

Center for Quantum Networks

NSF Engineering Research Center



CQN Testbed: Tucson → Maryland

Chaohan Cui

Maryland Testbed Lead

University of Maryland College Park

Funded by National Science Foundation Award #1941583



UNIVERSITY OF
MARYLAND

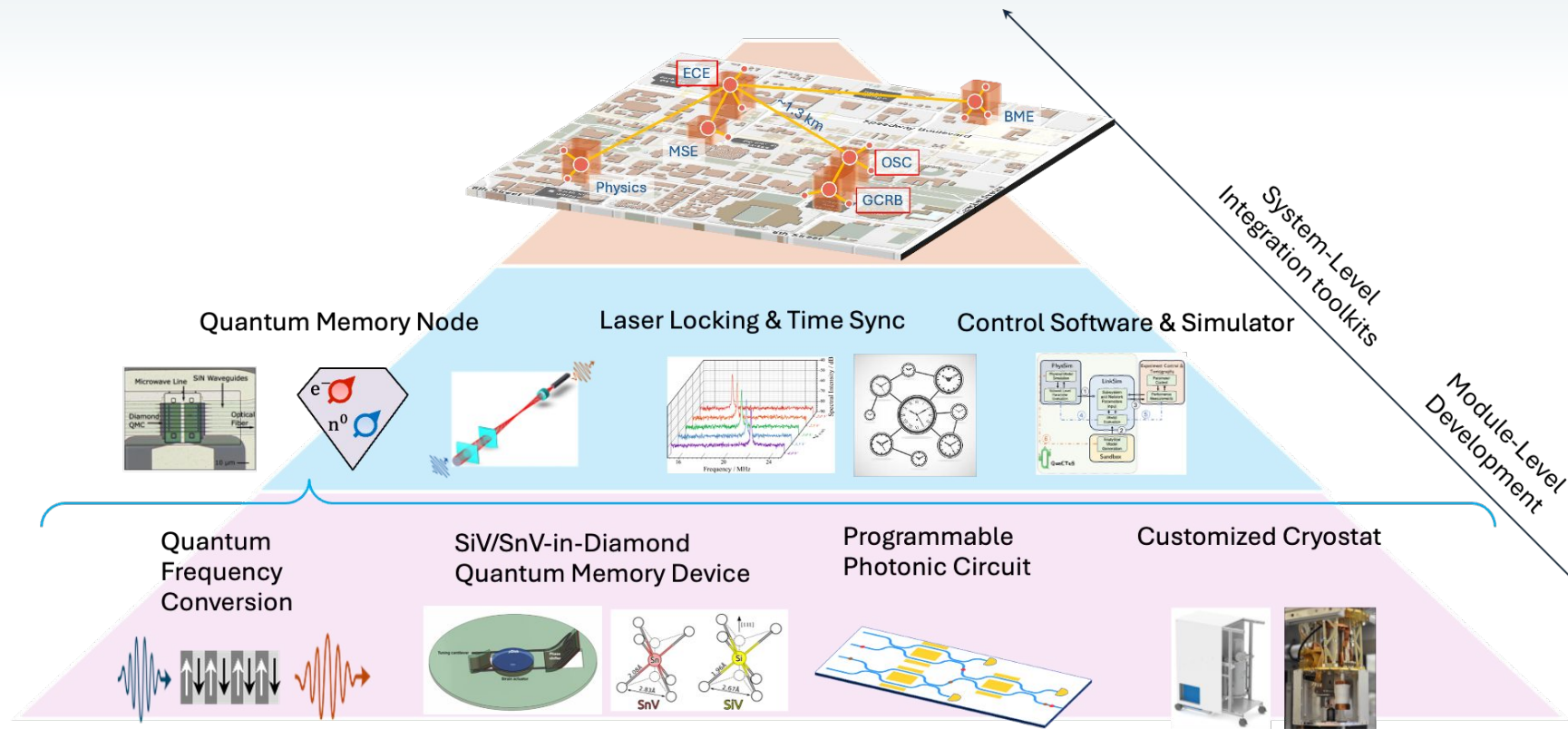
University of
Massachusetts
Amherst BE REVOLUTIONARY



NAU
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UNIVERSITY



UNIVERSITY OF
OREGON

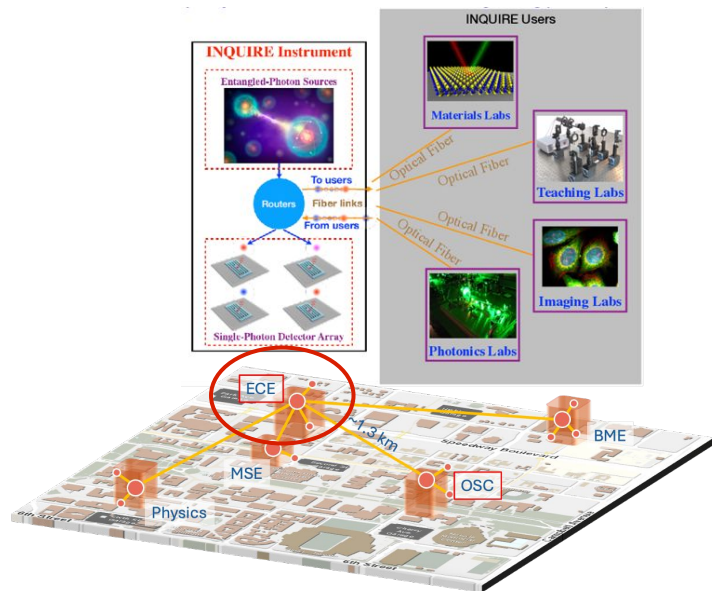




Tucson Testbed Y1-Y5 overview

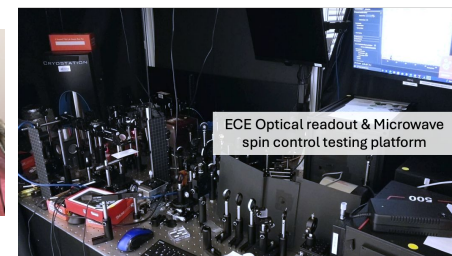


Birth of the Tucson Testbed: NSF INQUIRE project funds the new fiber network between five U. Arizona buildings for QIS education and research.



2020
2021
2022
2023
2024
2025

Establishing the central quantum hub: Recovering from COVID, we gradually established a central quantum network hub at ECE basement, equipped with SNSPDs, optical switches, one cryogenic platform for testing quantum memory.



