Quantum Sensors and Manufacturing Update

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Director, Quantum Technologies Accelerator

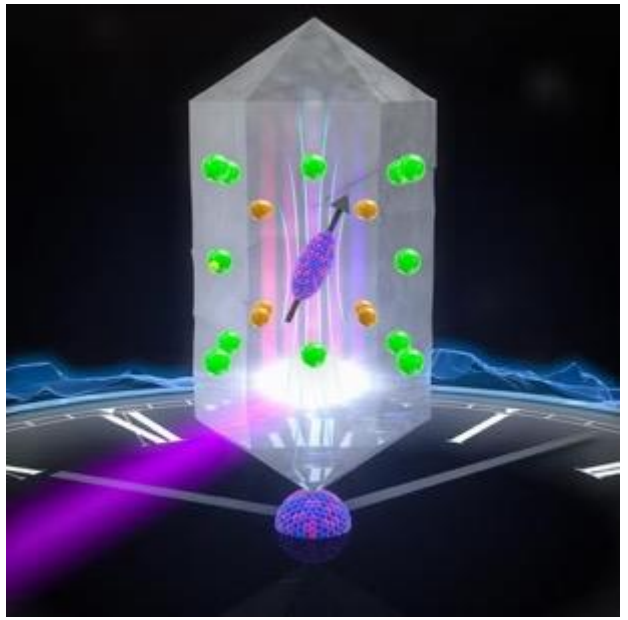
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
U.S. DEPARTMENT OF COMMERCE

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Quantum Technologies Accelerator

Vision: A coherent quantum research program that delivers global scientific leadership and clear impact on U.S. industrial competitiveness and innovation

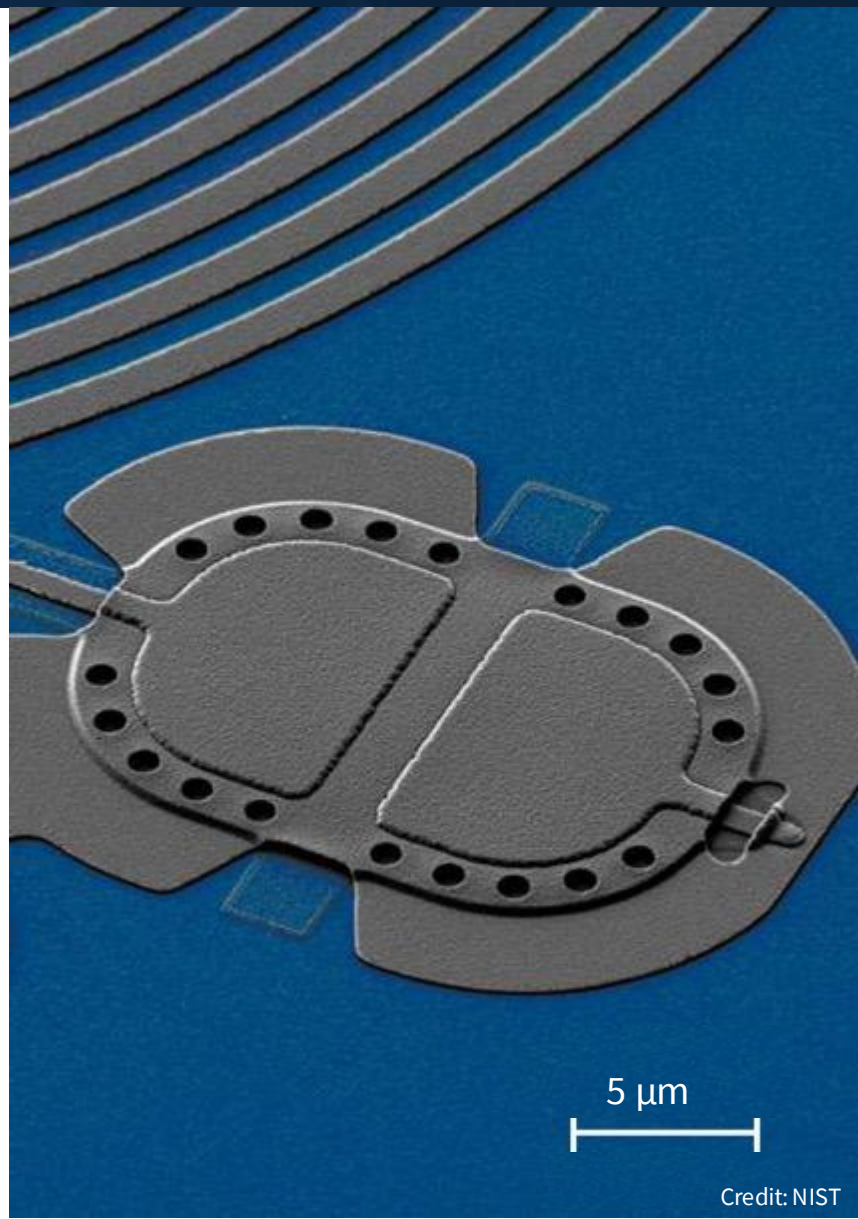
- A new approach to coordinating and overseeing the entire NIST quantum program
- Works with all NIST OUs, Divisions, Groups, and researchers where quantum research is being performed
- A force multiplier for a large and complex research program that spans multiple Laboratory OUs
- Supports world-leading science and researchers
- Supports new collaborations and partnerships for greater mission impact



