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Quantum networking and communication with remotely situated quantum memories

U.S. ARMY RDECOM

ARL open campus

S&T Campaign: Materials Research
Photonics

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Quantum Sciences Group: six postocs, 4 students

Research Objective

- **We wish to establish an intra-city multi-site quantum network with nodes that are quantum memories.**
- **This is the first-of-its-kind network that links quantum memories, quantum frequency converters and flying quantum bits over fiber and free-space.**

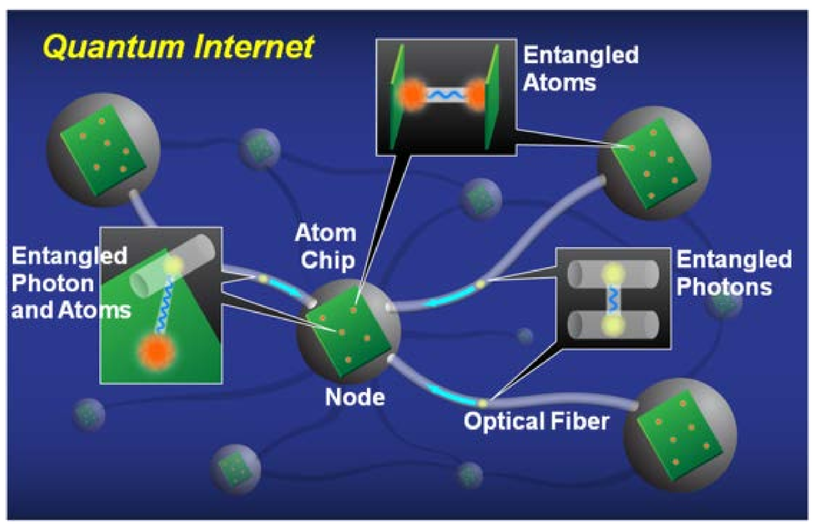

Fig. 1 Quantum network consisting of quantum memories, entanglement, interconnects and transmission lines.

ARL Facilities and Capabilities Available to Support Collaborative Research

- **We have two laboratory spaces at ARL and one at JQI:**
  - **lab 1: scalable systems with laser-cooled neutral atoms and single photons emitters**
  - **lab 2 (Open Campus lab): chip-based ion trap for long-lived quantum memory**
  - **lab 3 (at Joint Quantum Institute, Univ MD): ion & Rydberg**
- **We use ARL's state-of-the-art cleanrooms for all of our >30 step fabrication process.**
- **Leverage existing fiber link between ARL and nearby sites, including Univ of MD.**

Quantum networking & communication: best source of quantum information is a quantum bit (qubit) in laser-cooled atoms and best method to transmit quantum information is through single-photons (flying qubits)
Quantum memories: generates, stores, processes and later retrieves quantum information.