Seed fund: NSF INQUIRE, led by Prof. Zheshen Zhang (now at UMich)

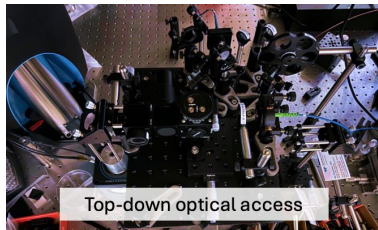


Tucson Testbed Y1-Y5 overview

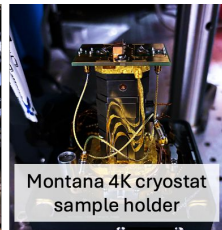


Birth of the Tucson Testbed

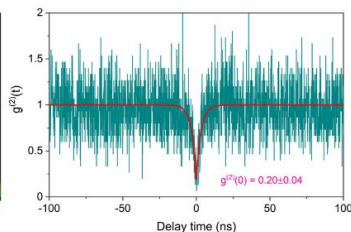
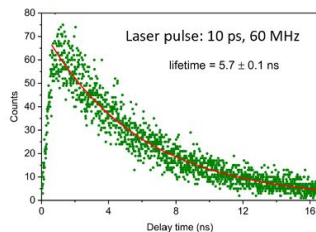
Characterizing SiC-4H SiV quantum memory: We characterized a single SiC-4H SiV color center as a potential candidate of quantum memory



Top-down optical access



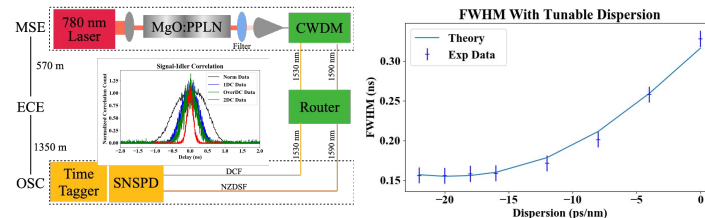
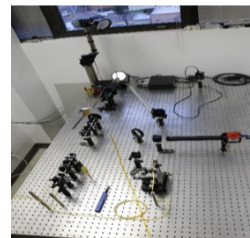
Montana 4K cryostat sample holder



Y. Xue, M. Titze, J. Mack, Z. Yang, L. Zhang, S.S. Su, Z. Zhang, L. Fan
Nano Letters 24 (7), 2369-2375, (2024)

Establishing the central quantum hub

First entanglement distribution in Tucson: We established a free-space optical channel from ECE to the roof of OSC. We generated entangled photon pairs, distributed them through both fiber and free-space channels, and characterized the time-frequency entanglement.



C. Cui, W. Horrocks, L. McCaffrey, V. Nafria, I.B. Djordjevic, Z. Zhang
2021 CLEO, 1-2

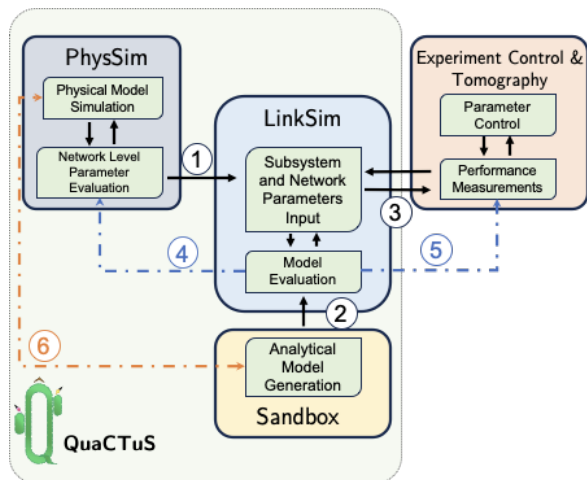


Tucson Testbed Y1-Y5 overview



Birth of the Tucson Testbed Characterizing SiC-4H SiV quantum memory

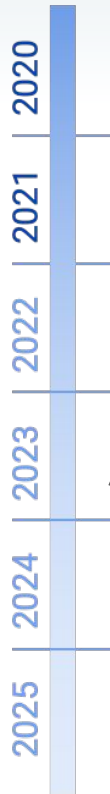
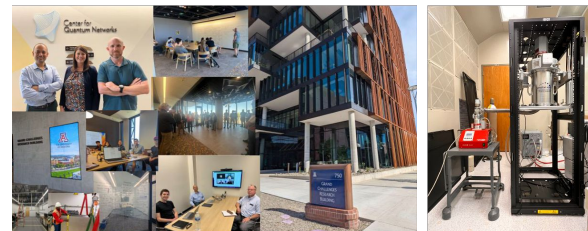
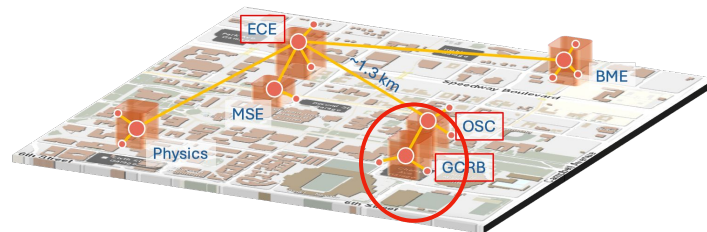
QuaCTUS - Tucson Testbed Simulator: We launch the development of a physical-layer digital twin of the quantum network as a complimentary interface between the Tucson Testbed and Virtual Tested.



P. Dhara, S. Guha, Python code 2023

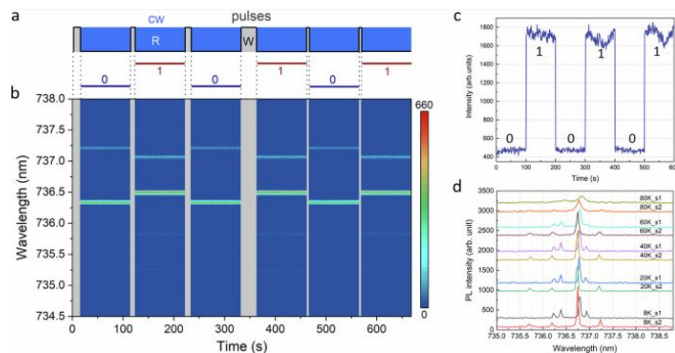
Establishing the central quantum hub First entanglement distribution in Tucson

New space and cryostat: The New GCRB building added another node to the Tucson Testbed. We received the co-designed low-cost cryostat that accommodates our quantum memory at sub-1K temperature with scalability.



Birth of the Tucson Testbed
Characterizing SiC-4H SiV quantum memory
QuaCTUS - Tucson Testbed Simulator

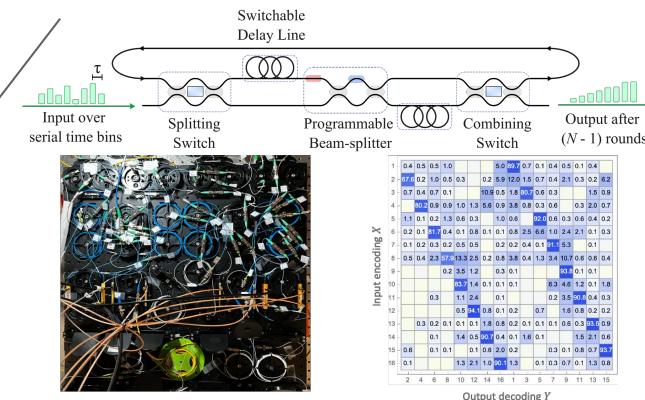
Characterizing SiV color center quantum memory: We found that a second pulsed IR laser can thermalize the lattice structure of SiV defect in diamond, which changes the ground state splitting drastically. It may make SiV a good quantum memory at >1K temperature.



Y. Xue, X. Ni, M. Titze, S.S. Su, B. Wu, L. Zhang, C. Cui, S. Guha, M. Eichenfield, L. Fan, *Nat. Commun.* 16 (1), 6275, (2025)
J. Chen, C. Cui, B. Lawrie, Y. Xue, S. Guha, M. Eichenfield, H. Zhao, X. Yan, *Nanophotonics* 14 (11), 1687-1713, (2025)

- Establishing the central quantum hub
- First entanglement distribution in Tucson
- New space and cryostat

Time domain interferometer: We developed the first scalable time-domain optical joint receiver - *Green Machine* with > 0.9 fidelity. This architecture is now being adapted for generating entanglement among many quantum memory.