Credit: NIST

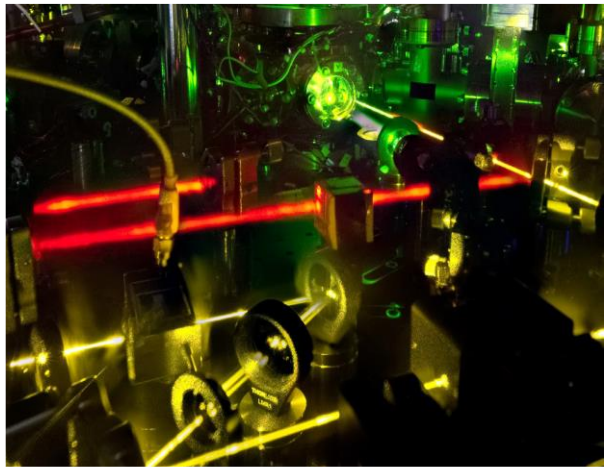
NIST Quantum Program Elements

- **Core Research Program**
  - Optical clocks and time transfer
  - Quantum sensing & precision measurement
  - Quantum networking
  - Quantum computing
  - Enabling technologies
- **QMEC – Manufacturing of scalable, high-performance quantum components**
- **Cooperative R&D (CRADAs) with companies and universities**
- **QED-C – Industrial ecosystem building**

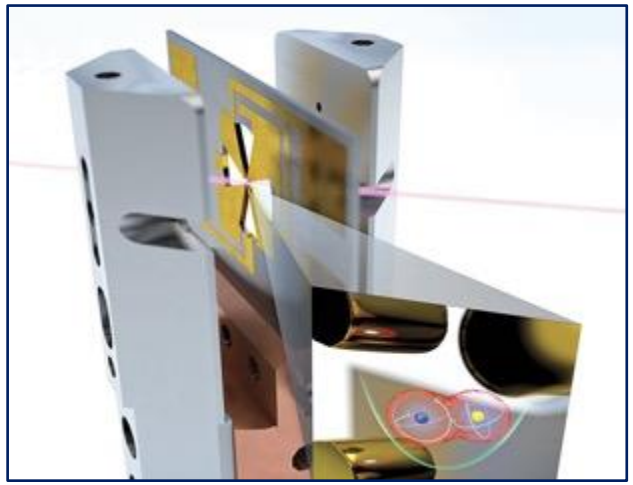


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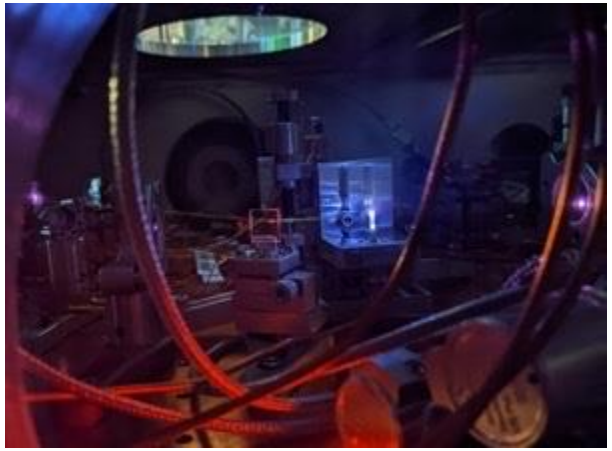
Advanced Optical Clocks and Time Transfer