Scalable quantum memories & nodes

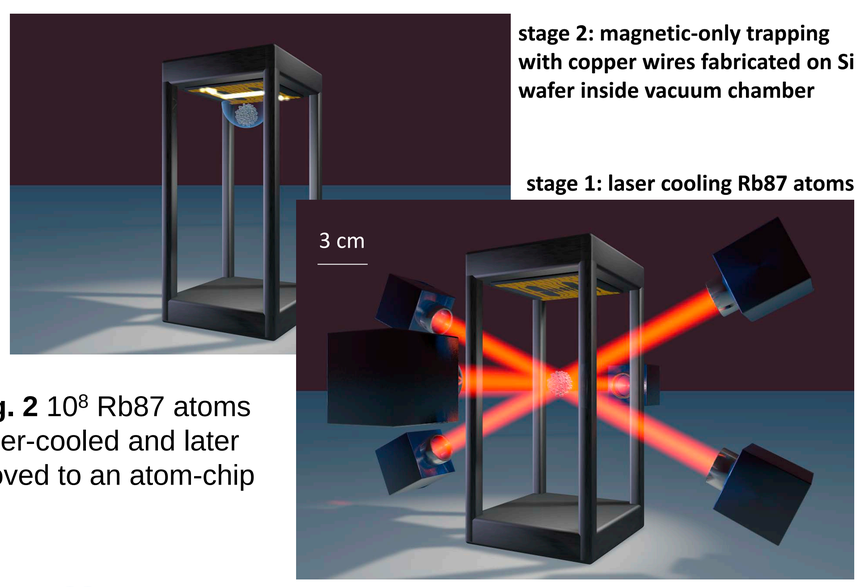

Fig. 2 10^8 Rb87 atoms laser-cooled and later moved to an atom-chip

ARL: ion trap fabrication

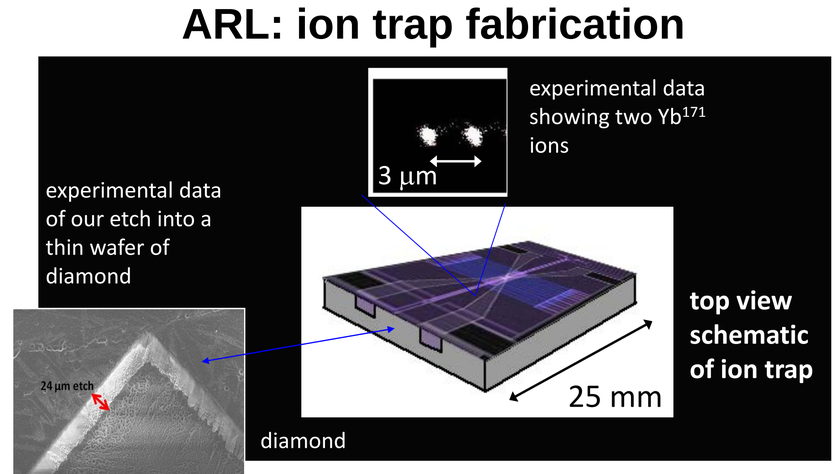

Fig. 3 laser-cooled Ba or Yb ions trapped on a chip for quantum control

Atomic ensembles for quantum memories, including Rydberg's

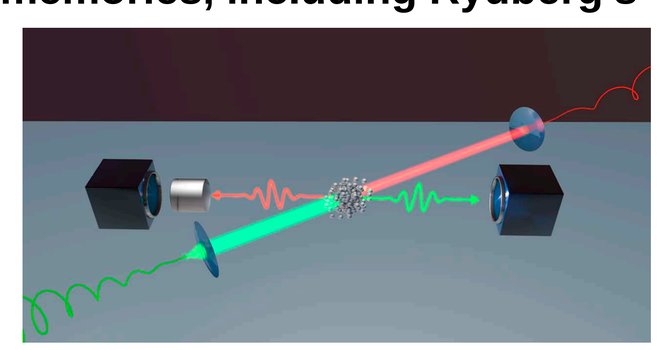

Fig. 4 10^8 Rb87 atoms laser-cooled and leveraging collective atomic effects, we obtain a single emitted photon.

Challenges

- **Remote entanglement of quantum memories calls for single photon to be emitted by each memory we need to**
- **Quantum frequency conversion: photons (entangled with quantum memories) must be frequency converted into the telecom regime for long-haul transmission.**
- **Imperfect operations: Ideal quantum memory requires strong correlation to its emitted photon but no correlation to environment.**

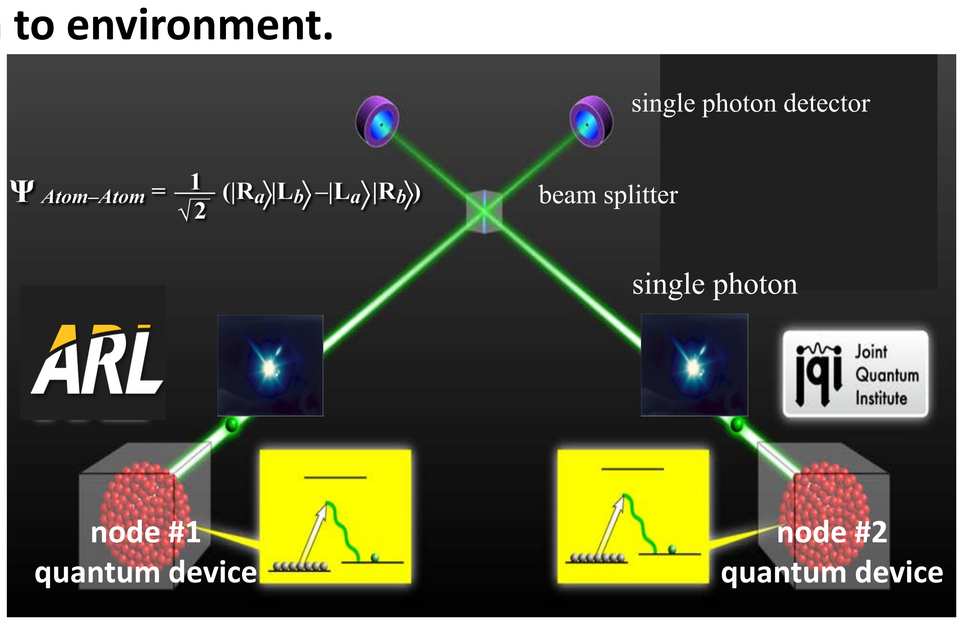

Fig. 5 Entanglement generation between two remotely situated quantum memories. Emitted single photons interfere on a beam splitter and then are detected.

Complementary Expertise/ Facilities/ Capabilities Sought in Collaboration

- **High-efficiency quantum frequency conversion from 650 nm – 800 nm into the telecom range – new materials, approaches for frequency conversion.**
- **Development of theoretical protocols beyond the quantum repeater (ie. limited only to single photons?).**
- **Development of applications for distributed entangled quantum systems.**
- **Improved fidelities between two quantum memories.**

References:
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N. Solmeyer and Q. Quraishi, "High teleportation rates for long-distance quantum networks using multiple Rydberg excitations in an atom ensemble," in preparation.
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