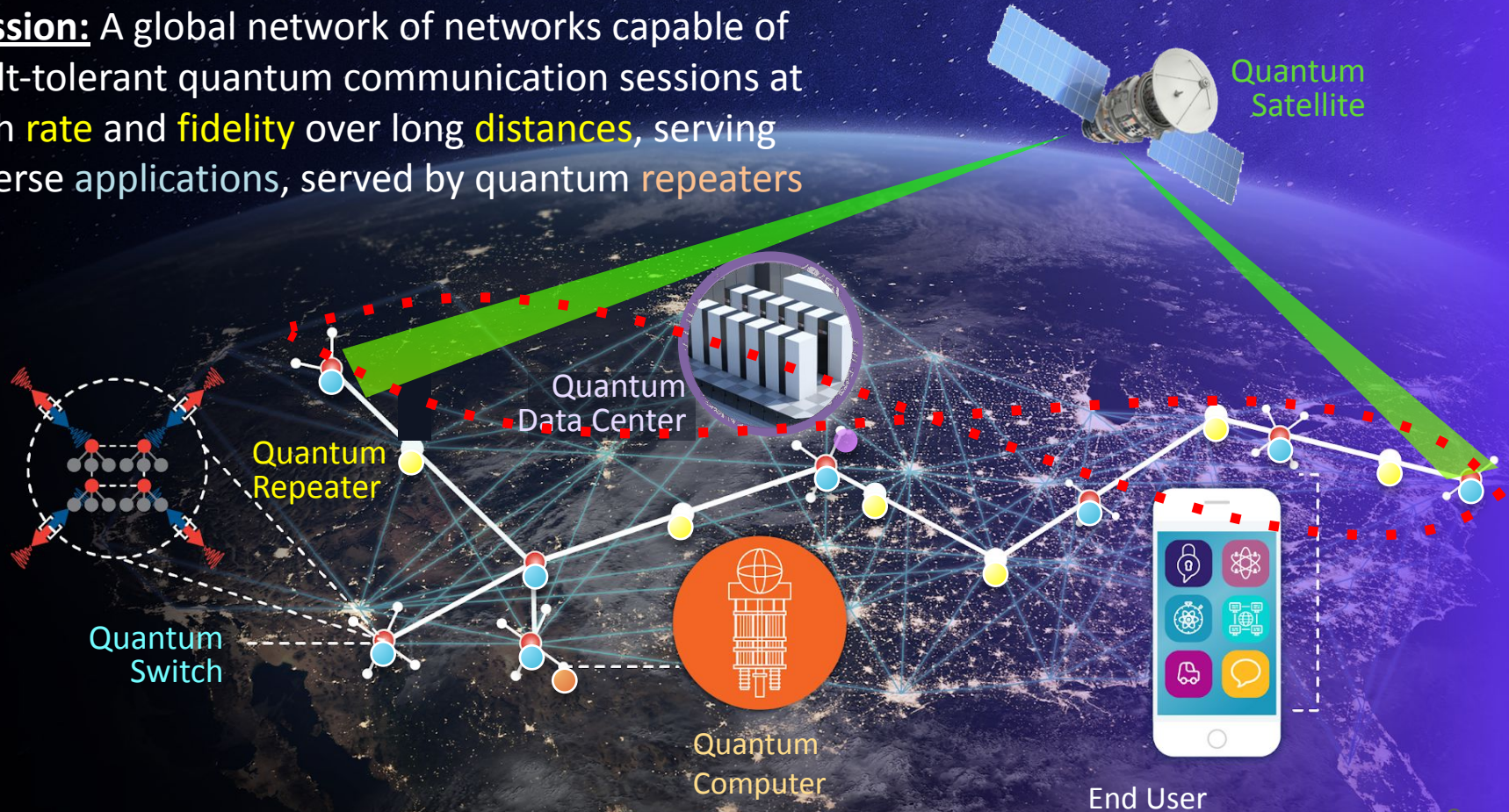
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OREGON

The Quantum Internet

Mission: A global network of networks capable of fault-tolerant quantum communication sessions at high **rate** and **fidelity** over long **distances**, serving diverse applications, served by quantum **repeaters**



Why quantum networking?

(1) Privacy and security

Secure communications



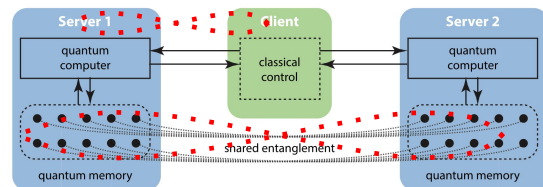
Auctions; and other multiparty privacy-preserving computations



Figure courtesy: ProQsmart

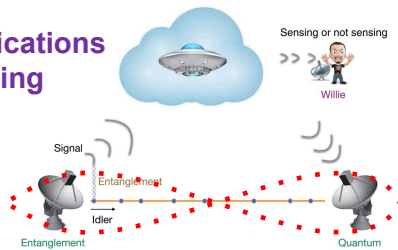
(2) Private and distributed quantum computing

Blind quantum computing



Fitzsimons, Nature npj Quantum Information, Vol. 3, No. 23 (2017)

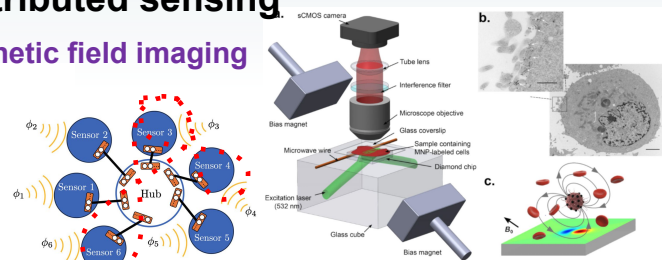
Covert communications and sensing



Hao, Shi, Gagatsos, Mishra, Bash, Djordjevic, Guha, Zhuang, Zhang, Phys. Rev. Lett. 129, 010501 (2022)
Gagatsos, Bullock, Bash, IEEE Journal on Selected Areas in Information Theory, Vol. 1, Issue: 2, (2020)