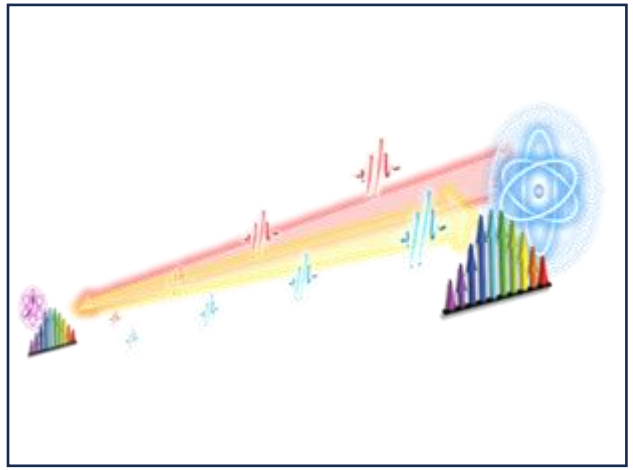
Lattice Clocks
Ytterbium lattice, strontium lattice with record-breaking stability and accuracy (< 1×10^{-18})



Trapped Ion Clocks
Quantum logic aluminum ion clocks with record accuracy (< 1×10^{-18})



Thorium Nuclear Clock
World's first nuclear clock. Studying systematic shifts - temperature shifts below the 10^{-18} fractional frequency uncertainty



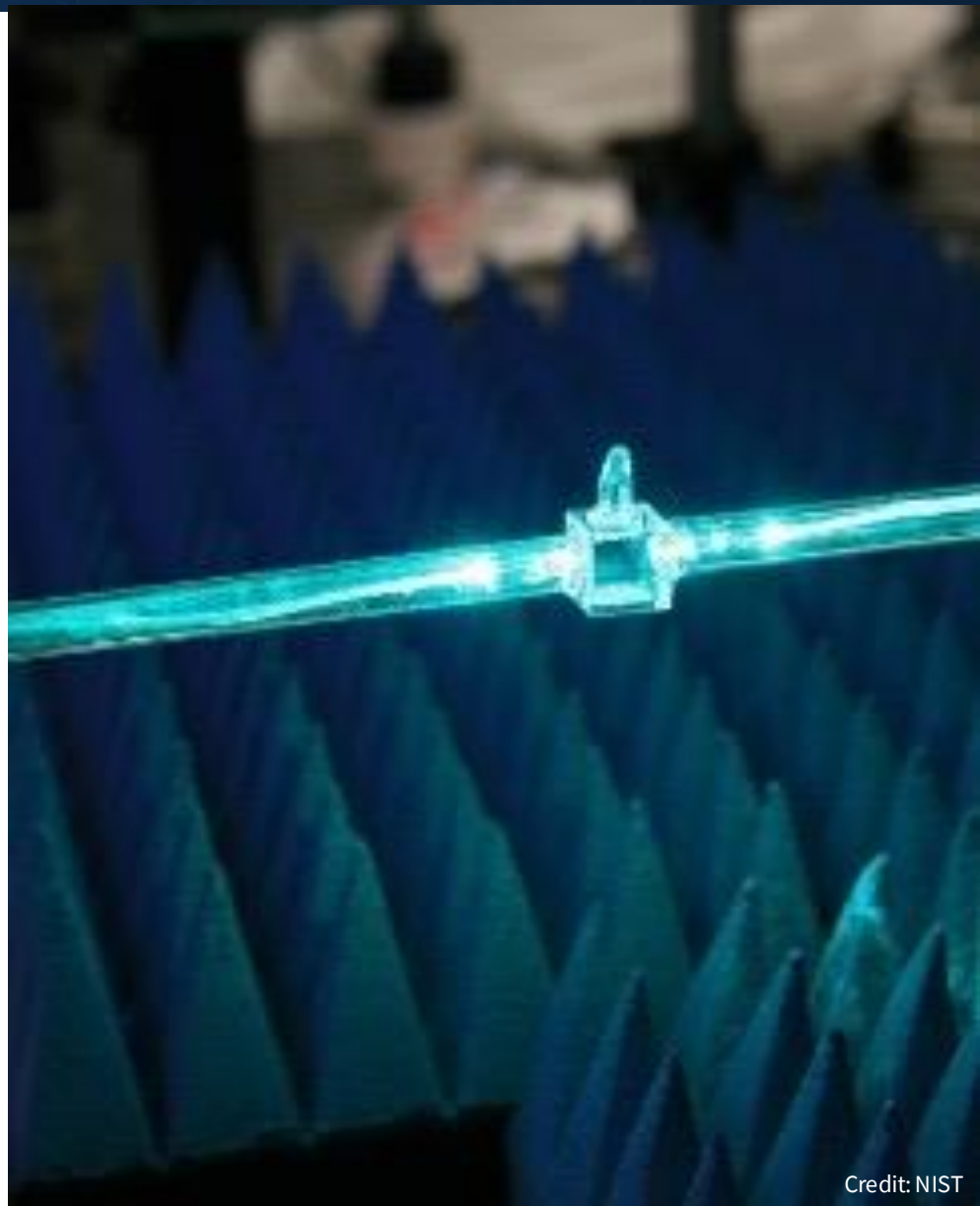
Optical Time Transfer
Femtosecond time transfer over 300 km of open air with quantum limited sensitivity (tolerant to >100 dB link loss)

