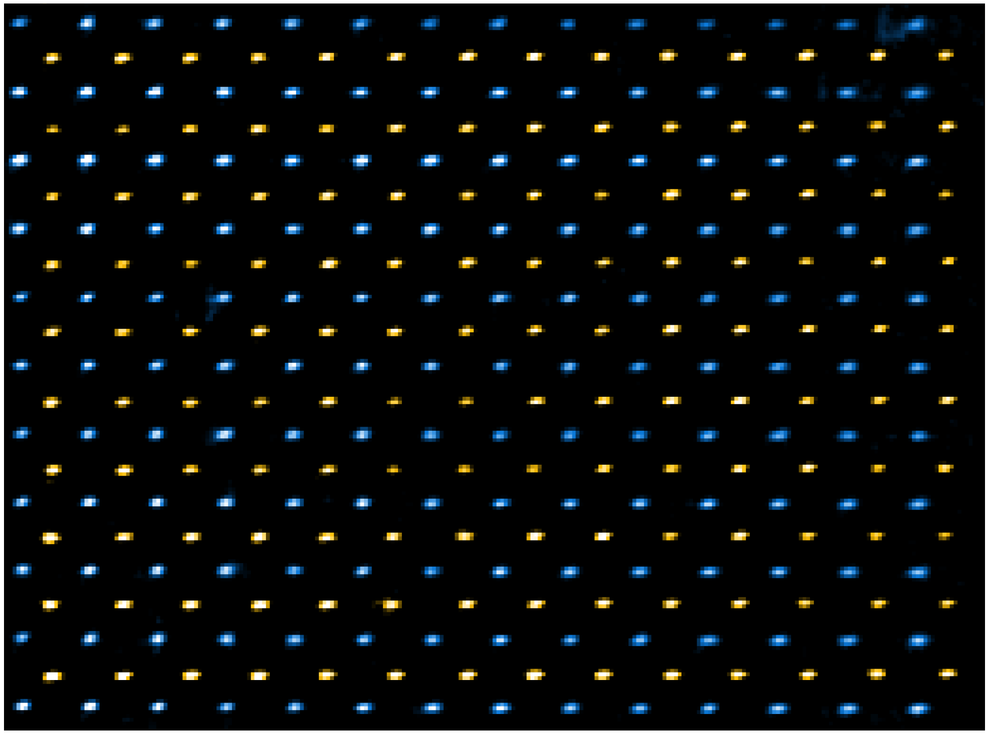
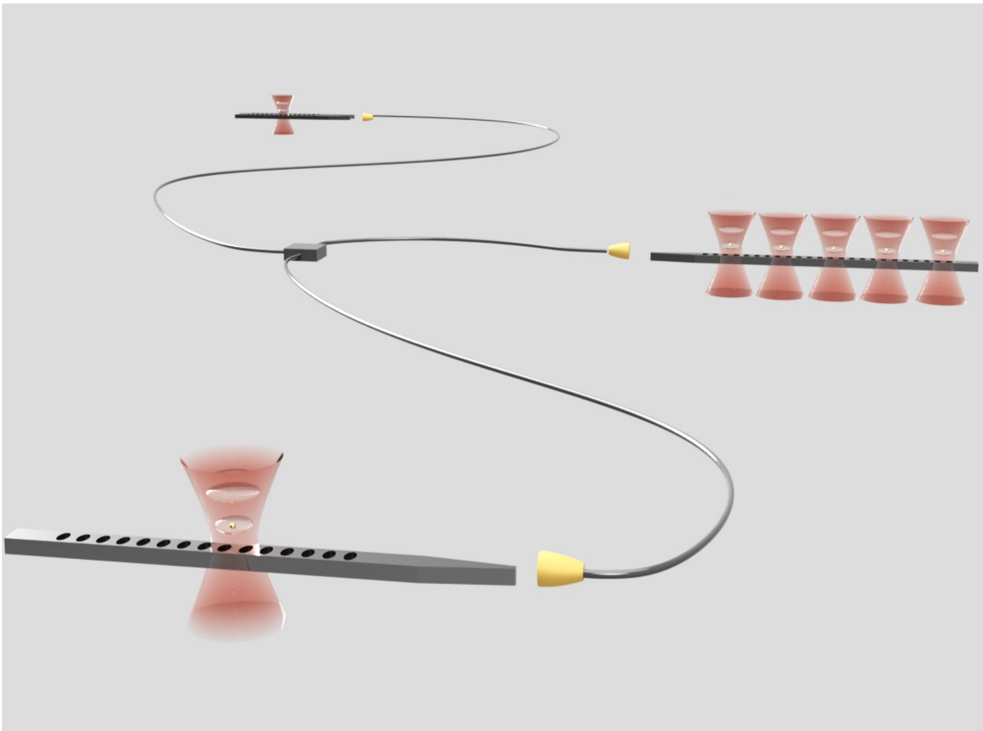
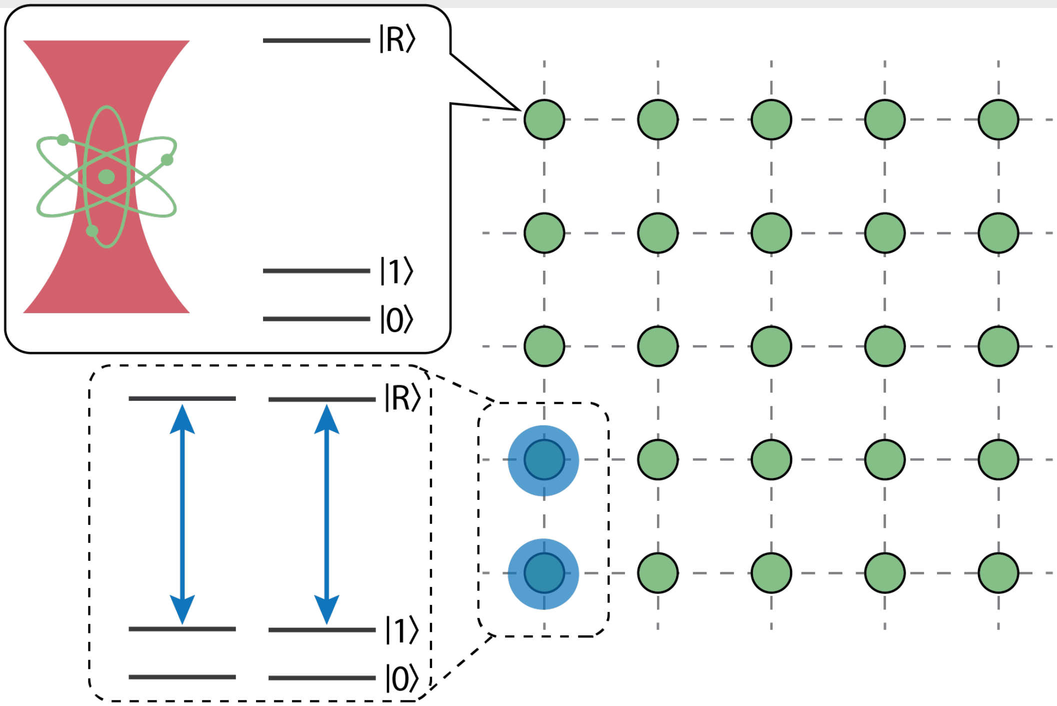
BernienLab@UChicago

Building quantum information processors and networks Atom-by-atom





Atom array quantum processors



- Identical qubits each in its own tweezer
- Long lived qubits states
- Coherent interactions via Rydberg states

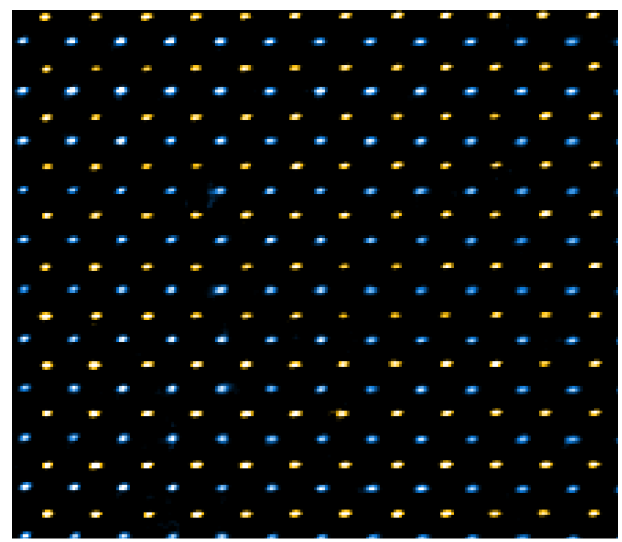
Unique opportunities:

- Long range connectivity
- Native multi-qubit gates
- Coherent movement of atoms
- Photonic interfaces

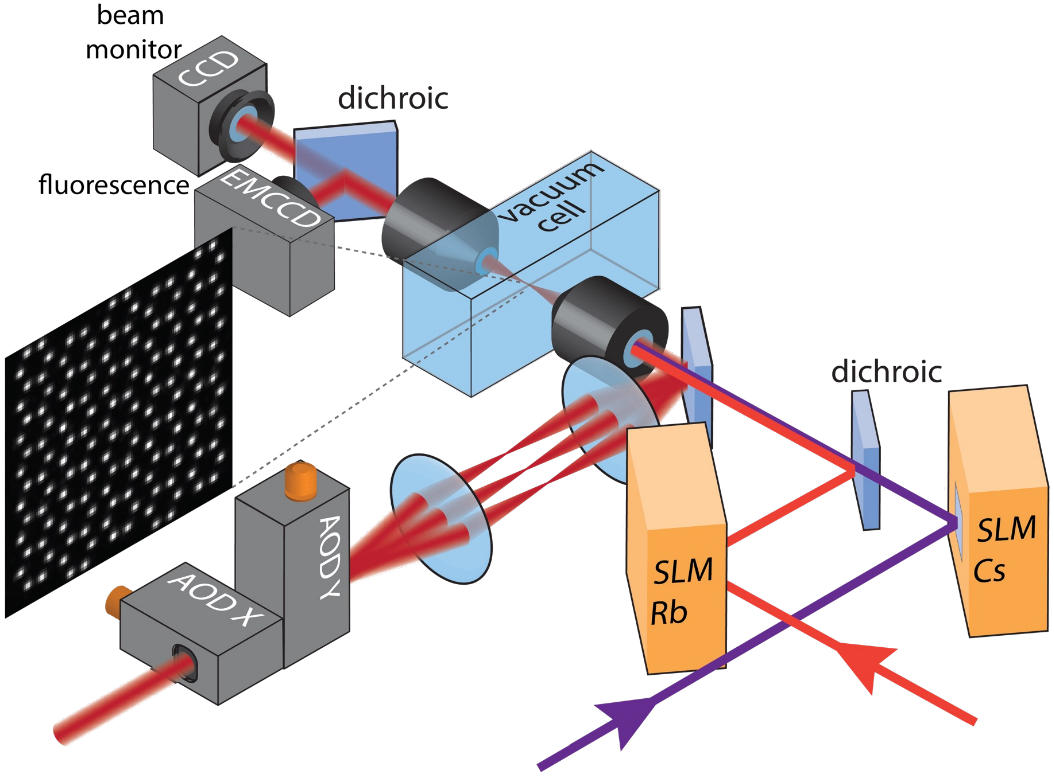
<u>*Challenges:*</u>

- Measurements (long and destructive)
- Atom loss
- Array preparation + measurements > algorithm execution time
- Individual addressing on large scale

Dual-species architecture

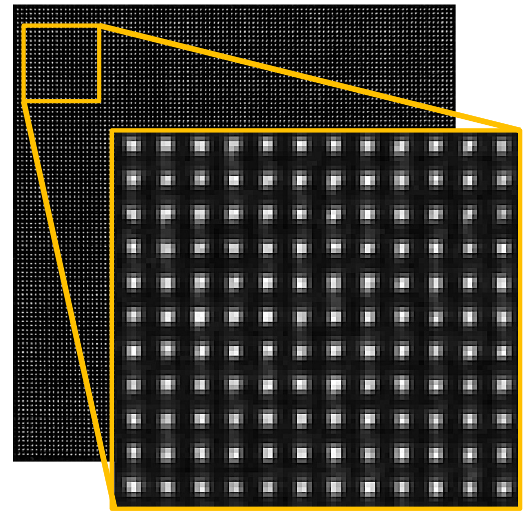


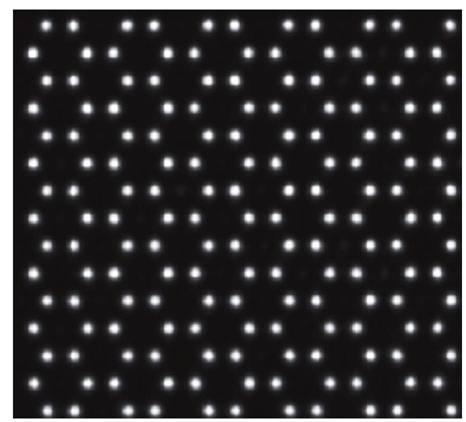
Setup scheme



- Static tweezer array with spatial light modulators
- Rearrangement tweezers generated with AODs