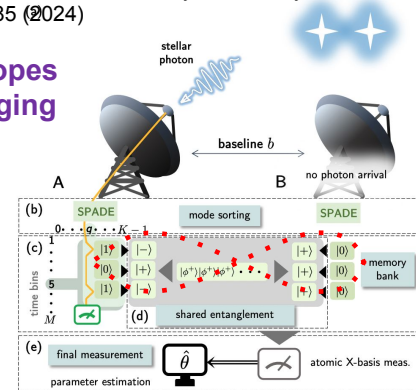
(3) Distributed sensing

Magnetic field imaging



Boretti et al., Beilstein J. Nanotechnol., 10, 2128–2151 (2019)
Van Milligen, Gagatsos, Kaur, Towsley, Guha, Phys. Rev. Applied 22, 064085 (2024)

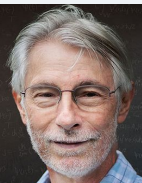
Long baseline telescopes and gravitational imaging (LIGO clusters)



Khabiboulline, Borregaard, De Greve, and Lukin, Phys. Rev. Lett. 123, 070504 (2019)
Brown, ... Raymer, Smith, Phys. Rev. Lett. 131, 210801 (2023)
Padilla, Sajjad, Saif, Guha, arXiv:2504.03117 (2025)
Stas, ..., Lukin, arXiv:2509.09464 (2025)
Liu et al., arXiv:2510.07898 (2025)