All photos credit: NIST

Quantum Sensing

Harnessing quantum mechanics for precision measurement of physical quantities:

- Atomic clocks, both compact and high-performance (timekeeping, PNT, gravity)
- Nano-mechanical and opto-mechanical devices (forces)
- Atomic magnetometers (magnetic fields)
- Atomic Rydberg sensing (electric, RF, microwave)
- Atom interferometers (motion)
- Specialized and single photon detectors (light)
- Combs/Spectroscopy (chemical and biological)
- Superconducting circuits (electromagnetic)
- Trapped cold atoms (pressure)
- Quantum realization of the International System of Units

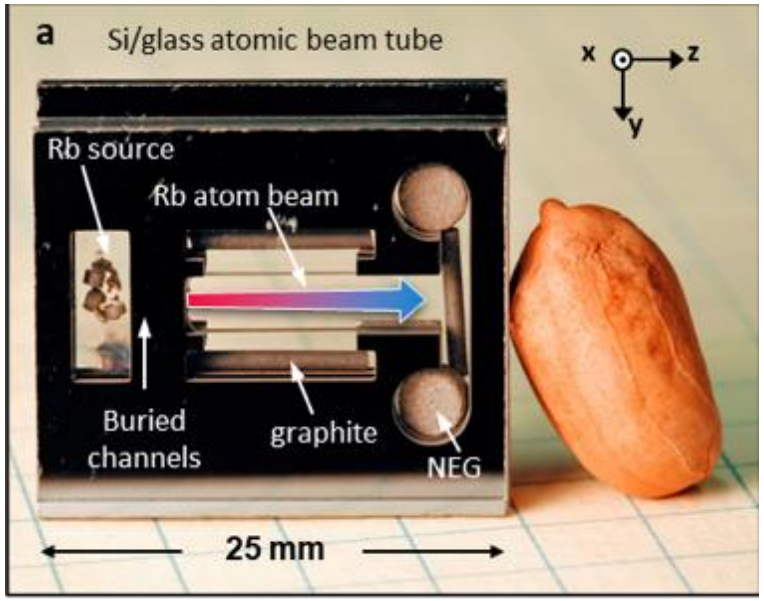


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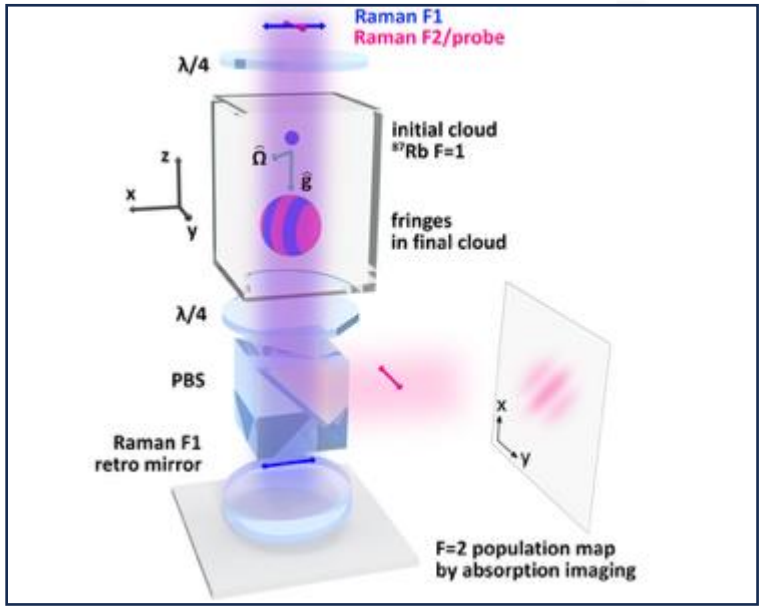
Example – Chip-Scale Atomic Sensors