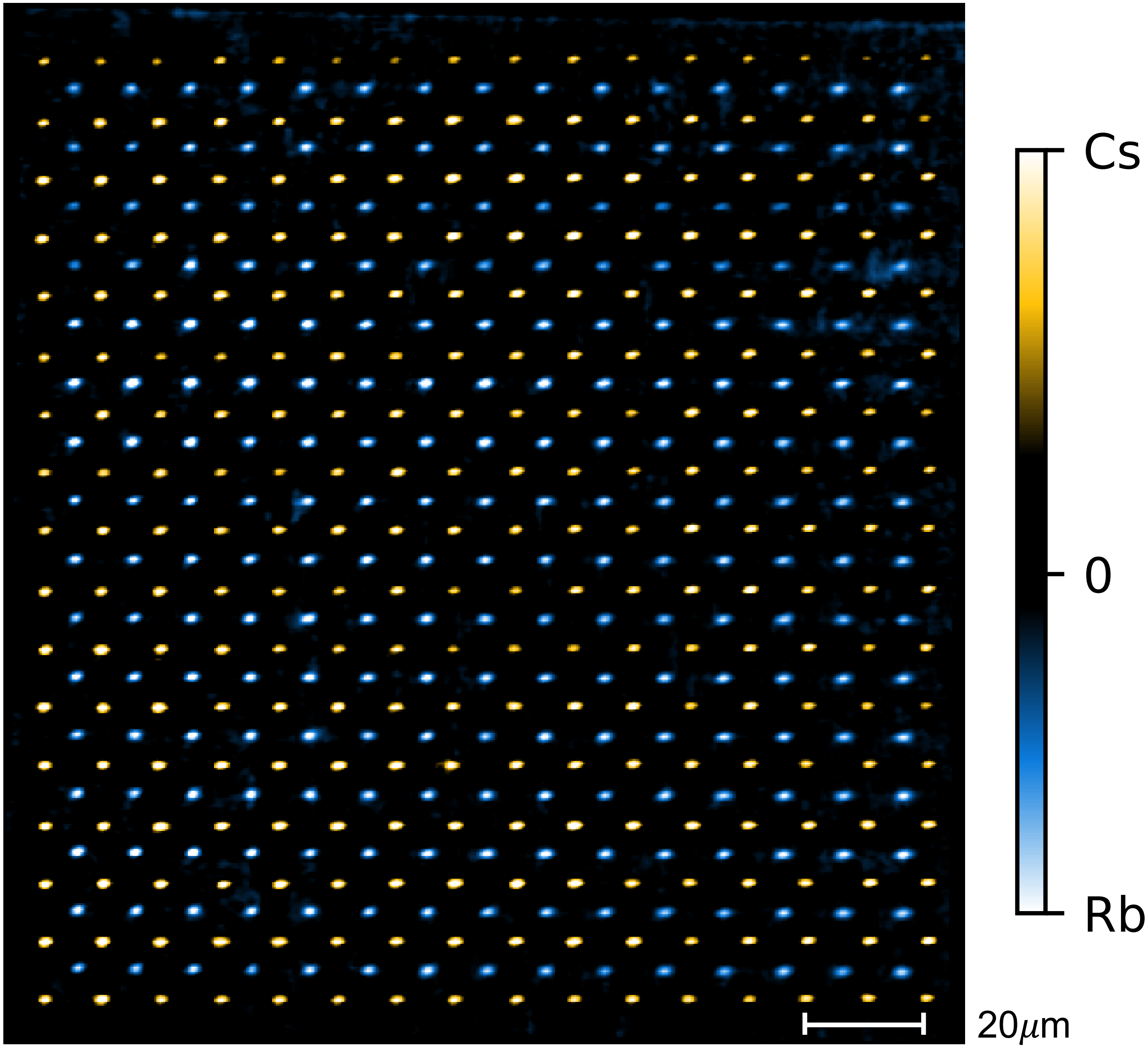
Flexible trapping patterns





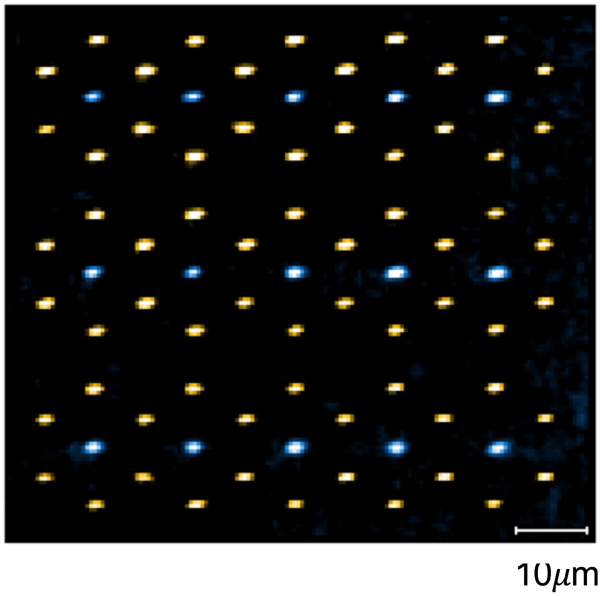
See also: Ebadi et al. Nature 595, 227 (2020)

A dual-element 512 site atom array

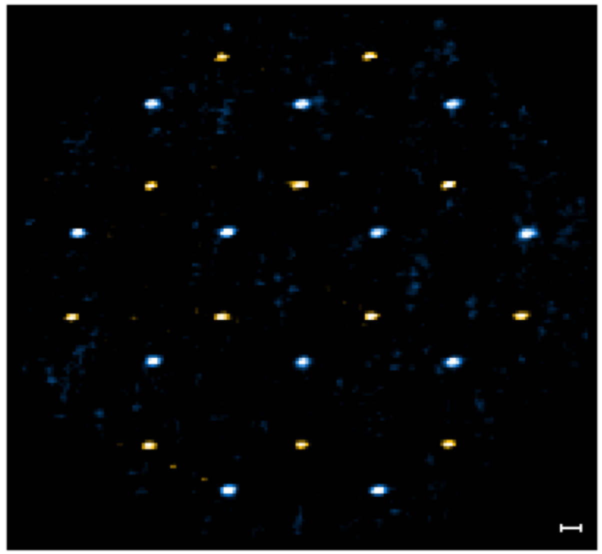


*Singh, Anand, Pocklington, Kemp, Bernien PRX **12**, 011040 (2022)*

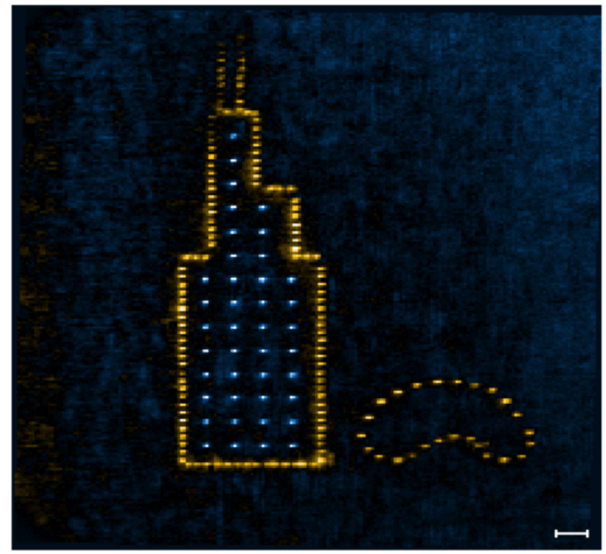
Arbitrary geometries with dual-element arrays



Hexagonal lattice



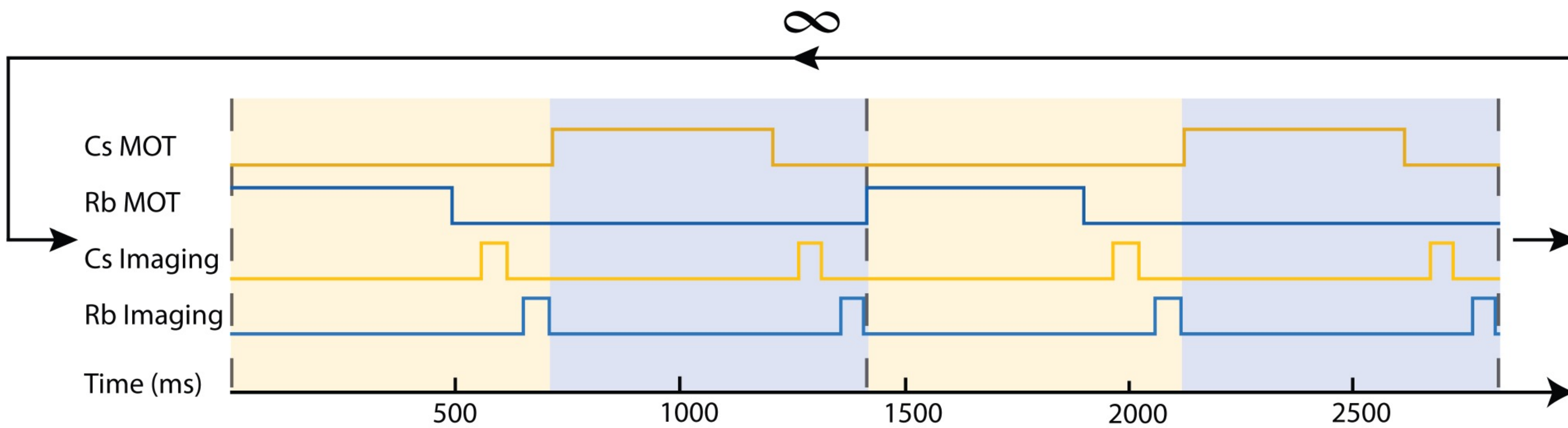
Bipartite Honeycomb

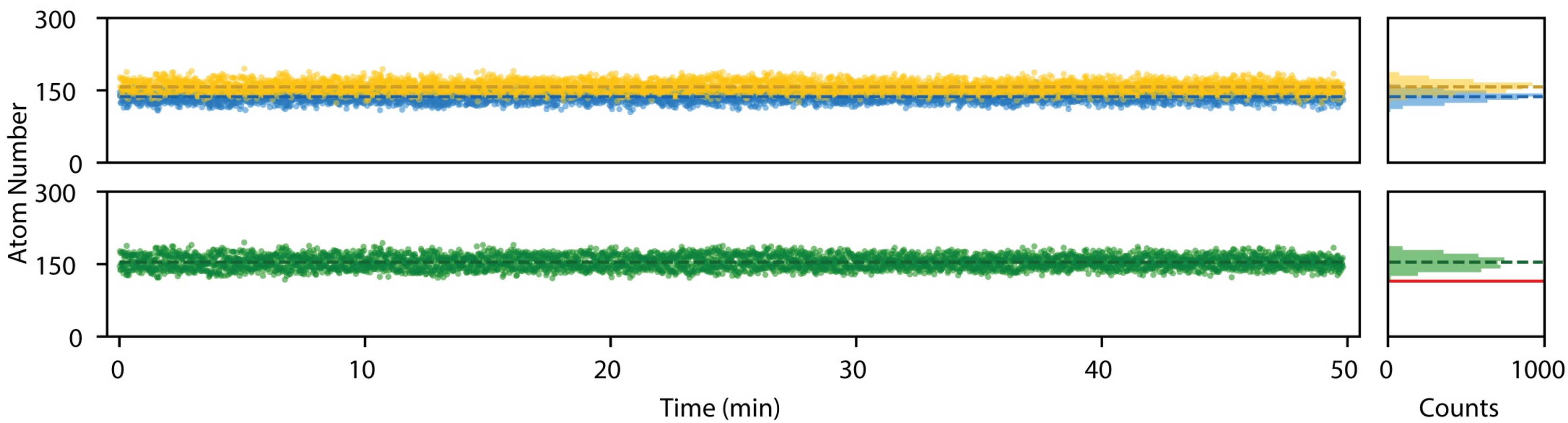


Sears Tower and the Bean

*Singh, Anand, Pocklington, Kemp, Bernien PRX **12**, 011040 (2022)*

Continuous-mode operation





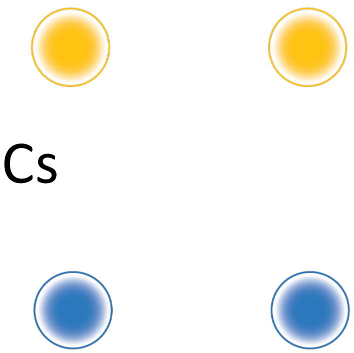
We can design experimental cycles where there are always atoms within the tweezer array available for measurements or computation