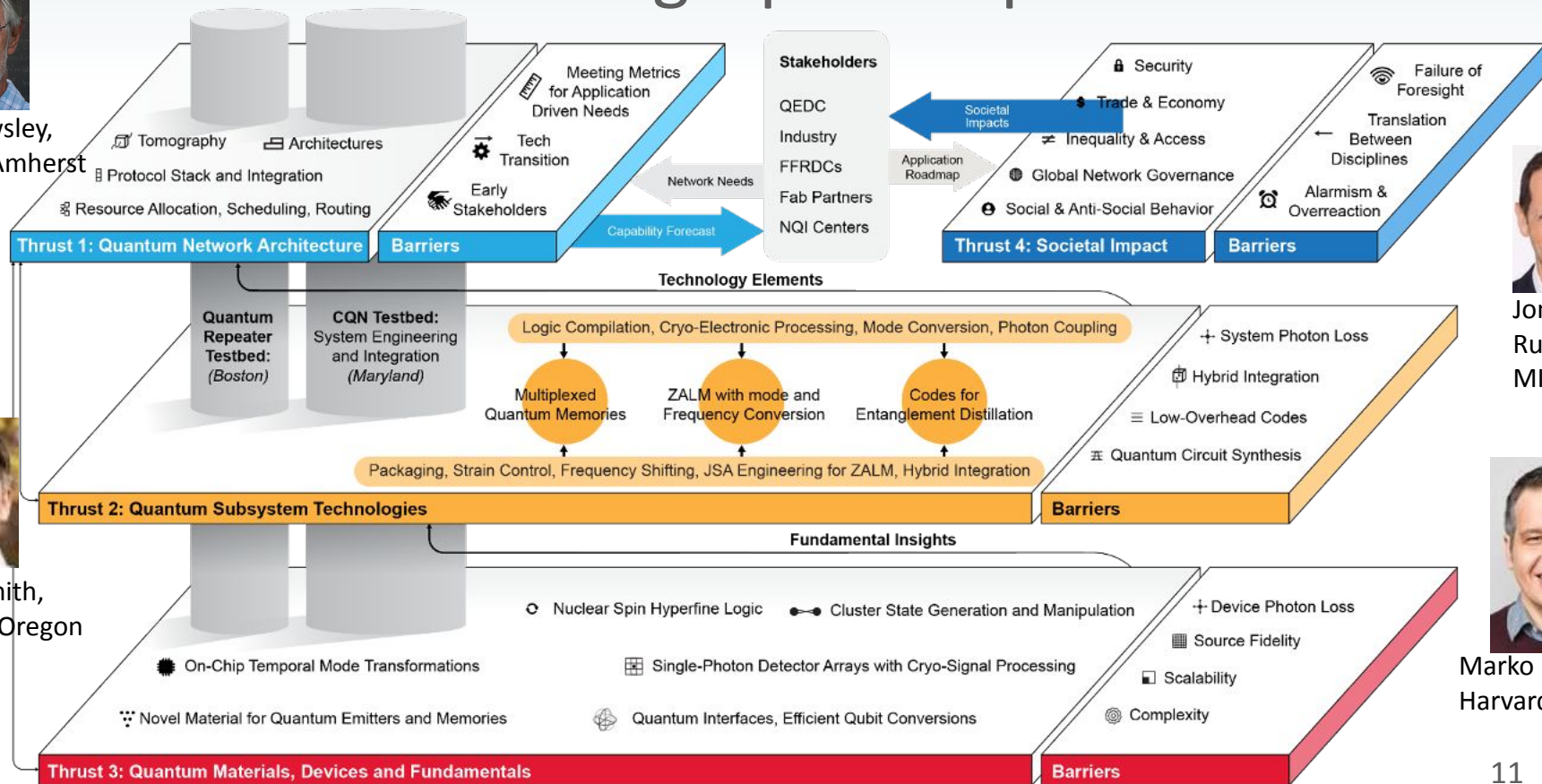
Highlights from the past year

- **Convergent research**
 - City-scale entanglement of quantum memories, demonstrations of blind quantum computing and distributed telescope primitives
 - High-fidelity hyperfine-mediated quantum logic in SiV and SnV color centers
 - All-optical strain engineering based tuning of ZPLs of an array of color center qubits
 - High-efficiency quantum frequency conversion from SiV frequency to telecommunications band
 - Capacity-approaching quantum link architectures for generating spin-spin entanglement, with and without classical feedback control
 - ZALM architectures with “island based” joint spectral amplitudes for optimized rate-fidelity operation
 - Measurement based entanglement distillation and fault-tolerant constant-overhead repeater architecture
 - Application-aware entanglement routing algorithms for serving entanglement-assisted distributed sensors in a network
 - Full network protocol stack replete with a versatile link-layer and connectionless transport, borrowing principles from the Internet
 - The quantum index report: a data-driven assessment of quantum technologies
- **Innovation ecosystem**
 - Applications Roadmap now a QED-C led national-scale QNAR2.0 effort: hosted first workshop in summer 2025
 - Virtual testbed development: a full time engineer supported by IPP, and center-wide integration via weekly open office hours
 - 99 provisional or full patents, a 23.75% YoY increase in 2025, shared with industry partners for licensing interest
 - Two diamond members, Cisco and L3Harris, conducted customized research projects with CQN PIs
 - Our PIs spun out two new companies: Diffraction (UMD) & Blanqet (UChicago), bringing new total to 6 active CQN-led startups
 - Ciena – telecommunications company joined CQN’s IPP, and has been interacting with Virtual Testbed group
- **Engineering Workforce Development**
 - Another year of successful Winter School, SPARCQS events, and REU
 - Graduate certificate program—drawing courses from the MS-in-QISE: in final approvals at UArizona
 - Co-hosted NSF Quantum Que webinar on professional development in between community college attendees and CQN institutions
- **Expanding participation**
 - GLEAM program to engage high school students at Maryland
 - Cross-campus student exchanges (multiple)
 - Community outreach via SPARQCS
 - Community of practice: CQN co-organized / co-sponsored multiple workshops, including ERVA report
 - SPLC organized the Q³ initiative (<https://q3initiative.org/>) - engaged with experts in art, policy, economics



Don Towsley,
UMass Amherst

Research strategic plan: 3-plane chart



Jonathan
Ruane,
MIT



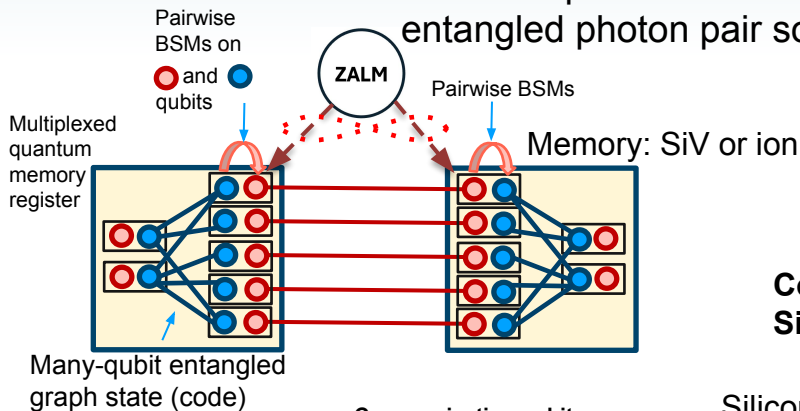
Marko Loncar,
Harvard



Brian Smith,
Univ. of Oregon

Quantum Network Architecture

ZALM: A quasi-deterministic entangled photon pair source



**Color center
SiV or SnV**

**Dual species
trapped ion**

Silicon or Tin
electron spin

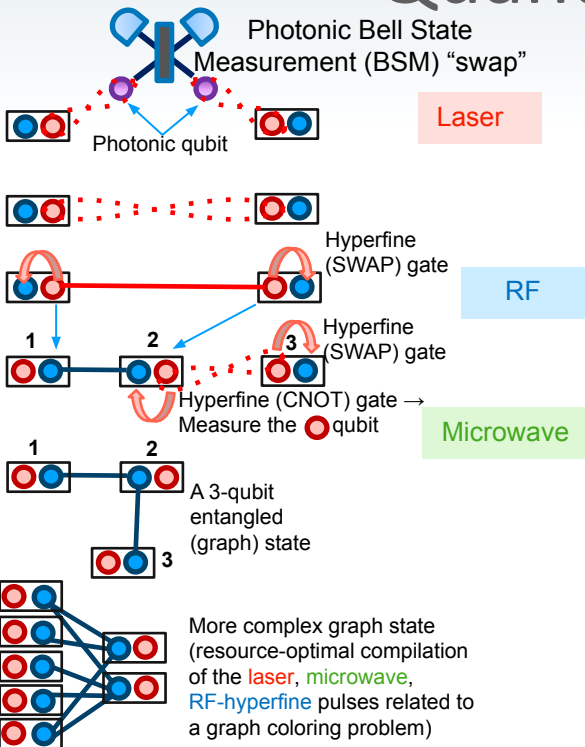
$^{138}\text{Ba}^+$ $^9\text{Be}^+$

^{29}Si or ^{117}Sn
nuclear spin

$^{171}\text{Yb}^+$ $^{25}\text{Mg}^+$

Communication qubit:
shorter lived, high-efficiency
coupling to optical photon

Memory qubit: longer lived,
high-Fidelity two-qubit gate allowed
to the communications qubit



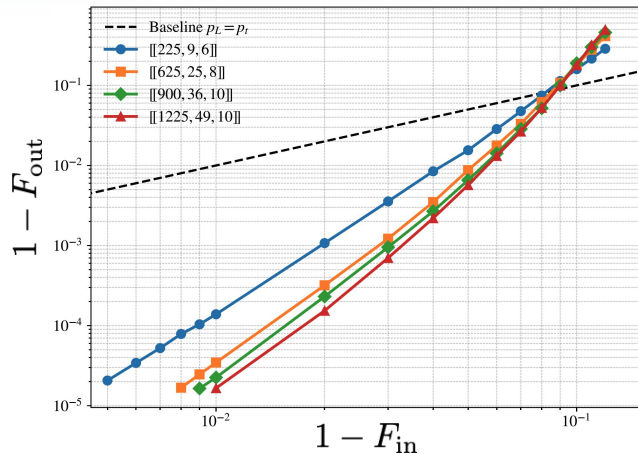
Lukin and Loncar groups, Science, Vol 378, Issue 6619, pp. 557-560 (2022)

Chen, Dhara, Heuck, Lee, Dai, Guha, Englund, *Zero-Added-Loss Entangled-Photon Multiplexing for Ground- and Space-Based Quantum Networks*, Phys. Rev. Applied 19, 054029 (2023)