C. Cui, J. Postlewaite, B.N. Saif, L. Fan, S. Guha, Nat. Commun. 16 (1), 3760, (2025)
J.R. Basani, C. Cui, J. Postlewaite, E. Waks, S. Guha, arXiv:2505.00865 (2025)



Tucson Testbed Y1-Y5 overview



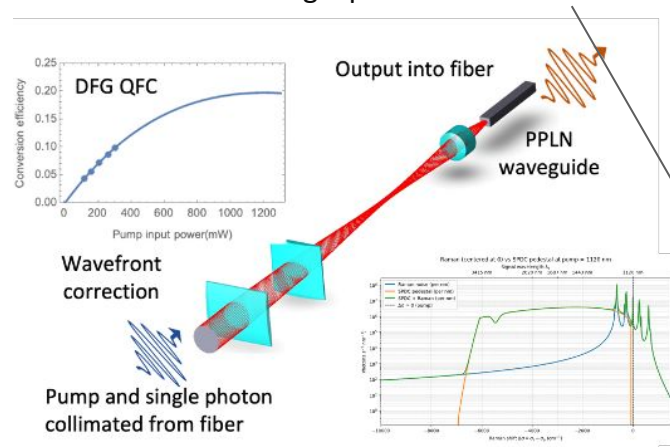
Birth of the Tucson Testbed

Characterizing SiC-4H SiV quantum memory

QuACTUS - Tucson Testbed Simulator

Characterizing SiV color center quantum memory

Quantum frequency conversion: We demonstrated 10% efficiency 737 nm single photon from SiV emitter -> 1392 nm single photon.



Team: M. Akbulut, C. Cui, Y. Wang, Y. Xue, M. Eichenfield

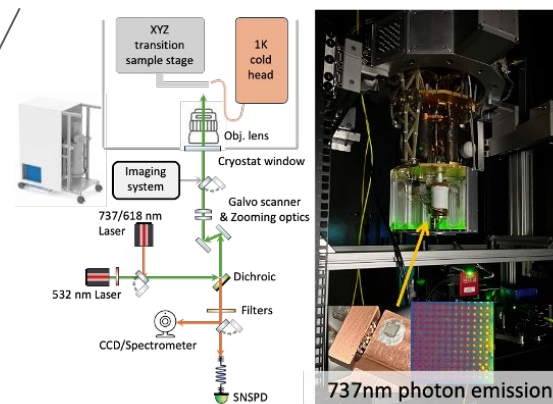
Establishing the central quantum hub

First entanglement distribution in Tucson

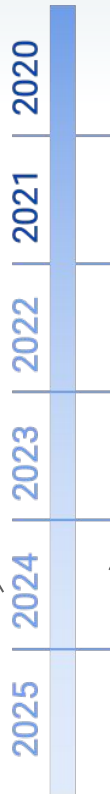
New space and cryostat

Time domain interferometer

Cryostat-compatible confocal scanning microscope: We designed a confocal scanning microscope for PhotonSpot crystal we received in mid 2023 and tested for collecting emissions from SiV in diamond.



Team: M. D. Ackerman, C. Cui, Y. Xue, M. Akbulut, M. Eichenfield





Tucson Testbed Y1-Y5 overview



Birth of the Tucson Testbed

Characterizing SiC-4H SiV quantum memory

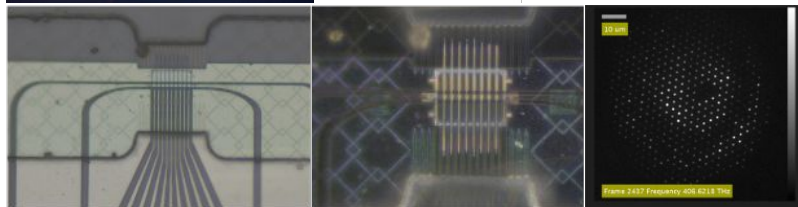
QuACTUS - Tucson Testbed Simulator

Characterizing SiV color center quantum memory

Quantum frequency conversion

Collaborations and technology sharing across testbeds:

In 2023-2024, we visited Boston testbed to learn their techniques and brought back some SiV chips from MIT, MIT Lincoln Lab, and our industrial partner Qunett.



Team: C. Cui, Y. Xue, M. Eichenfield, C. Li, Y. Hu, I. Christen
H. Raniwala, D. Englund, L. Andre, B. Shields, MITLL ...

2020
2021
2022
2023
2024
2025

Establishing the central quantum hub

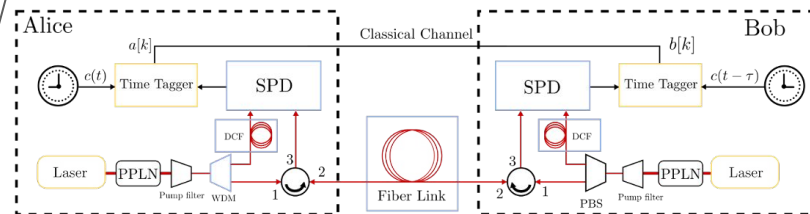
First entanglement distribution in Tucson

New space and cryostat

Time domain interferometer

Cryostat-compatible confocal scanning microscope

Granting access to industrial partners: We help L3Harris establish their experiments sharing the quantum networking facilities on U. of Arizona campus.

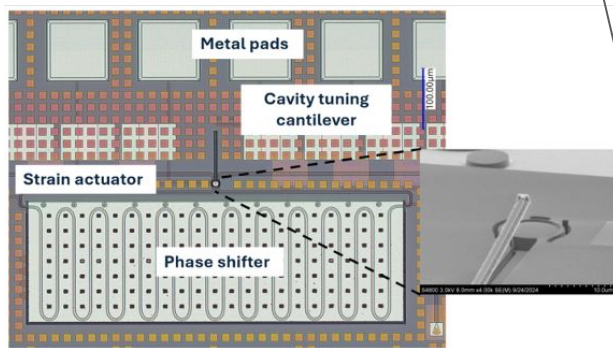


Team: M. Bullock, B. Bash, L3Harris

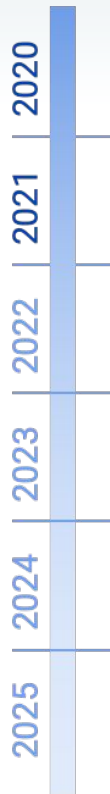


Tucson Testbed Y1-Y5 overview

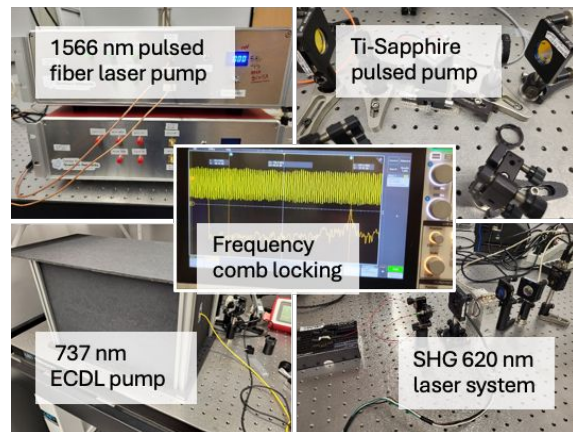
Birth of the Tucson Testbed
 Characterizing SiC-4H SiV quantum memory
 QuaCTUS - Tucson Testbed Simulator
 Characterizing SiV color center quantum memory
 Quantum frequency conversion
 Collaborations and technology sharing across testbeds
 Integrated quantum memory devices: We designed diamond micro-disk resonator for Purcell enhancement rate, scalability, and compatibility to photonic integrated circuits