*Singh, Anand, Pocklington, Kemp, Bernien PRX **12**, 011040 (2022)*

Rydberg for coherent inter/intra species interactions

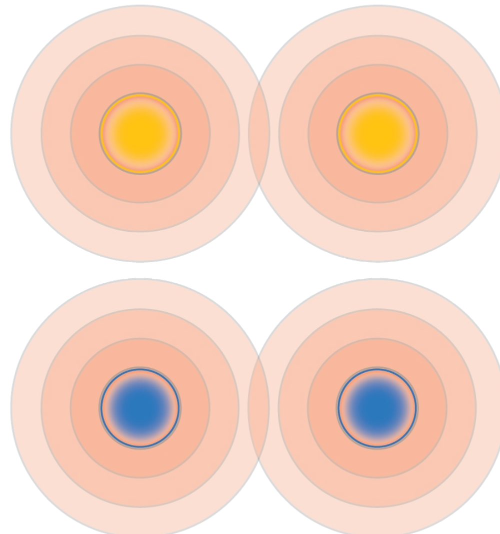
^{87}Rb

^{133}Cs



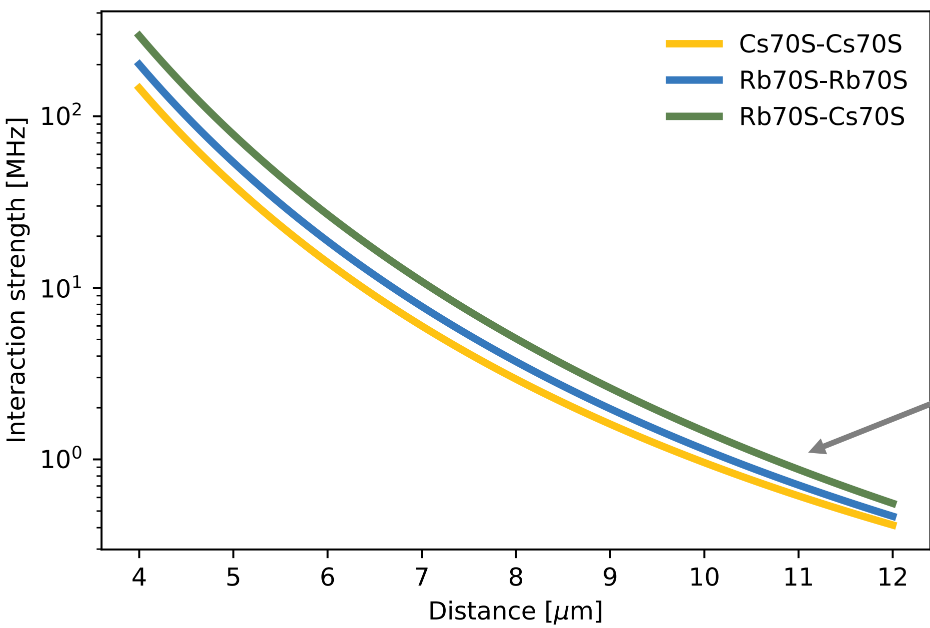
Couple to states

$N \gg 1$



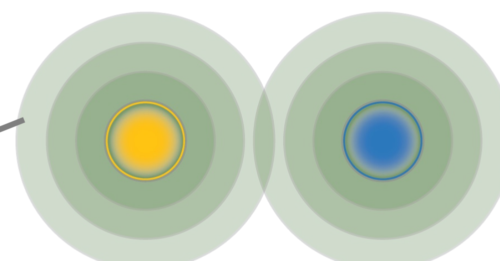
⇒ Strong dipolar interactions: $\sim \boldsymbol{N^{11}/R^{6}}$

⇒ GHz interaction over several micrometers



⇒ Inter species interactions possible with

$$V_{\mathrm{Cs}} \lesssim V_{\mathrm{Rb}} \lesssim V_{\mathrm{Rb\text{-}Cs}}$$

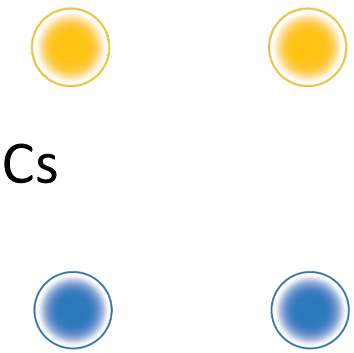


Rydberg review: Browaeys et al. J. Phys. B 49, 152001 (2016), Saffman J. Phys. B 49, 202001 (2016)