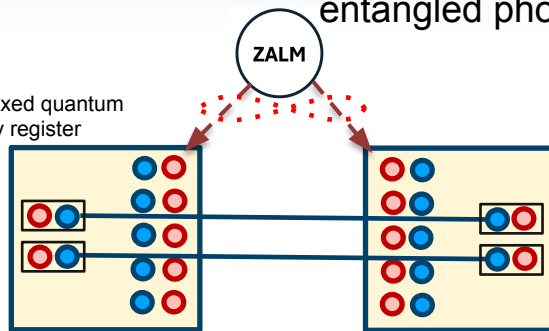
Englund group, *Large-scale integration of artificial atoms in hybrid photonic circuits*, Nature volume 583, pages 226–231 (2020)



Quantum Network Architecture

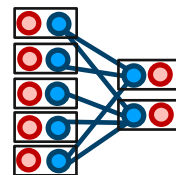


Multiplexed quantum memory register

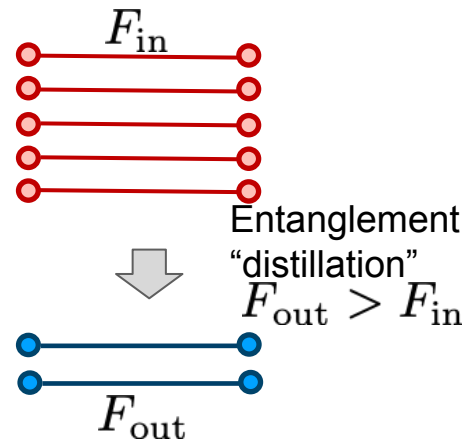


Rate 2/5 quantum (Stabilizer) code $\rightarrow$

5 + 2 qubit graph state



ZALM: A quasi-deterministic entangled photon pair source



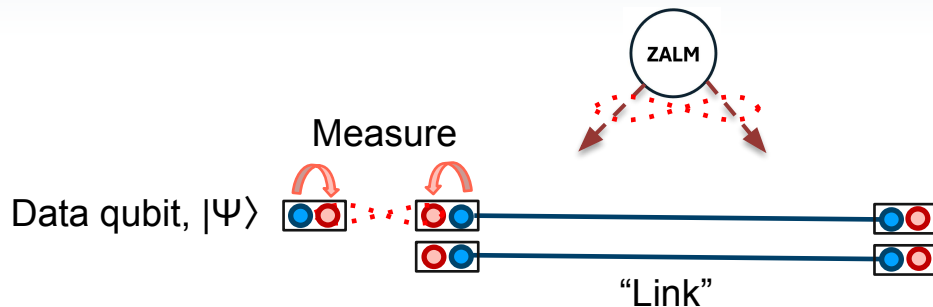
Shi, Patil, Guha, *Measurement-Based Entanglement Distillation and Constant-Rate Quantum Repeaters over Arbitrary Distances*, Phys. Rev. Lett. 135, 130803 (2025)

Lukin and Loncar groups, Science, Vol 378, Issue 6619, pp. 557-560 (2022)

Chen, Dhara, Heuck, Lee, Dai, Guha, Englund, *Zero-Added-Loss Entangled-Photon Multiplexing for Ground- and Space-Based Quantum Networks*, Phys. Rev. Applied 19, 054029 (2023)

Englund group, *Large-scale integration of artificial atoms in hybrid photonic circuits*, Nature volume 583, pages 226–231 (2020)¹³

Quantum Network Architecture



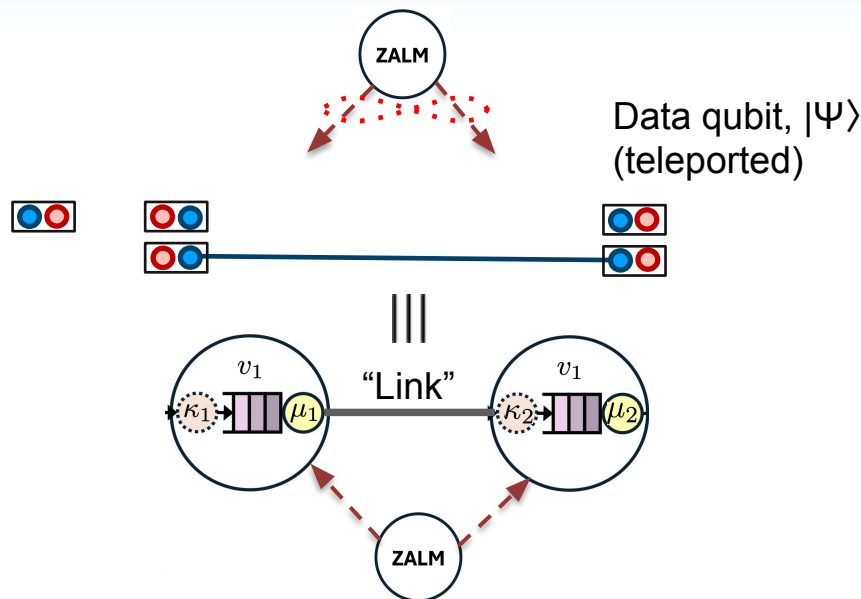
Shi, Patil, Guha, *Measurement-Based Entanglement Distillation and Constant-Rate Quantum Repeaters over Arbitrary Distances*, Phys. Rev. Lett. 135, 130803 (2025)

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Chen, Dhara, Heuck, Lee, Dai, Guha, Englund, *Zero-Added-Loss Entangled-Photon Multiplexing for Ground- and Space-Based Quantum Networks*, Phys. Rev. Applied 19, 054029 (2023)

Englund group, *Large-scale integration of artificial atoms in hybrid photonic circuits*, Nature volume 583, pages 226–231 (2020)

Quantum Network Architecture



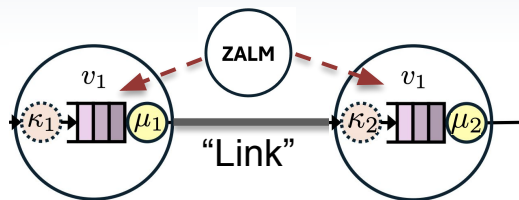
Shi, Patil, Guha, *Measurement-Based Entanglement Distillation and Constant-Rate Quantum Repeaters over Arbitrary Distances*, Phys. Rev. Lett. 135, 130803 (2025)