Team: A. Zhai, M. Eichenfield, Sandia National Lab



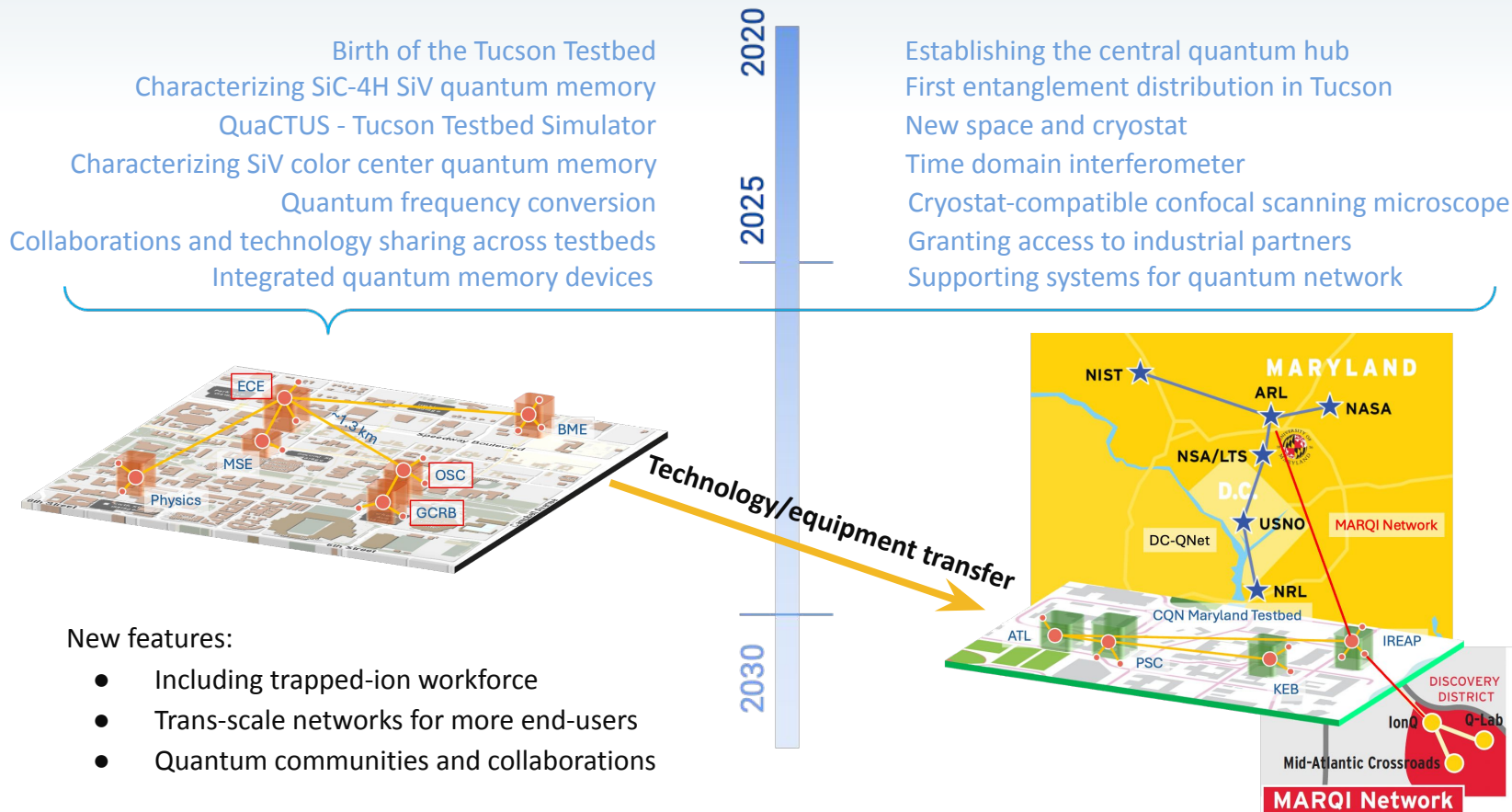
Establishing the central quantum hub
 First entanglement distribution in Tucson
 New space and cryostat
 Time domain interferometer
 Cryostat-compatible confocal scanning microscope
 Granting access to industrial partners
 Supporting systems for quantum network: remote laser locking and special pump laser systems



Team: M. Akbulut

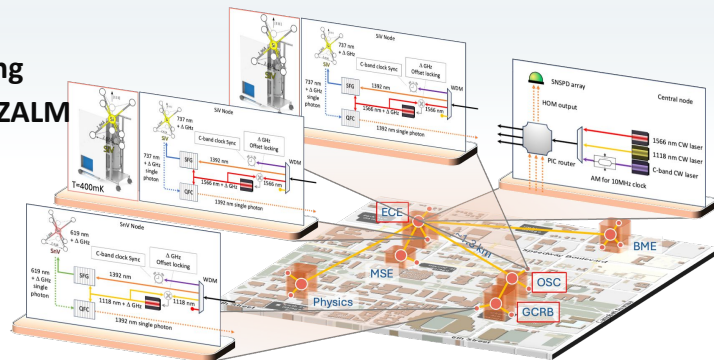


Tucson Testbed → UMD Testbed

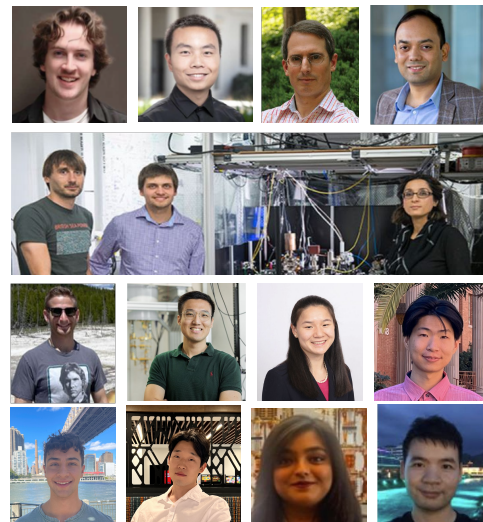
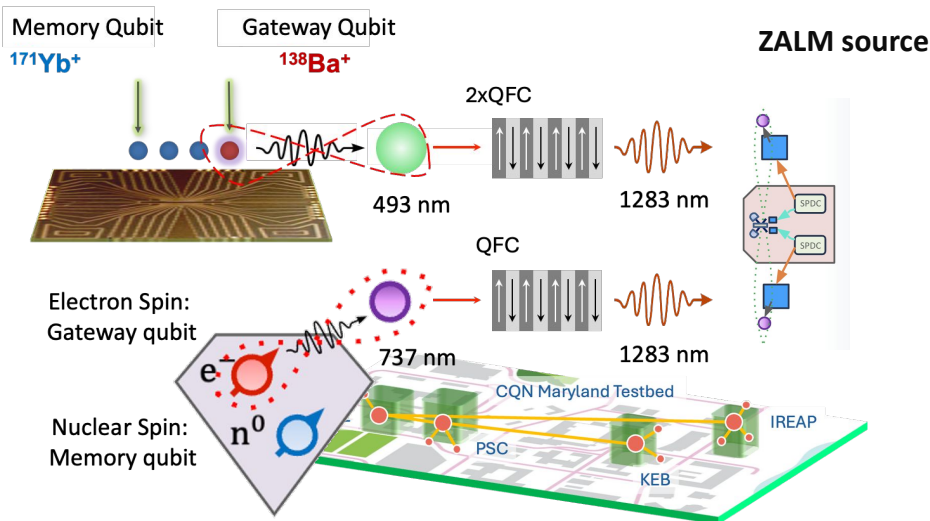