Inertial navigation in GPS-denied environments

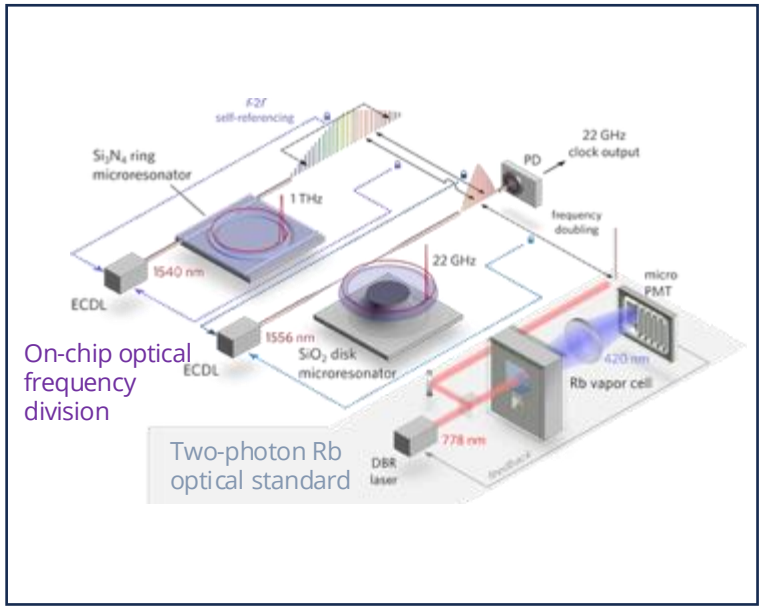
Atomic Beam Clock
(1 ms @ 1 week on 150 mW)



Atom Interferometer
(compact motion sensor)



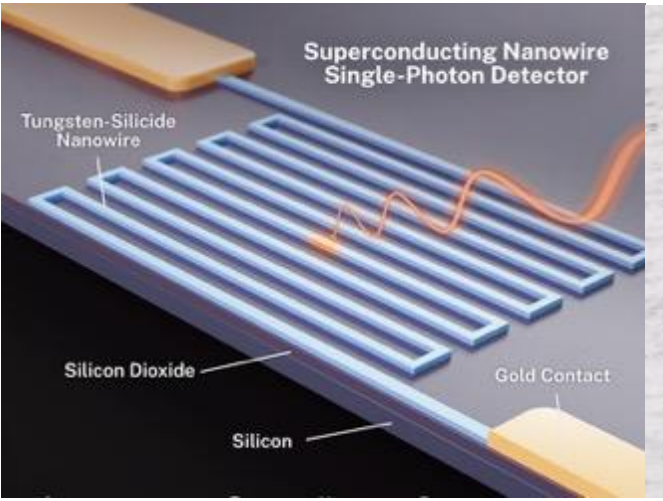
Next Gen Chip-Scale Atomic Clock (with integrated photonics)



Similar technology is being developed at NIST for precision magnetic sensors (also for navigation)