Lukin and Loncar groups, *Science*, Vol 378, Issue 6619, pp. 557-560 (2022)

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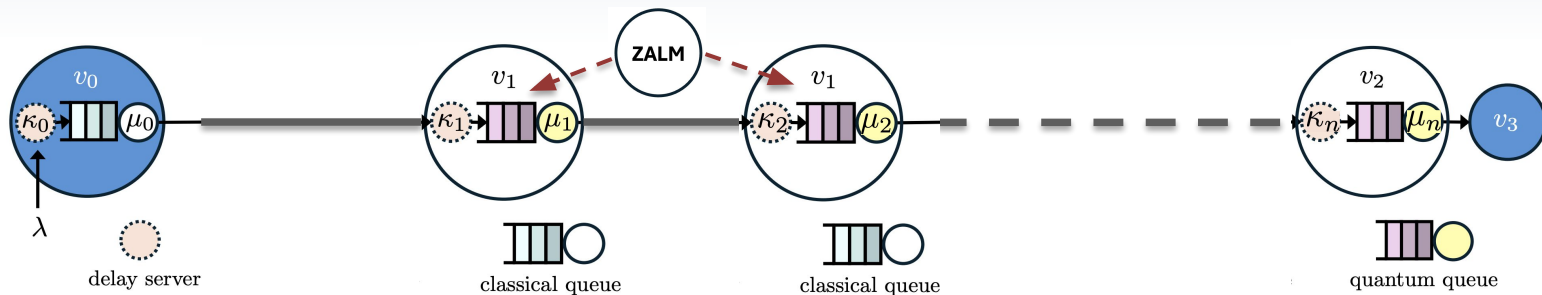
Englund group, *Large-scale integration of artificial atoms in hybrid photonic circuits*, Nature volume 583, pages 226–231 (2020)

Quantum Network Architecture

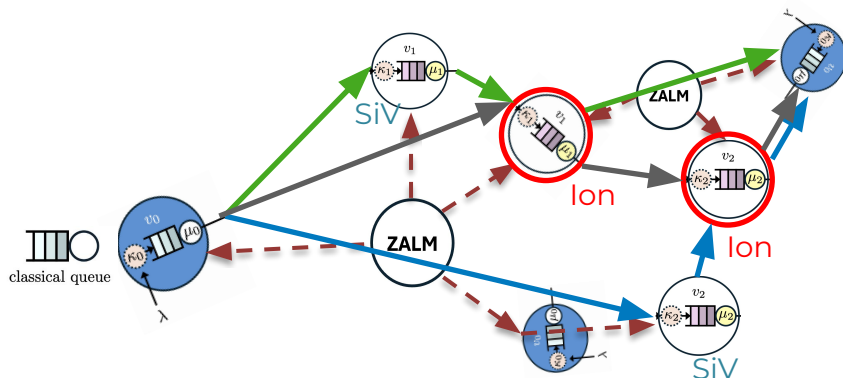
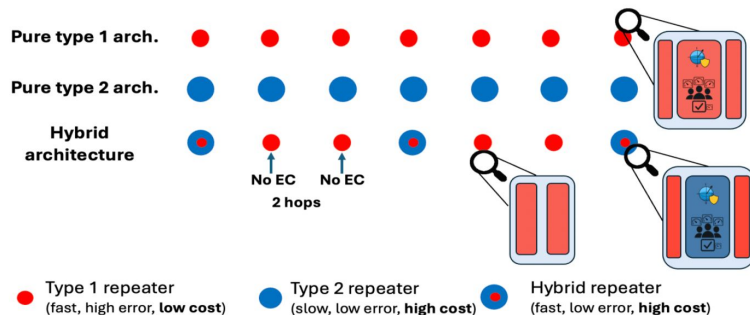


"Leveraging Internet Principles to Build a Quantum Network", Leonardo Bacciottini, Matheus Guedes De Andrade, Shahrooz Pouryousef, Emily A. Van Milligen, Aparimit Chandra, Nitish K. Panigrahy, Nageswara S. V. Rao, Gayane Vardoyan, **Don Towsley**, IEEE Network, May 12, 2025

Quantum Network Architecture



Architectures combining Hybrid and Pure repeaters



"Leveraging Internet Principles to Build a Quantum Network", Leonardo Bacciotini, Matheus Guedes De Andrade, Shahrooz Pouryousef, Emily A. Van Milligen, Aparimit Chandra, Nitish K. Panigrahy, Nageswara S. V. Rao, Gayane Vardoyan, **Don Towsley**, IEEE Network, May 12, 2025

"Hybrid repeaters with encoding for long distance entanglement distribution", Halder, Guha, Towsley, Rozpedek; IEEE QCE 2025



Work packages

T2 T3

WP1

Near-deterministic high-rate photonic entanglement source (bulk-optic/ integrated)