Tucson Testbed → UMD Testbed

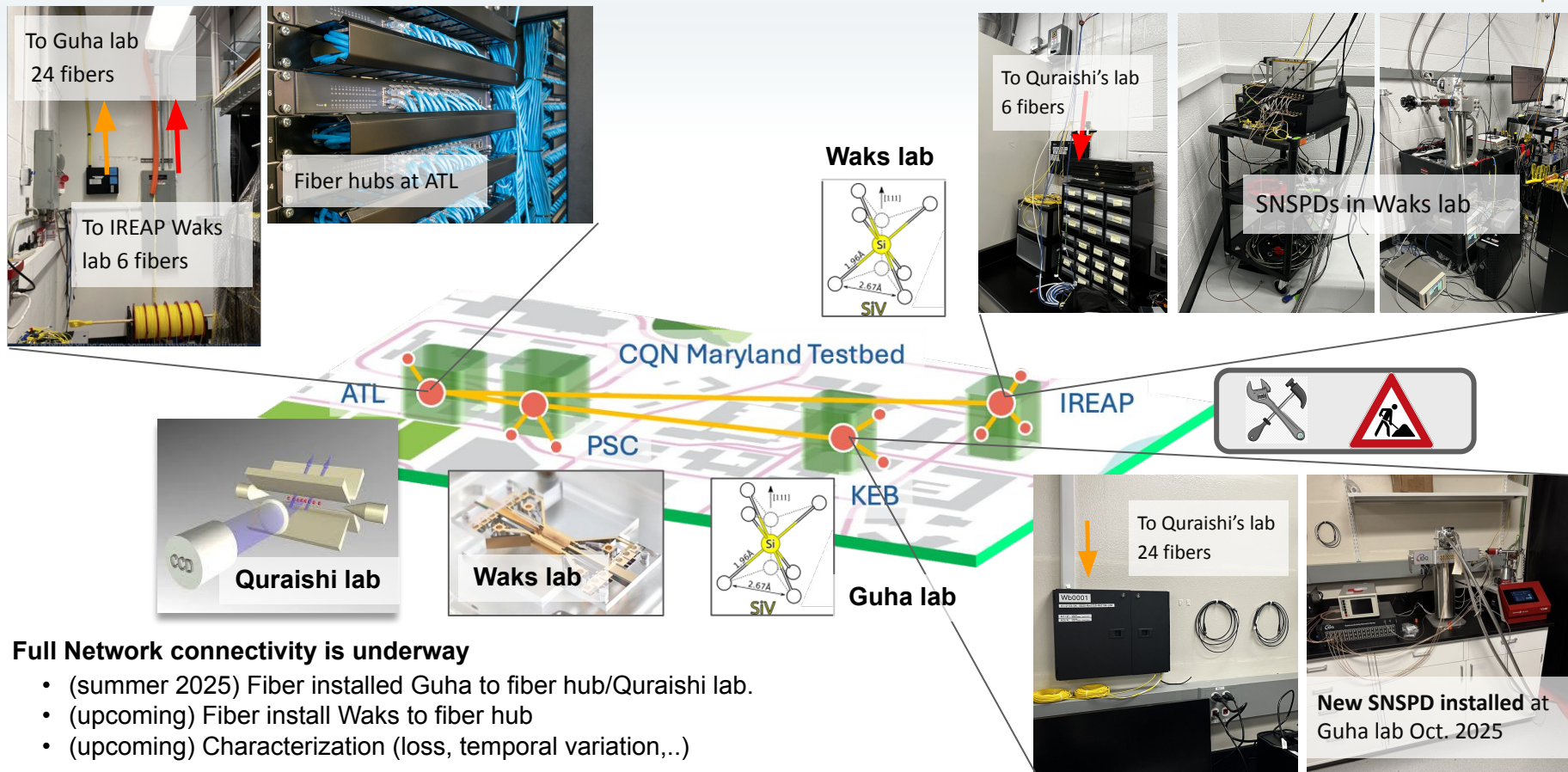
Design change: Including
Trapped-ion QPU, and ZALM
source for practical
quantum networking



Team change:
Adding specialties of
trapped-ion systems



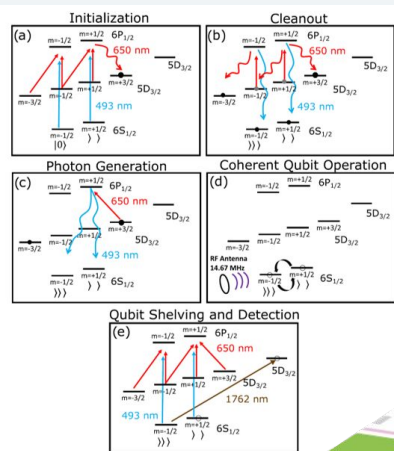
Maryland Testbed in Y5: Facilities



Full Network connectivity is underway

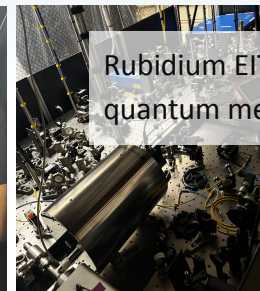
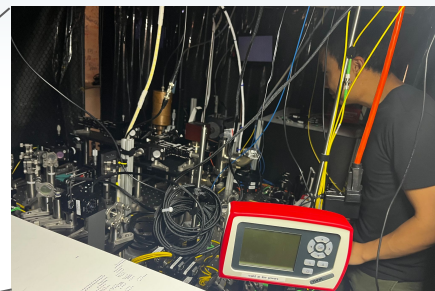
- (summer 2025) Fiber installed Guha to fiber hub/Quraishi lab.
- (upcoming) Fiber install Waks to fiber hub
- (upcoming) Characterization (loss, temporal variation,...)