Rydberg for coherent inter/intra species interactions

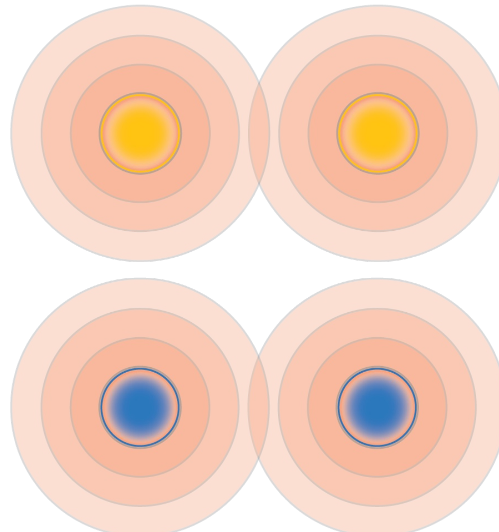
^{87}Rb

^{133}Cs



Couple to states

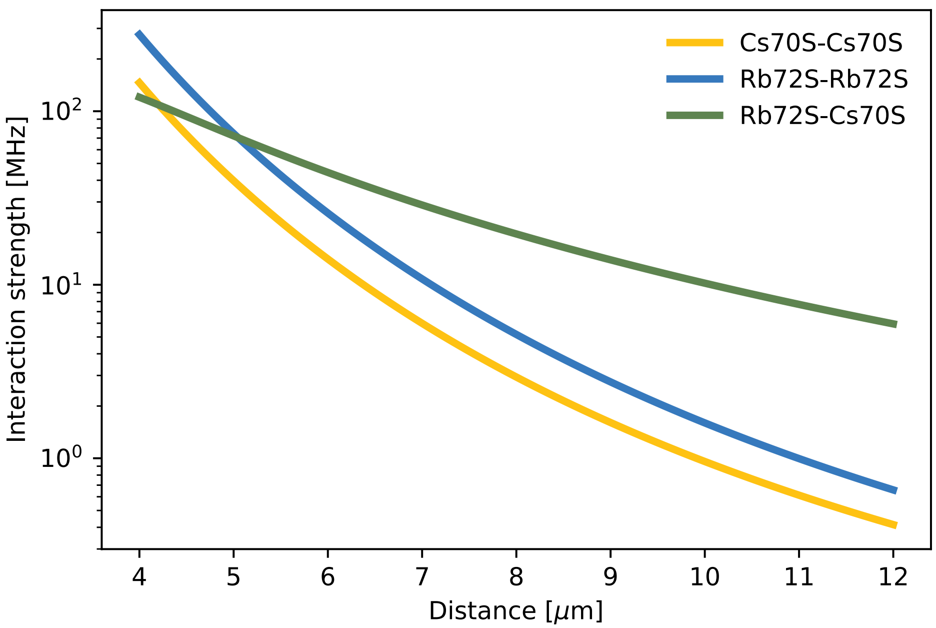
$N \gg 1$

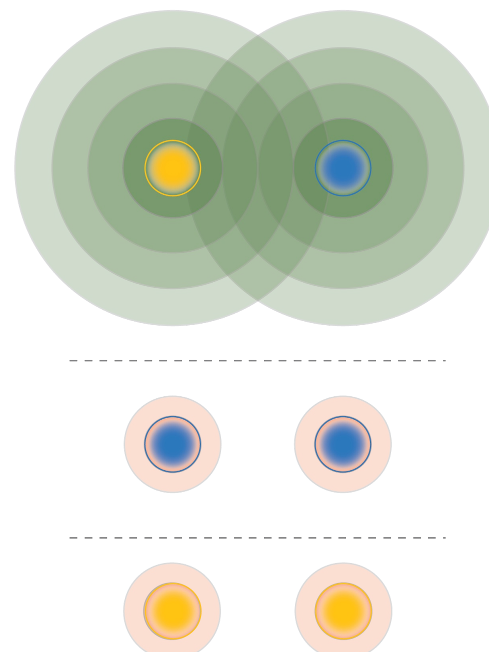


⇒ Strong dipolar interactions: $\sim N^{11}/R^6$

⇒ GHz interaction over several micrometers

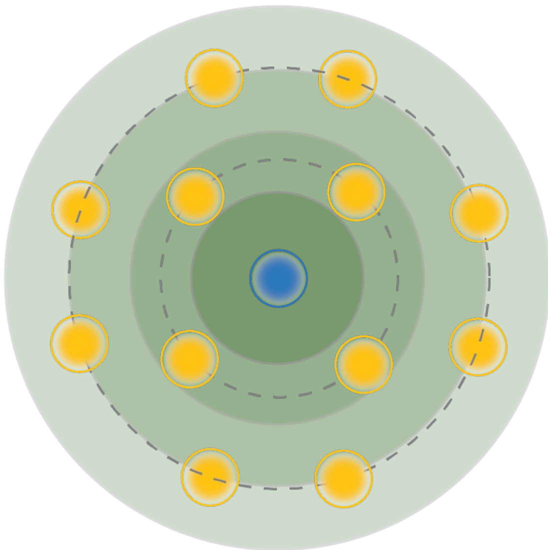
Asymmetric interaction regimes close to Förster resonances:



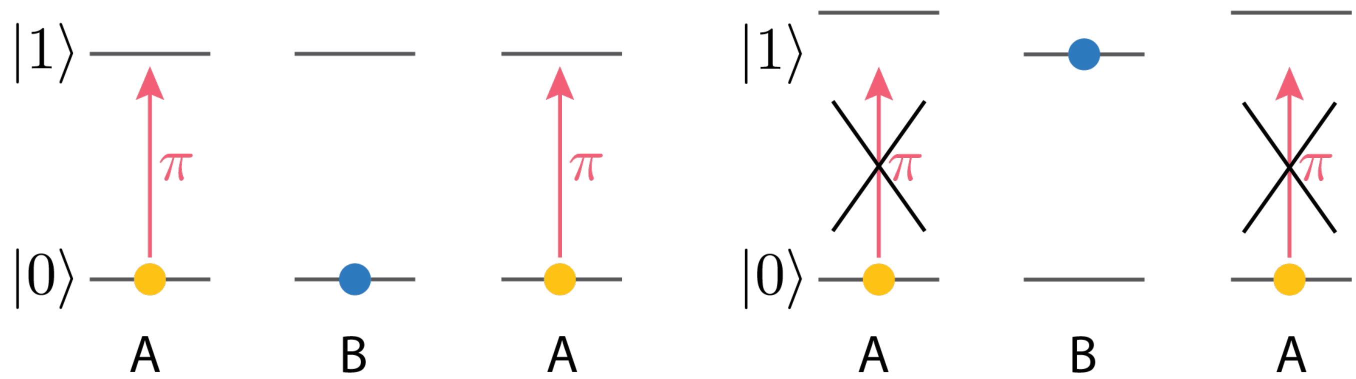


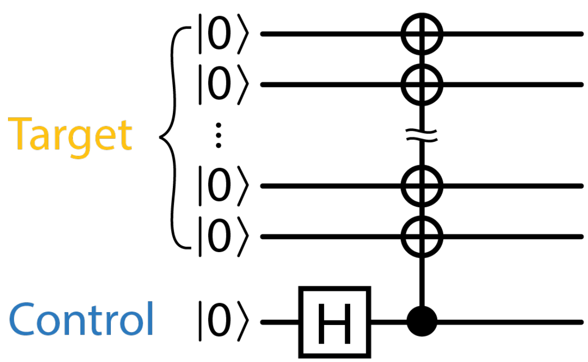
Inter species Förster resonances: Beterov, Saffman PRA 92, 042710 (2015)

Efficient GHZ generation



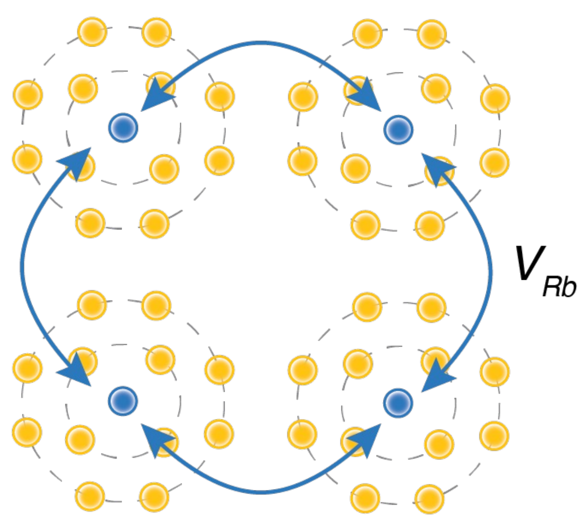
$V_{Cs-Rb} \gg V_{Cs}$





$|00...00\rangle_t |0\rangle_c + |11...11\rangle_t |1\rangle_c$

Going larger?



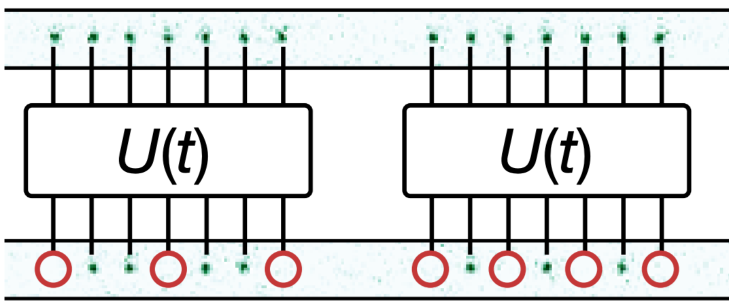
$V_{Cs-Rb}, V_{Rb} \gg V_{Cs}$

- Efficient GHZ generation
- Extendable to hyperfine states

See also proposal: Müller et al. PRL 102, 170502 (2009)