T1 T2 T3

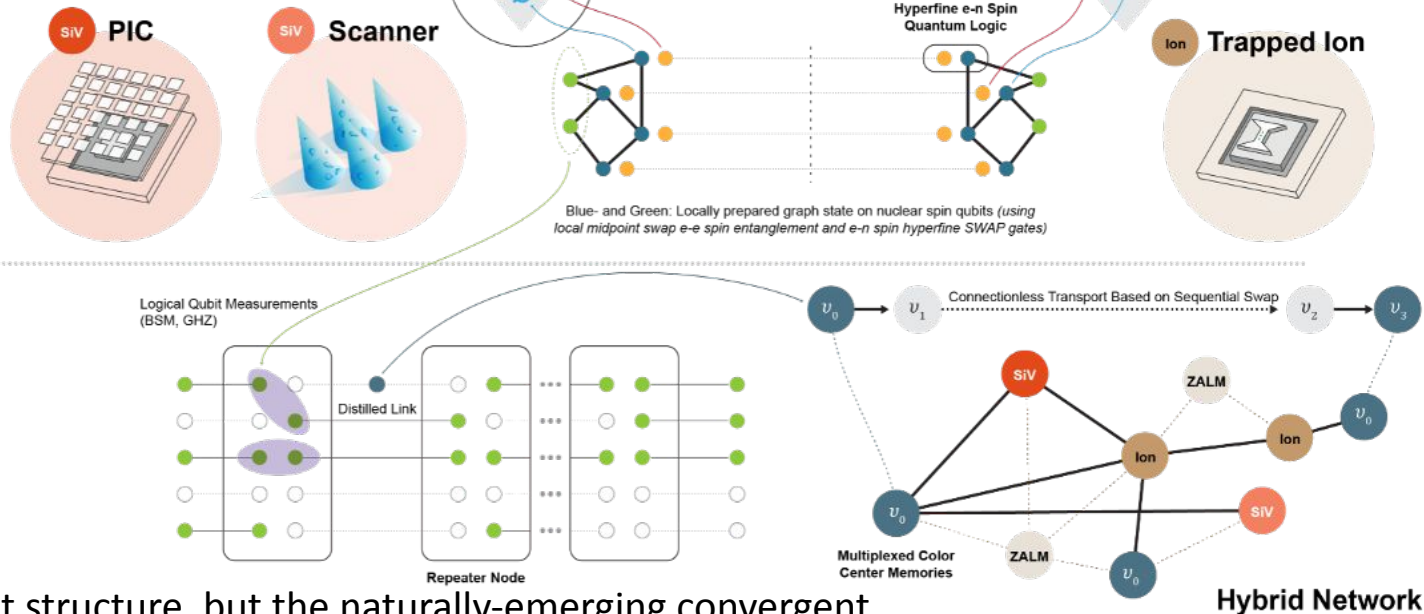
WP2

Multiplexed quantum memories

T1 T2

WP3

System integration and performance evaluation



CQN retains its Thrust structure, but the naturally-emerging convergent research is best described in terms of these interconnected work packages: each straddling all Thrusts, with their regular working group meetings.

CQN Testbeds

Boston testbed



Dirk Englund



Mikhail Lukin



Chao Li, MIT



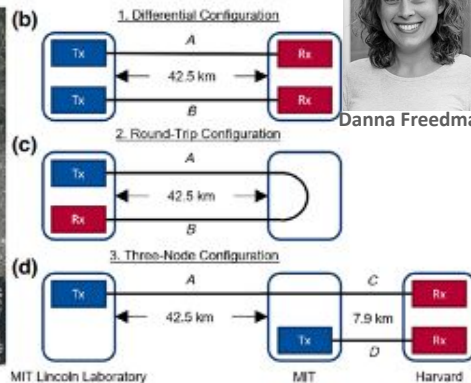
Julia Mundy



Marko Loncar



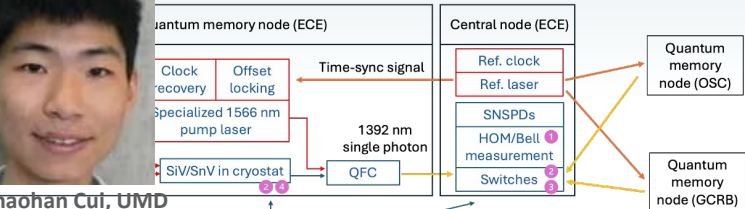
Danna Freedman



Tucson testbed



Chaohan Cui, UMD



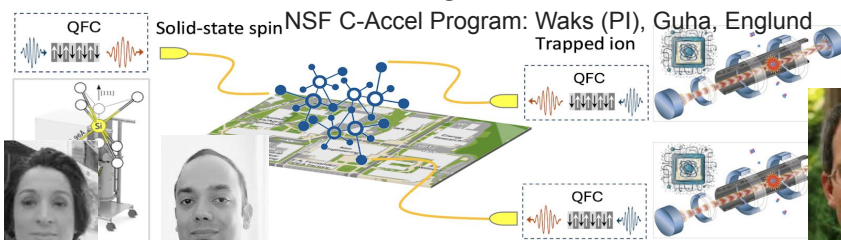
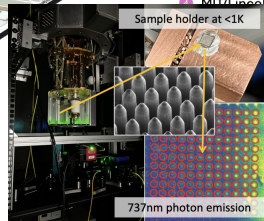
Matt Eichenfield



Linran Fan



Zheshen Zhang



UMD (MARQI) Testbed

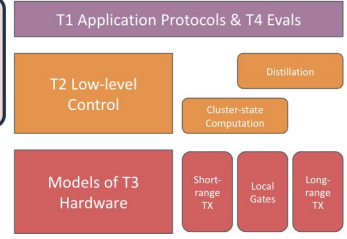
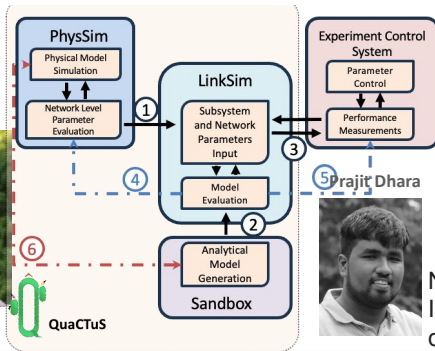
Qudsia Quraishi