Maryland Testbed in Y5: Trapped Ion



Barium ion entangled with
photon polarization 50k/s

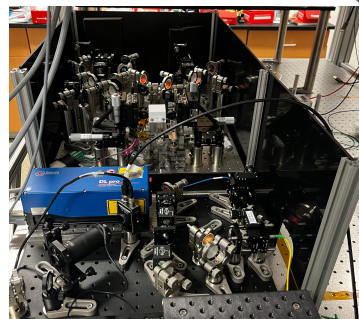
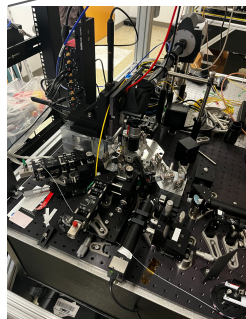
Trapped-ion system in Quraishi ATL lab



Rubidium EIT-based
quantum memory

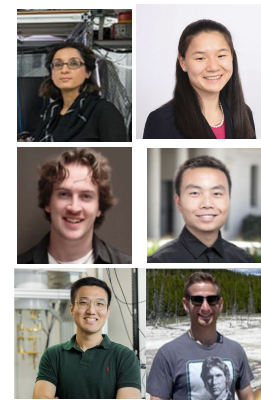


Trapped-ion system & QFC setups in Waks PSC lab

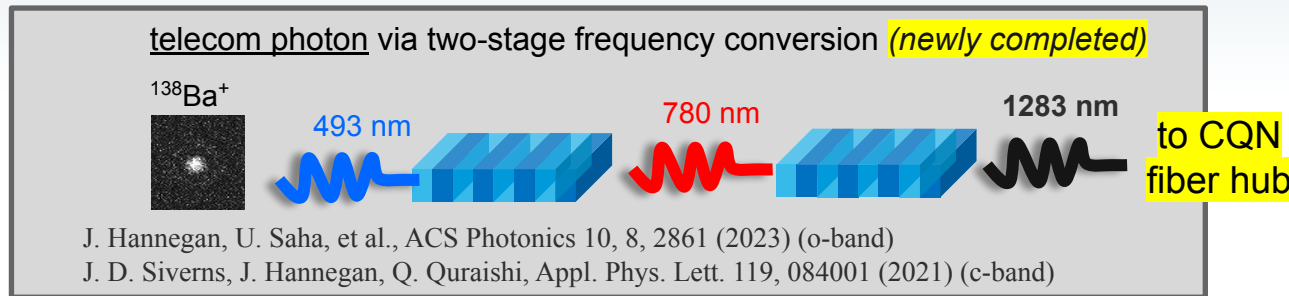


Upgrading the Trapped-Ion Systems

- (summer 2025) Polarization-independent QFC to 1283 nm
- (upcoming) Ion to telecom photon entanglement fidelity
- (upcoming) HOM with QFC-converted photon from SiVs



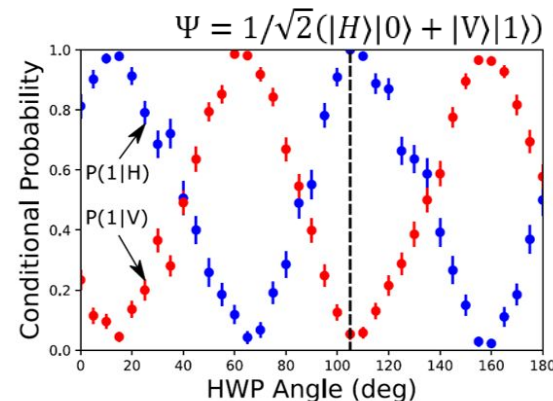
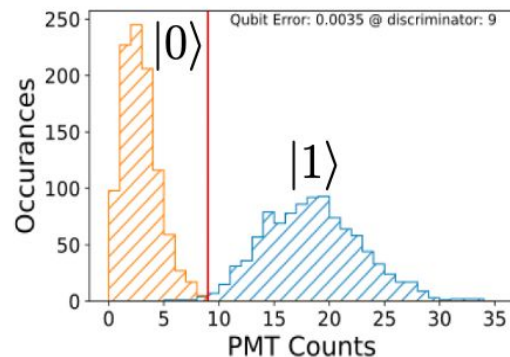
Overview trapped ion system + frequency conversion



Thermally phase-matched ZnO-doped periodically poled lithium niobate (PPLN)

Trapped Ba⁺ ion system

- Ba⁺ emits 493 nm photon.
- First-stage frequency conversion 493 nm (93% fidelity) → 780 nm (84%) (ion-visible-photon entanglement fidelity)
- (upcoming)** Second-stage frequency conversion 780 nm → 1283 nm ion-telecom-photon entanglement fidelity.