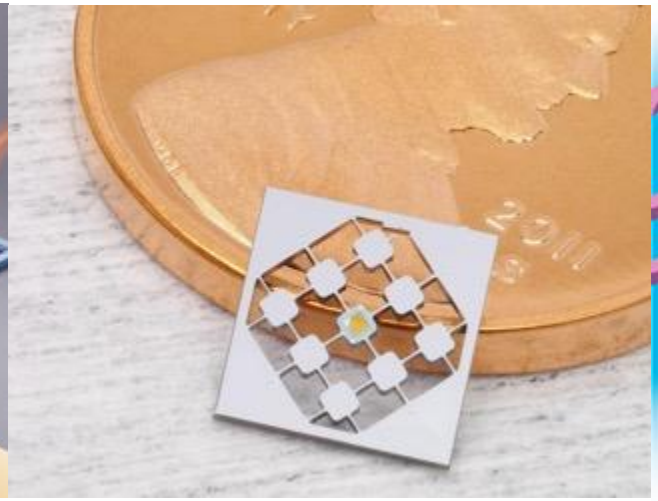
All photos credit: NIST

Critical Components for Future Quantum Networks



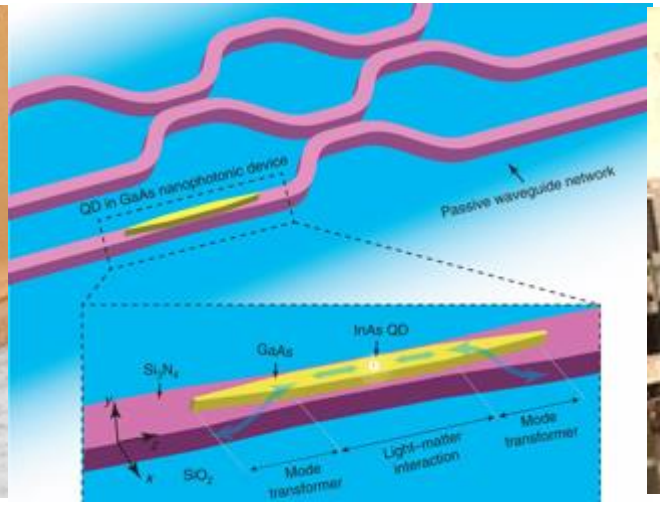
Single-Photon Detectors

Superconducting nanowire sensors with very high detection efficiencies



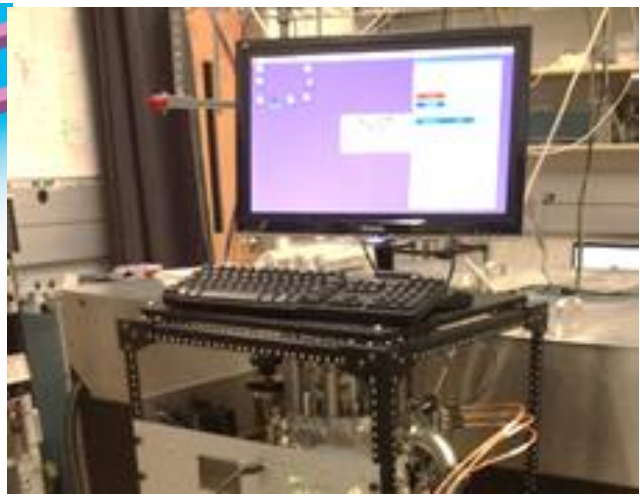
Transducers & Repeaters

Critical for connecting different quantum modalities and for long-distance quantum communication



Integrated Photonics

Low-loss photonic integrated circuits and high-performance light coupling



Network Metrology Testbeds

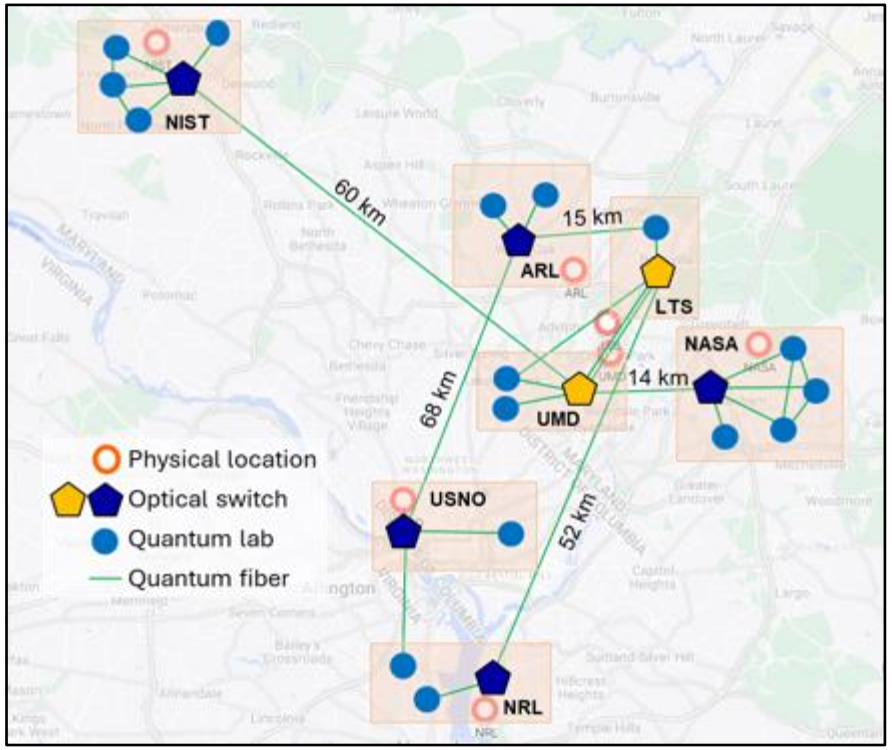
Characterizing the performance of critical components and emerging quantum networks

