Development of a Photonically Linked Ion Trap Network

A promising approach to scale both quantum communication and quantum computing into useful technologies is to use many similar ion trap nodes connected together in a modular network. Raw entanglement between ions in separate nodes, created by interfering and measuring the photons they emit, can be purified using local operations in each node, to generate high fidelity entanglement distributed across the network.

Using two different ion species, "Ca" as a high fidelity logic qubit for operations within each node, and "Sr" to create photonic connections between them, allows one to harness the advantages of each species for both tasks without a trade-off.

The goal
To generate high fidelity entanglement over a quantum network, ions in separate traps emit single photons whose interference is measured to create a raw entangled state [1], which is purified using an entanglement distillation scheme [2].

High fidelity local operations improve the fidelity by over two orders of magnitude, using two ion species, without focused beam addressing, with only nearest neighbour operations and two trap zones.


The requirements
- Prepare Ca & Sr crystals ✓ [99.83%]
- Prepare quantum states and measure ✓ [99.9934(3)%]
- Single qubit gates ✓ [99.9(1)%]
- Local Ca-Ca gates ✓ [98.5%]
- Local Ca-Sr gates ✓ [~85%, WIP]
- Create ion–photon entanglement ✓ [~77%, WIP]
- Trap in a pair of multi–zone traps
- Create remote ion–ion entanglement

Mixed species gate
The gate mechanism does not depend on the qubit splitting, hence is robust to qubit frequency noise and allows gates between different ion species ("Ca", "Sr", "Sr+Sr").


A single pair of Raman beams, detuned by approximately 10 THz from the S–P transitions of both "Sr" and "Ca", provide the force for a geometric phase gate [3].

Ion–photon entanglement
In our initial demonstration, with the emission collected perpendicular to the magnetic field, we obtained a Bell state fidelity of 0.77 (entanglement of formation 0.081).

Current

Rack–mounted laser systems
Compact rack–mounted laser systems for "Ca" and "Sr" have been built to house the lasers, optics, AOMs and EOMs necessary for each beam path, with independent control for each of the two trap systems.

1/2 optics are built on to breadboards which stack in a rack, along with the drivers, controllers and diagnostics to run the system, reducing the footprint of more than an optics table into two racks.

Twin ion trap systems
Two identical vacuum system assemblies, each containing a HOA2 linear multi–zone surface trap (courtesy of Sandia Nat’l Labs), are currently under construction.

Each have two imaging systems, with independent readout for "Ca" and "Sr" on the back, and a high N.A. (0.6) lens to fibre couple ion emission on the front.

Closed loop oven control
As the time between recrystallisation events may limit experiments, we have designed atomic ovens optimised for short loading times, by reducing their thermal mass and controlling the oven temperature.

A PID control loop of the temperature is closed using a thermocouple spot–welded to the oven. The system reaches operating temperature in ~5 seconds, with atomic flux reaching steady state in ~12 seconds.