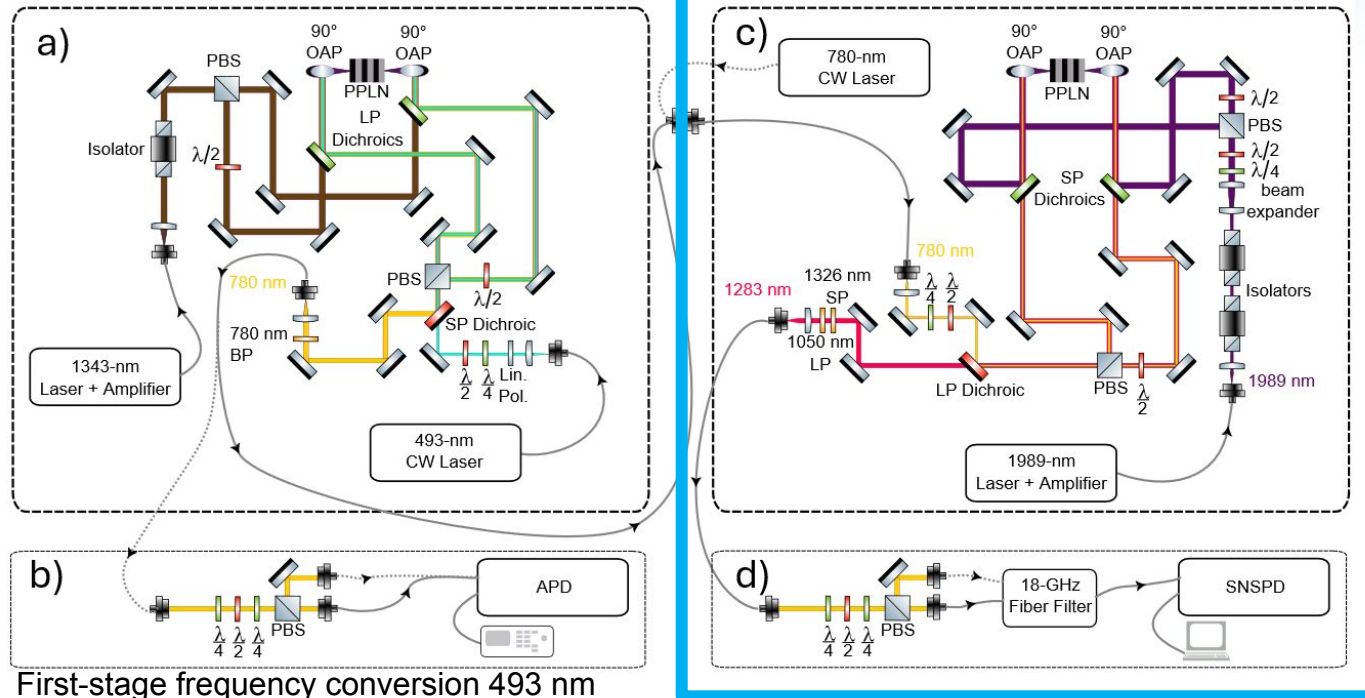


J. Hannegan, J.D. Siversns and Q. Quraishi, Phys. Rev. A 106, 042441 (2022).

J. Hannegan, Doctoral thesis, Uni. of MD, (2022).



Maryland Testbed in Y5: Trapped Ion

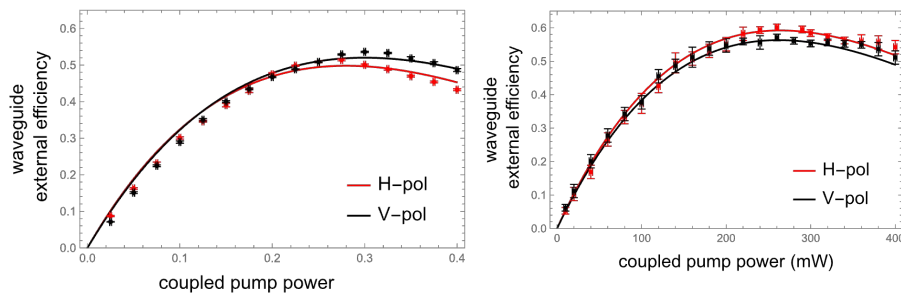


NEW QFC stage for telecom for connecting to converted photon from SiV side

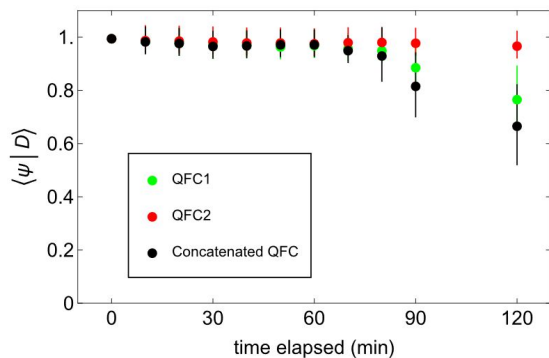
Summer 2025:
Characterized two-stage,
polarization-preserving
QFC to 1283 nm.

493 nm $\rightarrow$ 1283 nm two-stage QFC results

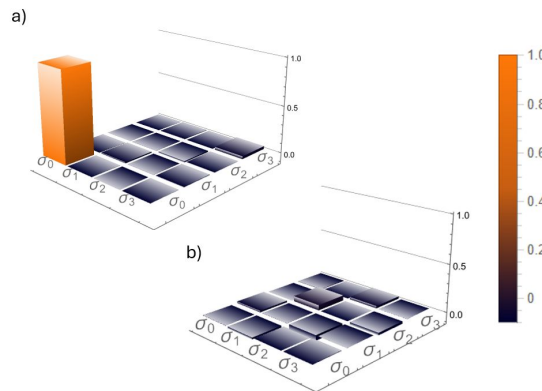
>33% fiber-to-fiber conversion efficiency of each stage



> 60 min polarization stability



97.(0)% process fidelity (polarization-preserving)



projected ion-photon entanglement rate and fidelity

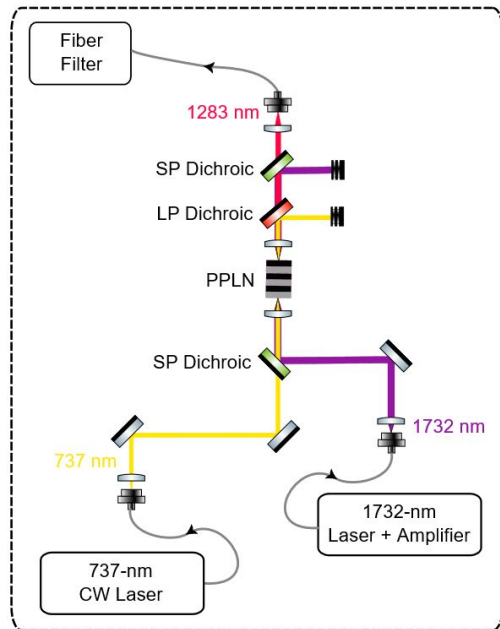
	rates	fidelity
493 nm	137/s	> 0.93(2)
780 nm	45/s	> 0.84(2)
1283 nm (projected)	15/s	> 0.7(5)



Maryland Testbed in Y5: Trapped Ion + QFC

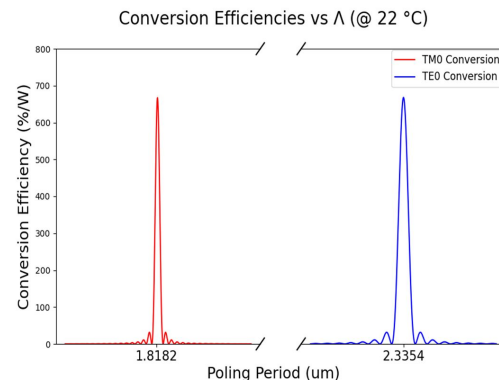
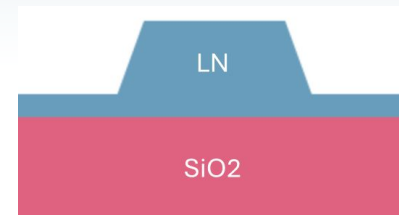


Upcoming:



737 nm $\rightarrow$ 1283 nm QFC (Winter 2025)

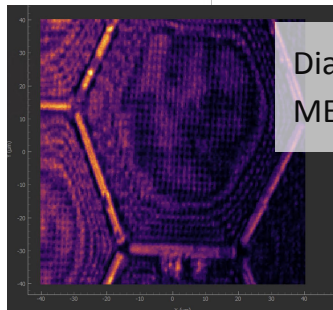
Waks Lab and TAMOS:
next-generation ion trap system
(Winter-Spring 2026)



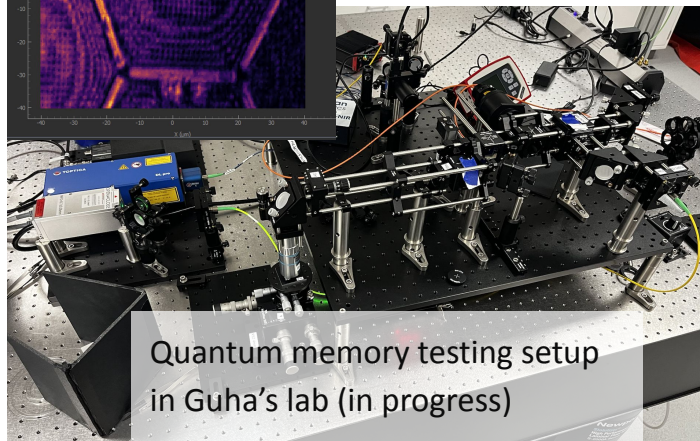
Waks Lab & Loncar Group: next-gen 493
nm $\rightarrow$ 737 nm Pol-Res QFC on TFLN
(Summer-Fall 2026)



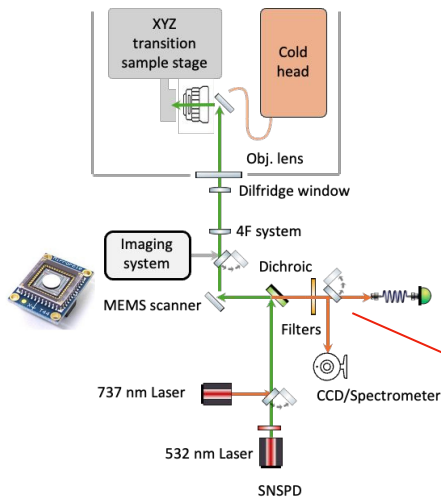
Building a dil-fridge compatible confocal MEMS-scanner microscopy