Saikat Guha



Edo Waks



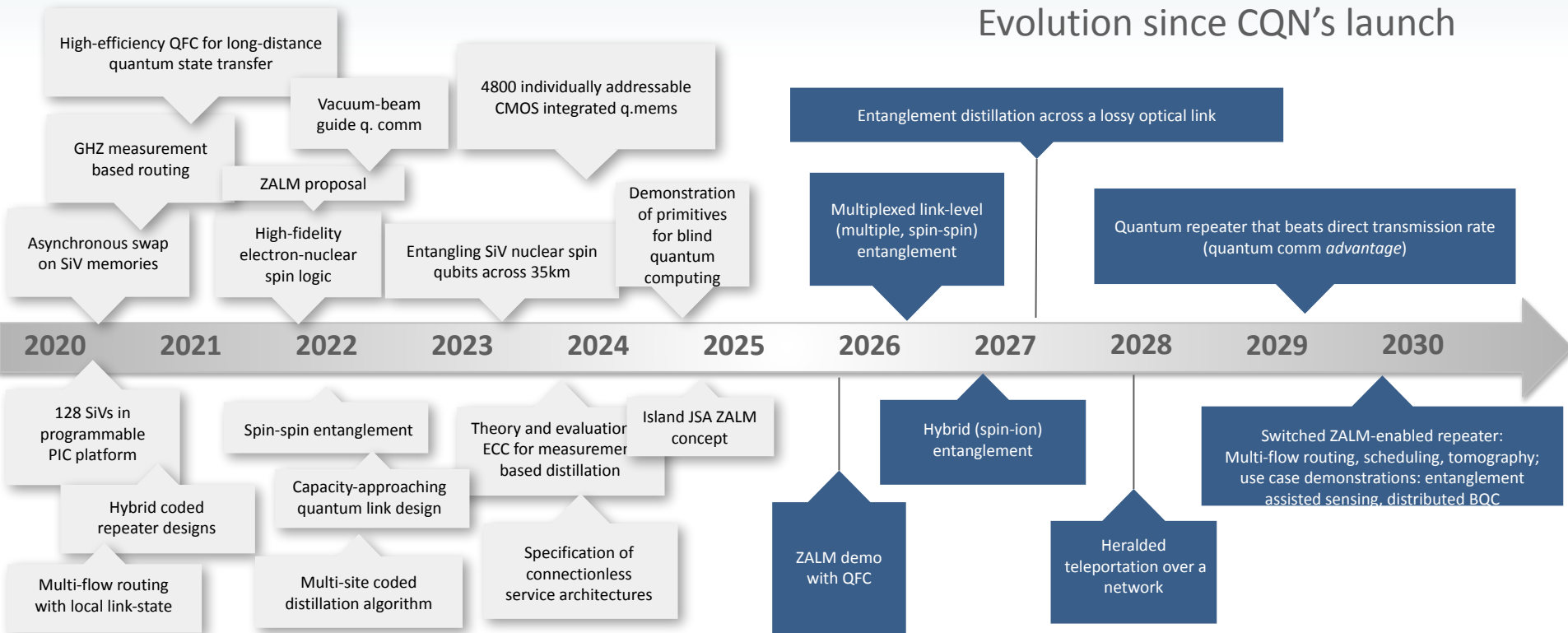
NSF Award # 2346089 "Research Infrastructure: CIRC: Full-stack Co-design Tools for Quantum Hardware"



Stefan Krastanov

Virtual testbed

Research Strategic Plan: Evolution since CQN's launch





Societal impacts and stakeholders



Satellite-assisted remote entanglement distribution, for long-baseline sensing and imaging

Quantum-Augmented Networks for physical and network layer security

DARPA



Quantum enhanced receivers for deep-space laser-communications

Entanglement assisted magnetic field sensing



Federal Government

Entanglement. Enhanced Quantum Secure Covert Comms. and Sensing

MURI on Quantum Network Science



Raytheon Technologies



L3HARRIS

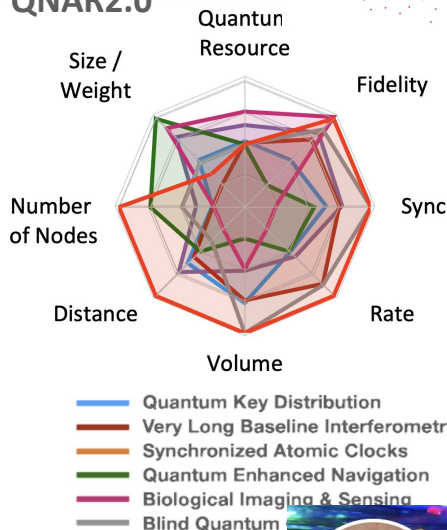


Defense

Associated Project Ecosystem,
Applications Development

Applications Roadmap QNAR2.0

QED-C



Startup



Qunett

LIGHTSYNQ

Laura B. Andre 1st
CEO @ Qunett

Techyawn (UMass), Hydroteck (BYU)



International

Engineering Workforce Development



Dr. Noel Hennessey,
UA, EWD Director



Winter
School

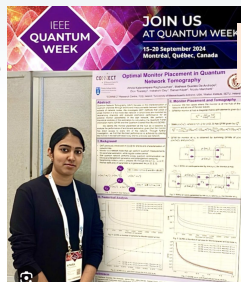
2024 WINTER
SCHOOL ON
**QUANTUM
NETWORKS**

Registration Open Now

Michael Raymer, Univ. Oregon

600+ people
trained
worldwide

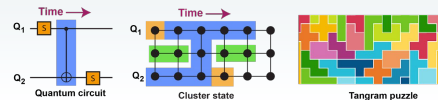
Conferences



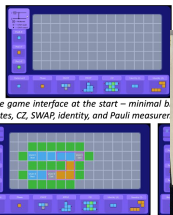
Ines Montano, NAU



Sparking Curiosity in Quantum Science (SPARCQS)



EWD
Fellowship



Ashlesha Patil, CQN student UA

ChatCQN

Quantum computing as a Tangram Puzzle

Student Innovator of the Year Award 2023, UA

Patil, Jacobson, Towsley, SG, arXiv:2210.11465, IEEE QCE 2022

WYANT COLLEGE OF OPTICAL SCIENCES

QISE EMPHASIS REQUIREMENTS (version 2024.06.05)

MS Thesis option: 26 units of coursework + 6 units of OPTI 910: Thesis = 32 total units
MS Report option: 29 units of coursework + 3 units of OPTI 909: Report = 32 total units

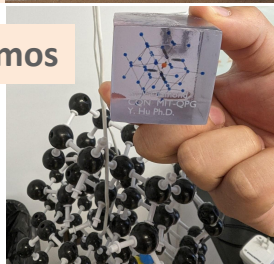
- * Total coursework units include Core and Approved Elective units (below) + 3 additional units of any graded OPTI coursework not listed below.
- * With advisor and Associate Dean approval, up to 3 units of OPTI 599: Independent Study may be taken in place of the same number of units of Approved Electives.
- * Courses listed as available online may require a minimum online enrollment to be offered as a distance course in any given semester.