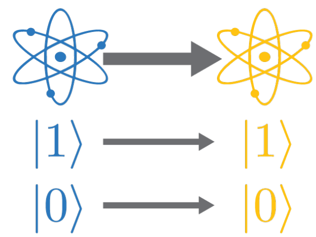
Auxilary atoms for QND readout

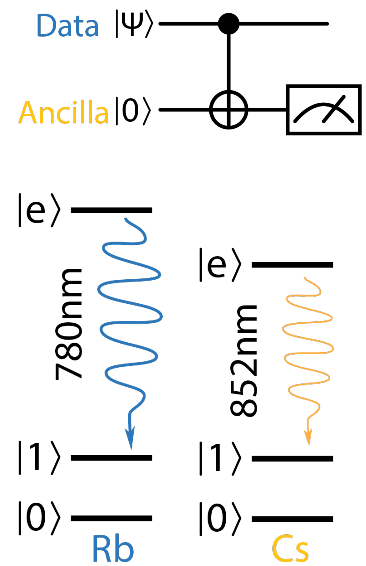
Typical readout: state dependent loss



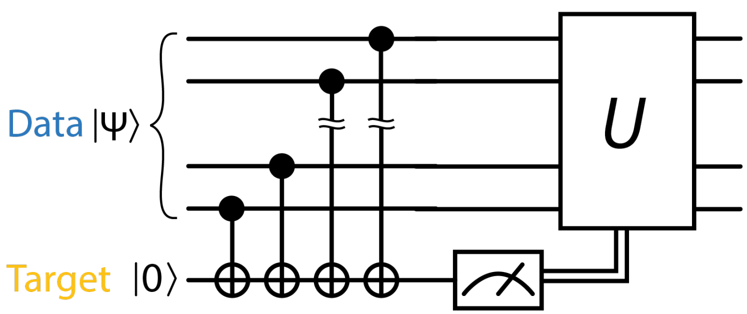
- High fidelities
- Destructive

New approach:
Ancilla based readout

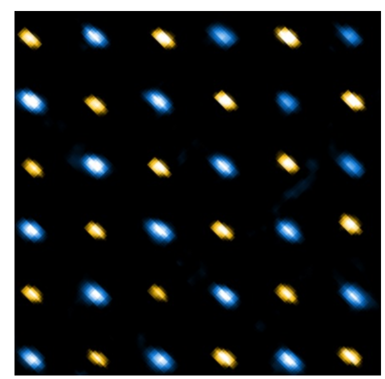




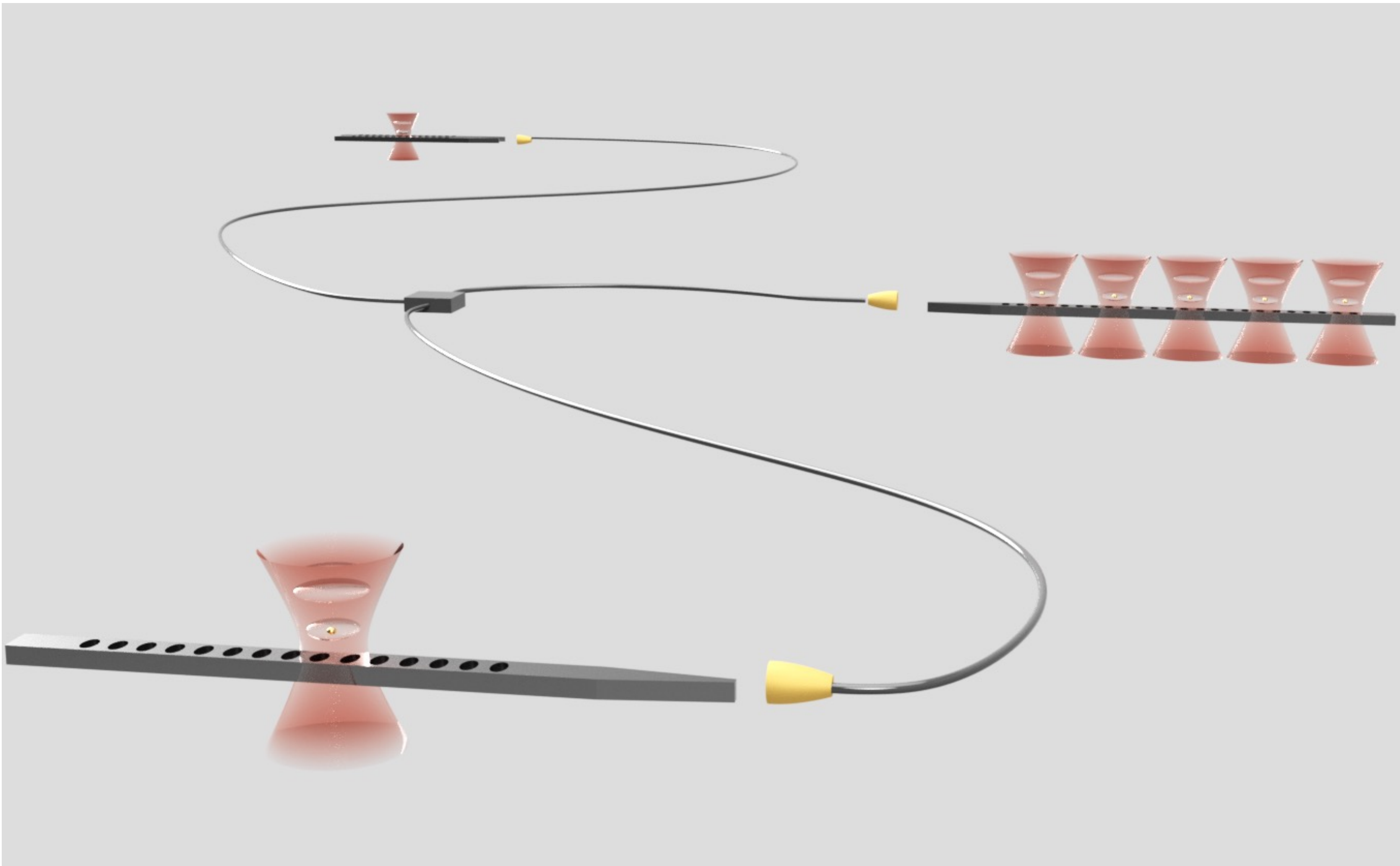
- QND measurement of multiple atoms
- New probes for many body states
- feedback



Stabilizer measurements:

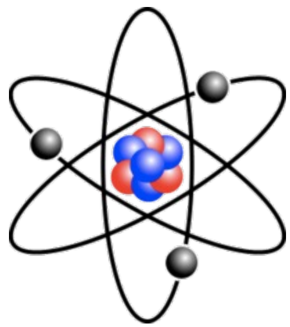


Scaling the distance between nodes



Hybrid system of nanophotonic devices & cold atoms

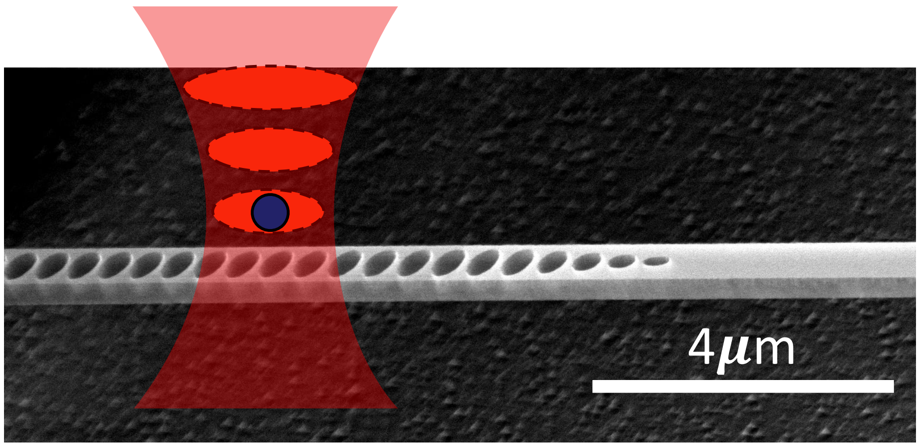
Neutral atoms:



- Excellent coherence
- Controllability
- Indistinguishability

+

Nanophotonics:

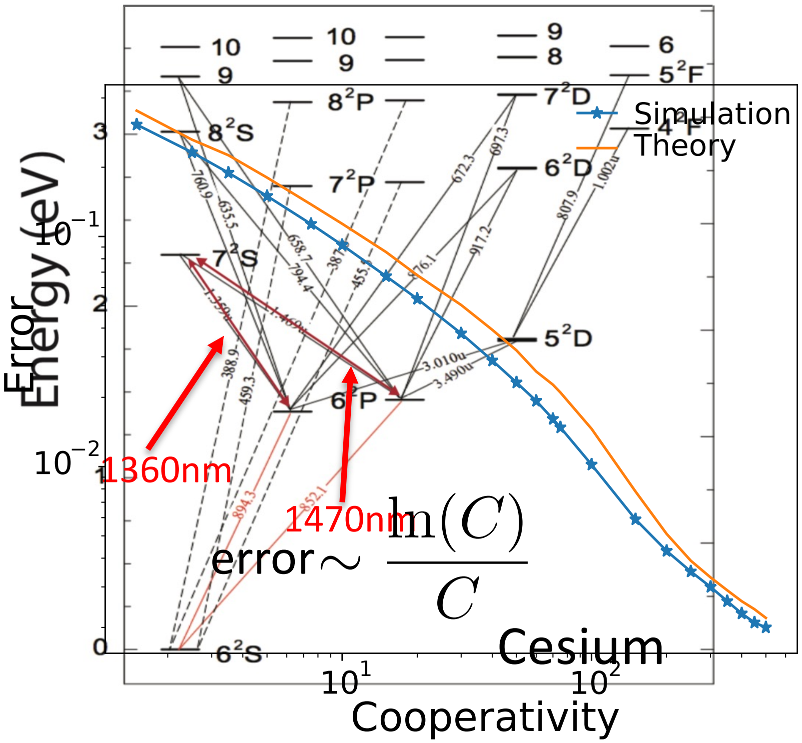


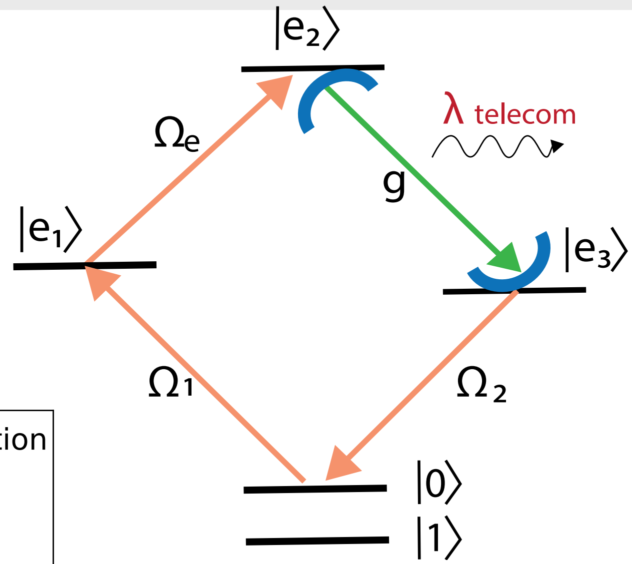
- Strong light confinement
- Engineered functionalities
- Scalabilty

Thompson et al. Science (2013), Dordevic, Samutpraphoot, Ocola, Bernien et al., Science (2021)

Can we work at telecom wavelengths?

Challenge: no telecom transitions from the ground state.

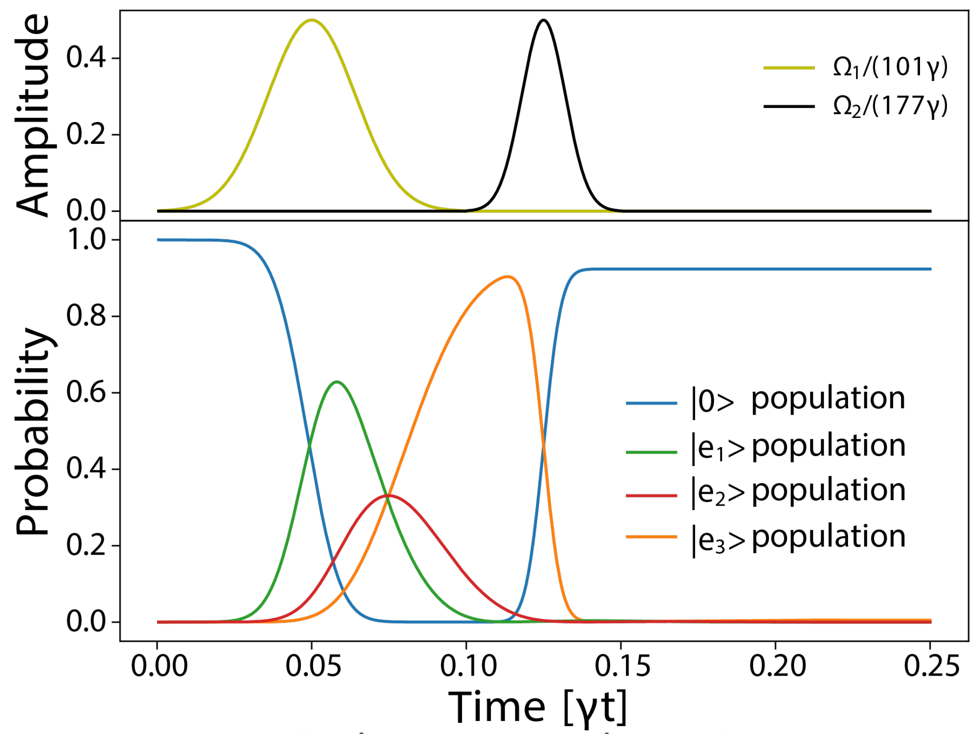




Combination of long-lived qubit states with efficient telecom interface

Goal:

$$\psi = \frac{1}{\sqrt{2}}(|0\rangle|\lambda_E\rangle + |1\rangle|\lambda_L\rangle)$$