Diamond nanopillars under
MEMS confocal scanner



Quantum memory testing setup
in Guha's lab (in progress)

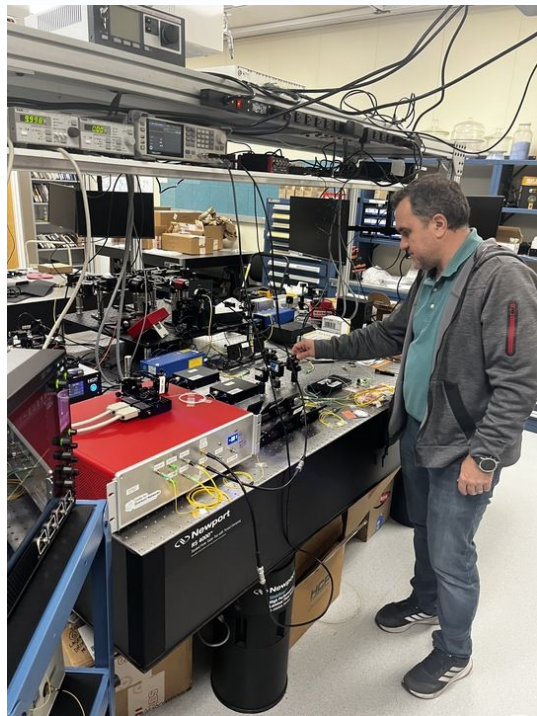


Dil-fridge in IREAP Waks's lab

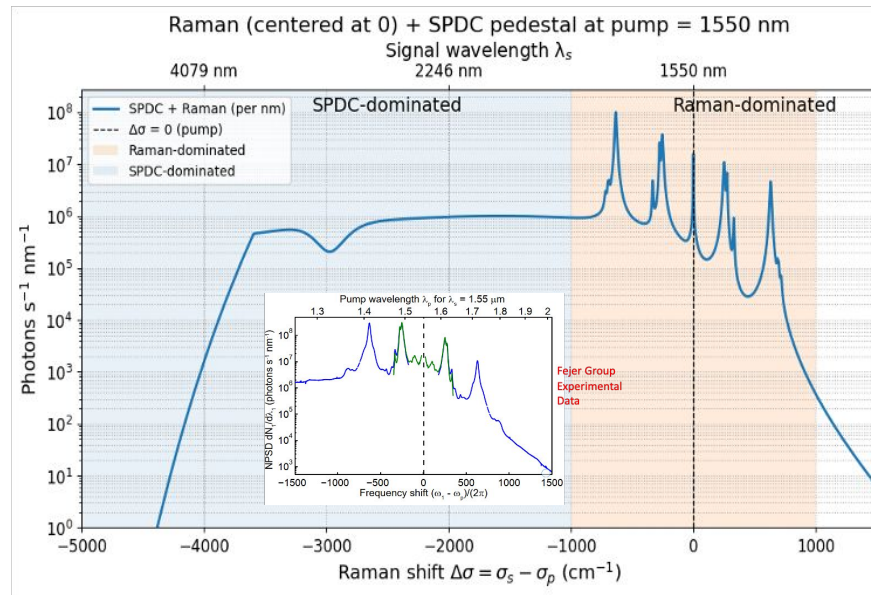




Transferring SiV QFC setup from UArizona to UMD

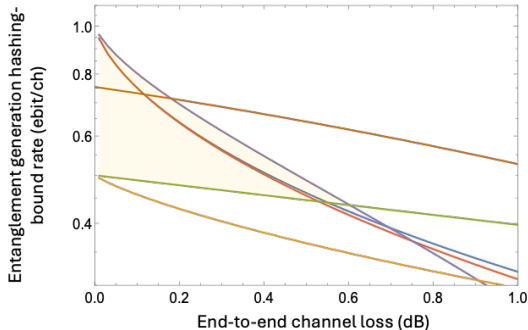
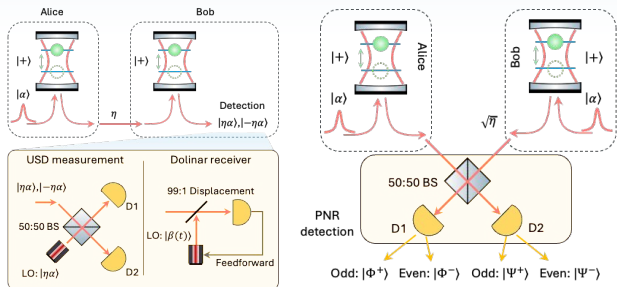


PPLN high-power pump noise photon simulations





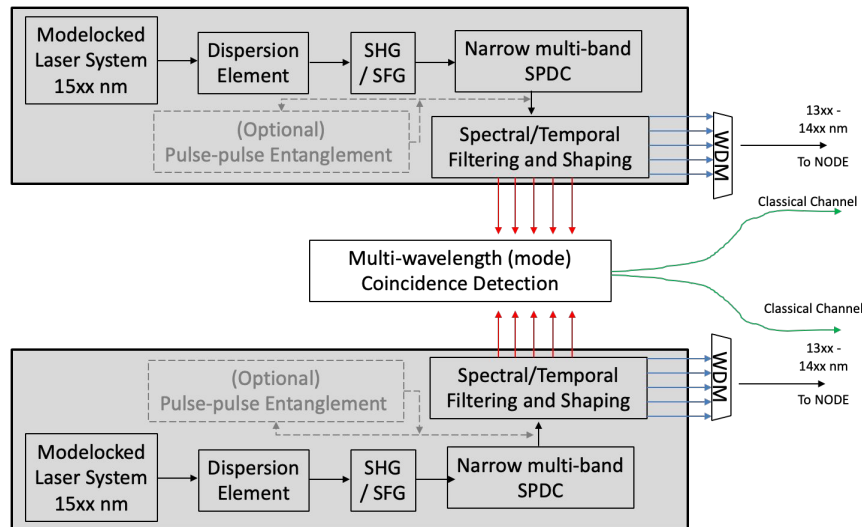
Coherent-state-assisted entanglement distribution



- Coherent Two-Way
- Coherent One-Way USD
- Coherent One-Way DR
- Single-rail Single Photon
- Dual-rail Single Photon
- Sq GKP state @ 5dB



ZALM-source based entanglement distribution, working with UArizona, UOregon, MIT



C. Cui, P. Dhara, S. Guha, arXiv:2504.20344 (2025)



Year 6-10 Maryland Testbed

- 2026** — Develop the MEMS-scanner quantum memory module and ZALM source together with other CQN thrusts
Set up new TAMOS ion trap system in Waks lab & build QFC modules.
Testing next-gen QFC module in fiber networks throughout the testbed and MARQI network
- 2027** — Integrate the network and classic control with quantum memory and the trapped ion system. (Together with MARQI)
Investigating temporal mode shaping and other potential bottlenecks.
Wrap up QFC noise characteristics of using PPLN together with U of A team
- 2028** — Demonstrate basic quantum memory functions and HOM interference between SiVs and trapped ions. Open testbed access to industrial partner.
- 2029** — Benchmark ZALM entanglement-generation scaling and optimize toward the target rate, implement it together with Boston testbed.
- 2030** — Demonstrate high-rate entanglement distribution over multiple quantum memory nodes.
Demonstrate advanced quantum networking protocols