MS in QISE



REU 2025

Demos



CORE COURSES - COMPLETE AT LEAST 4 COURSES, ONE PER GROUP: 12 UNITS TOTAL	Units	Term	Online?	Prereq
OPTI 570 Quantum Mechanics (or other graduate-level Quantum Mechanics course)	3	F	yes	OPTI 511R or undergraduate quantum mechanics, or proficiency with linear algebra
OPTI 544 Foundations of Quantum Optics	3	S	yes	OPTI 570 or equiv
OPTI 646 Introduction to Quantum Information and Computation	3	F	yes	OPTI 570 or equiv, OPTI 544 recommended
OPTI 647B Photonic Quantum Information Processing	3	S	yes	OPTI 570 or equiv, or OPTI 647A
OPTI 560 Quantum Nanophotonics	3	S	yes	E&M (OPTI 501 or equiv), intro. QM (OPTI 511R)
OPTI 572 Quantum Photonic Integrated Circuits (may not be offered every year). This course also counts as a lab class.	3	S	yes	E&M (OPTI 501 or equiv), intro. QM (OPTI 511R)

APPROVED ELECTIVES - 11 UNITS FOR MS THESIS OPTION OR 14 UNITS FOR MS REPORT OPTION (includes minimum 2 units of lab courses)	Units	Term	Online?	Prereq
One lab may be waived for relevant industry experience (with Assoc. Dean approval)	1	F		OPTI 511R or other QM course; or 507 co-req
OPTI 571L Lasers and Solid-State Devices	1	F	yes	OPTI 570 or equiv
OPTI 571L Optical Physics Computational Laboratory	1	S		
OPTI 587L Photonics Communications	1	S		
OPTI 572 Quantum Photonic Integrated Circuits	3	S	yes	E&M (OPTI 501 or equiv), intro. QM (OPTI 511R)

Expanding Participation

Powered by QuEST teams



Brianna Moreno,
Administrative Director

Mentorship Program

- Inaugurated in April 2024
- Mentors from 3 NSF entities: CQN, NoirLab, CUA—faculty, senior researchers, postdocs, and grad students
- Mentees from Quantum Que and REU, undergraduates and graduates

Seven Falls trail, Annual Retreat 2024



Outreach



Arizona Quantum Boot Camp

EP Council

- Inaugural meeting 04/12/24 to discuss EP programming and equity in CQN [UG, G, faculty, IPP, REU]

Community of Practice





Joint research

Cisco: Towsley (design of quantum data center networks)

L3Harris: Bash and Guha (secure comms theory and demo)

Advent: Eichenfield (SBIR new quantum sensor architecture)

RTX: Zhang and Guha (covert comms and sensing)

Juniper: Jiang (quantum repeaters and network routing)

GDMS: Zhang and Guha (RF photonic sensors, squeezed)

Xia, Li, Clark, Hart, Zhuang, Zhang, Phys. Rev. Lett. 124, (2020)

Rozpędek, Seshadreesan, Polakos, Jiang, Guha, Phys. Rev. Research 5, 043056 (2023)

Van Milligen, Gagatsos, Kaur, Towsley, Guha, arXiv:2407.15652, to appear: Phys. Rev. App. (2024)
Webb, Bullock, Knarr, Burt, Drakes, Guha, Bash, Bucklew, MILCOM 2023

Innovation Ecosystem



Alireza Shabani,
UA, ILO co-officer



John Sawyer
UMD, ILO co-officer

Testbed integration

1. L3Harris [demonstrating quantum clock synchronization],
2. Qunett [fiber connection to LL and MIT, incorporating confocal scanner into CQN testbeds],
3. Qunnect [exploring integration of room temp memories into testbed via synergistic QFC]



CQN's Industry Partnership Plan (IPP): An "IUCRC like" tiered membership plan

Total financial
support > +2M



External Advisory Board (EAB)

Advisory Boards

Industry Advisory Board (IAB)



Alan Migdall

NIST

Leader, Quantum Optics
Group



**Ananthram
Swami**

U.S. Army Research
Laboratory

Senior Research Scientist



Ben Sussman

National Research Council
Canada

Program Director



Chip Elliott

Raytheon BBN

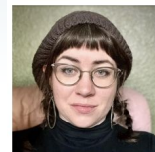
Retired CTO



Christopher Yoo

University of Pennsylvania

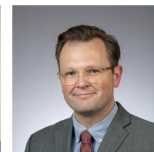
Professor of Law,
Communication, and
Computer & Information
Science



Alex Tingle

Inflection

Technical Product Manager



Bryan Spann

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Staff Research Scientist



**Domenico di
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Mark Meisner

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Derya Cansever

US Army Research Office

Program Officer



Fredrik Fatemi

U.S. Army Research
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Senior Research Scientist
for Quantum Science



Ian Walmsley

Imperial College London

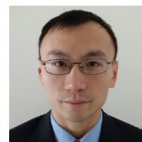
Provost & Chair of
Experimental Physics



Jeff Lundeen

University of Ottawa

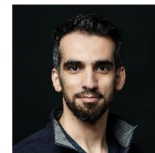
Associate Professor,
Physics



John Zhang

City of Chicago

Division Chief, Smart Cities



Mehdi Namazi

Gunnnet

Founder and CSO



Peng Zhao

Cisco Systems

Quantum Research Scientist



Reza Nejabati

Cisco Systems

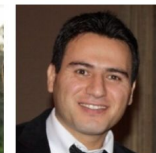
Head of Quantum Research



Samuel Knarr

L3Harris

Optical Engineer, Quantum
Solutions



Siamak Dadras

Topica Photonics

Quantum Application
Scientist



**Konrad
Banaszek**

University of Warsaw

Professor; Director, Centre
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Nicolas Treps

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Professor, Multimode
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**Norbert
Lutkenhaus**

University of Waterloo

Professor, Physics and
Astronomy

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Sara Chavarria

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Assistant Dean, Research
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**Stephanie
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William Clark

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Zac Dutton

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Lead Scientist, Physical
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Questions?

CQN Annual Retreat, Tucson 2024