All photos credit: NIST

Prototype Metro-Scale Quantum Networks

Infrastructure to conduct testing of component technologies, metrology tools, network protocols, and systems integration

Washington DC (DC-QNet)



Boulder, Colorado



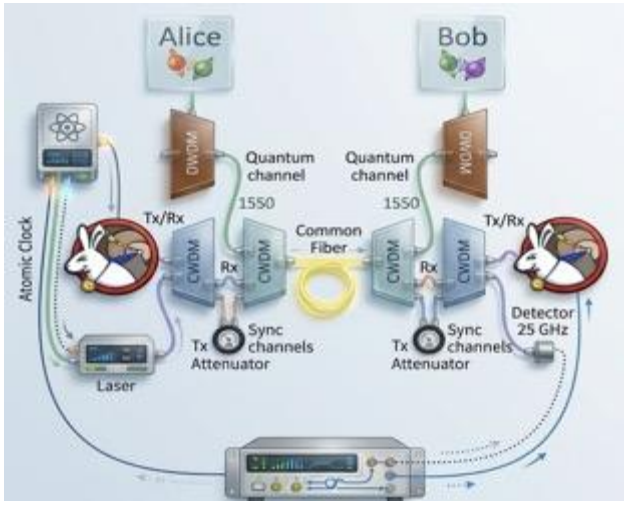
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Precision Timing and Synchronization Across Networks



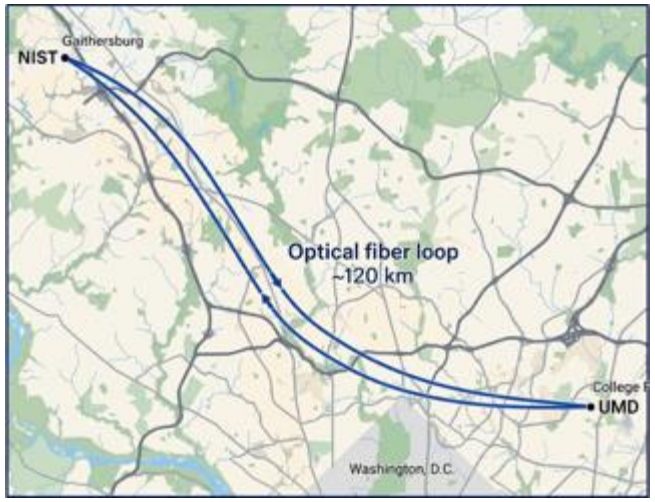
Optical Clock Comparisons

Stabilized optical fiber link between JILA and NIST (~1 km) for record-breaking clock comparisons at 10^{-18} level



Between Quantum Network Nodes

Sub-pico-second precision with just a few-photons for compatibility with quantum networks



Phase Stabilization Across Networks

Kilometer-length phase-stable fiber links for quantum network protocols



Multicore Fiber

Optical frequency transfer at the 10^{-19} level using advanced fiber technology.

All photos credit: NIST

Quantum Manufacturing Engineering Center (QMEC)

Partnering with the U.S. quantum industry to overcome technical barriers to scaled manufacturing

- New co-development model directly with industry to accelerate domestic production and commercial adoption
- Jointly with SRI International for commercialization expertise
- $20 M initial investment
- Initial focus on lasers, photonics, and cryogenics R&D
- Key goal is reduced size, weight, power, or cost (SWaP-C) by a factor of at least 10
- Working with companies to match technical manufacturing challenges with NIST expertise



Credit: NIST

Questions?



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