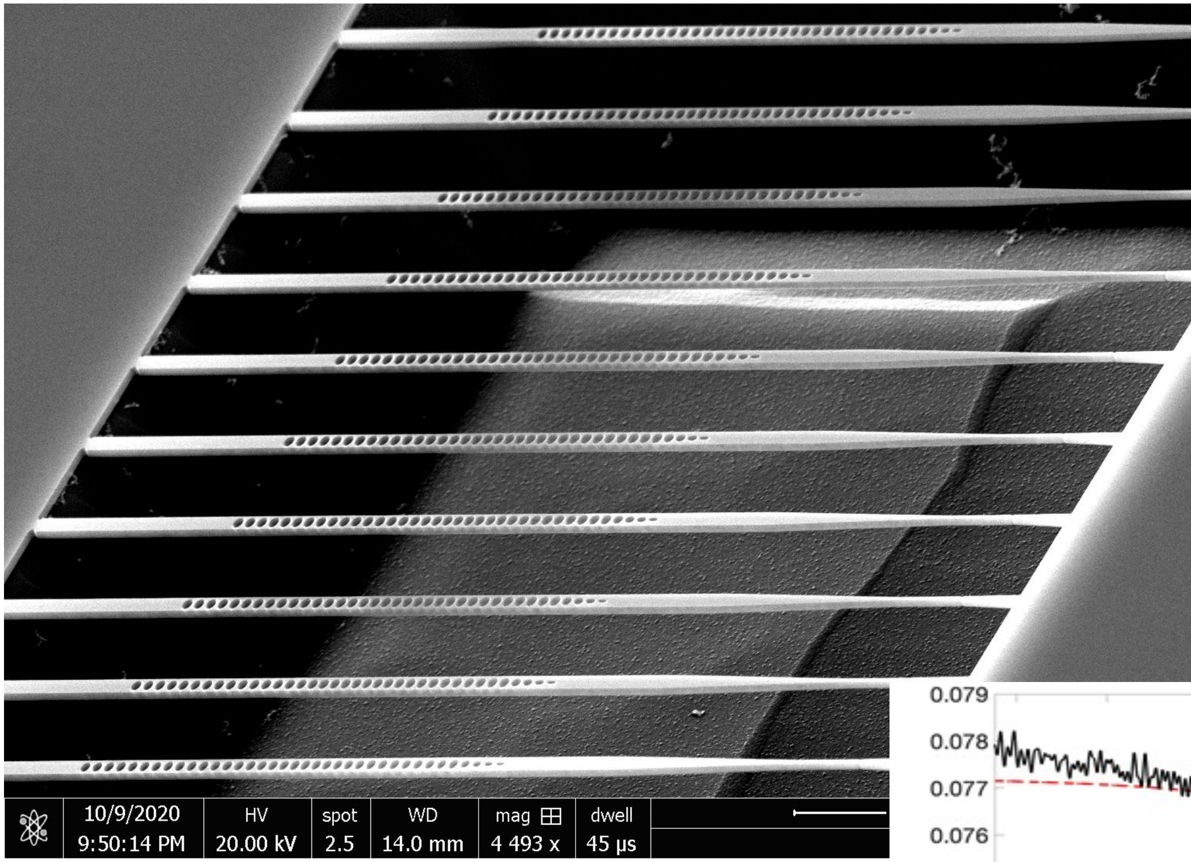


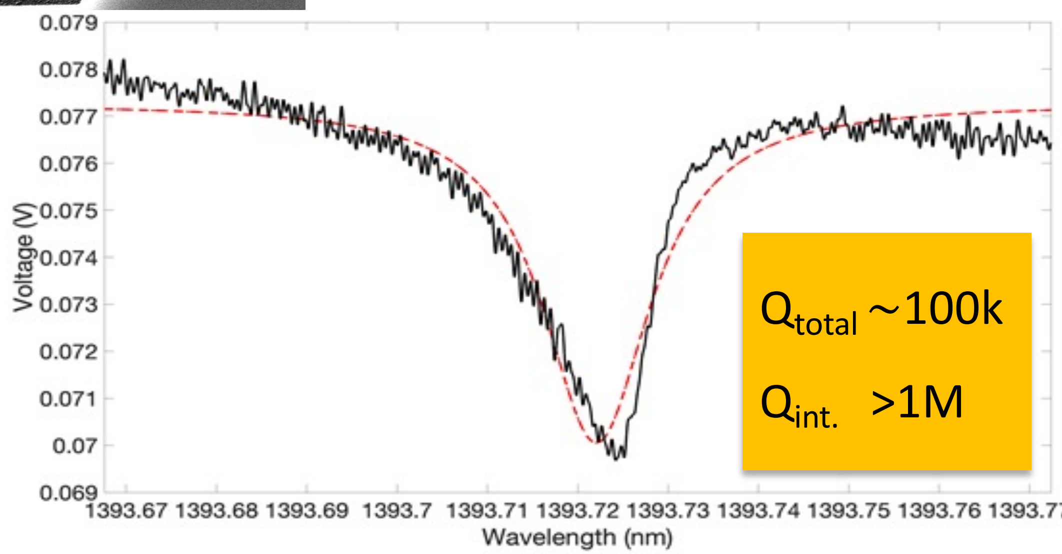
Menon, Singh, Borregaard, Bernien NJP 22, 073033 (2020)

See also with Yb: Covey et al. Phys Rev Applied 11, 034044 (2019)

Progress: Telecom cavities

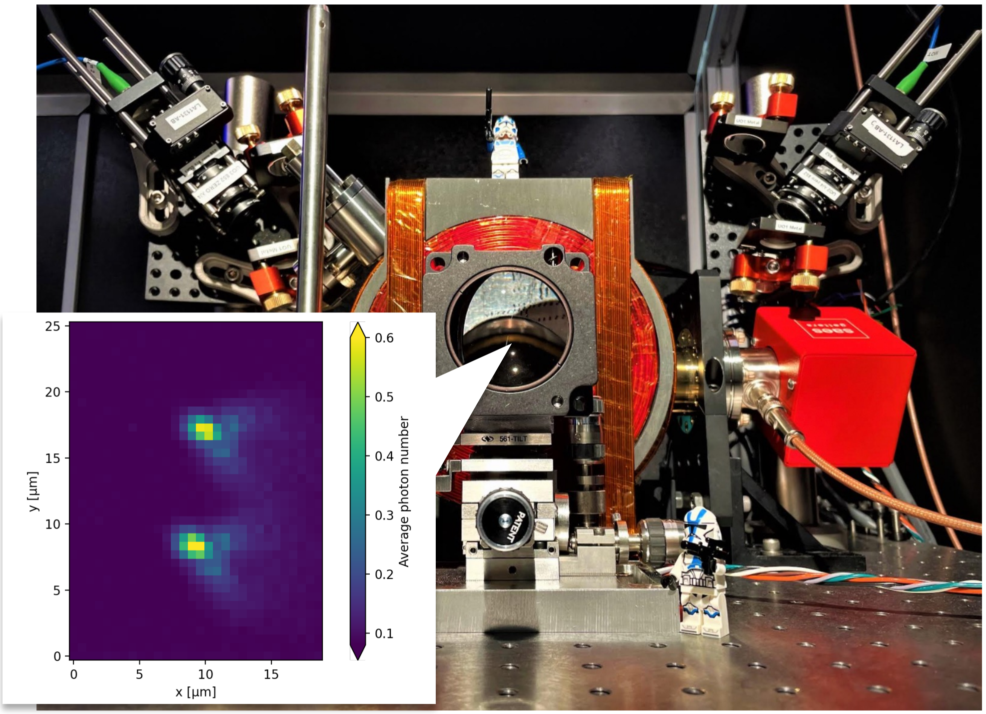
Fabricated SiN cavities:





In collaboration with Alan Dibos (ANL)

The setup:



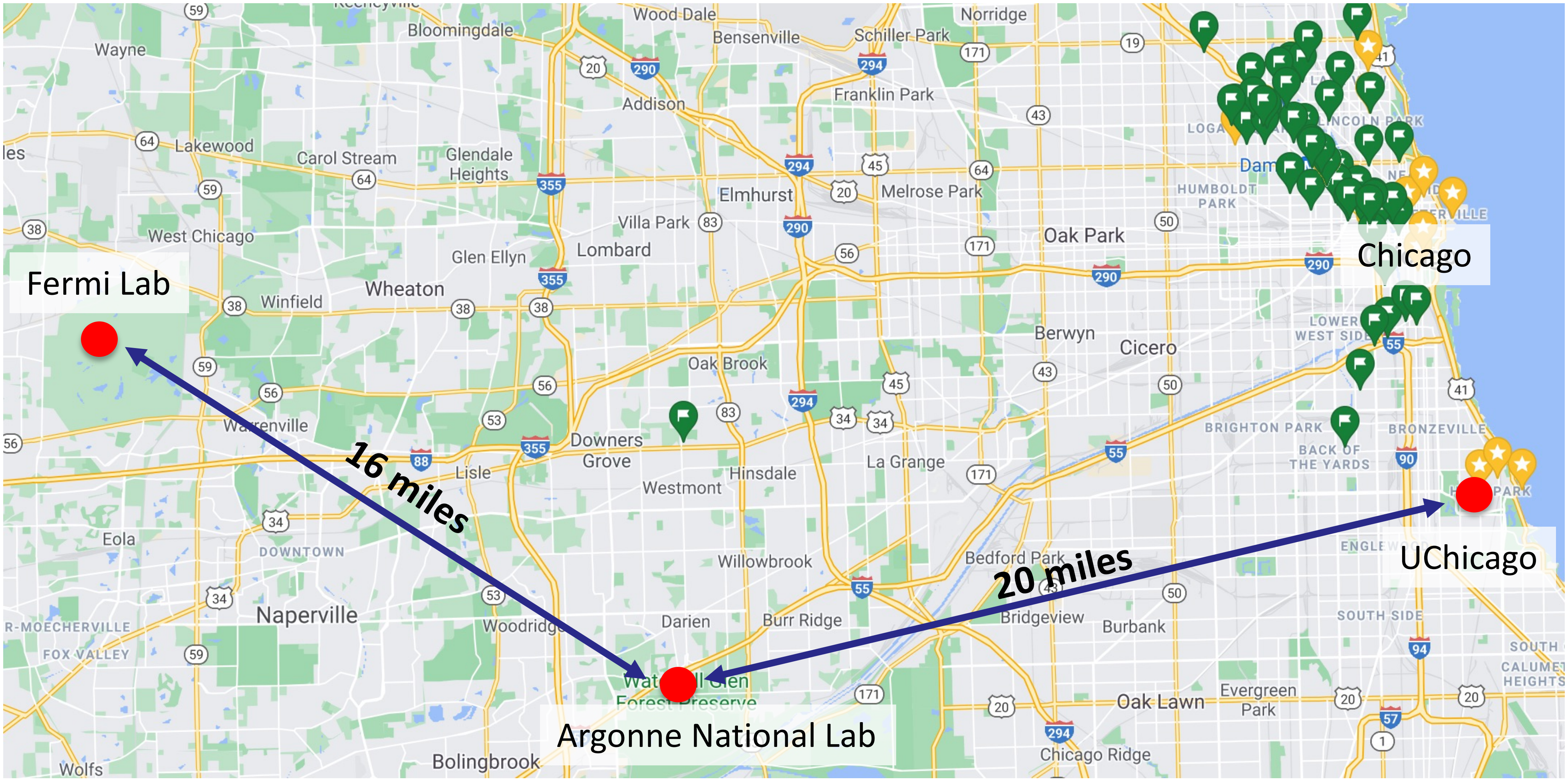
- Compact steel chamber
- Three objectives for traps, imaging and free space coupling
- Compatible with photonic chip

Features:

- Atom array generation
- Chip integration (prelim. 50% coupling)
- Multiplexing with multiple nodes

Free space coupling see also: Kimble group: Adv. Quantum Technol. 3, 2000008 (2020)

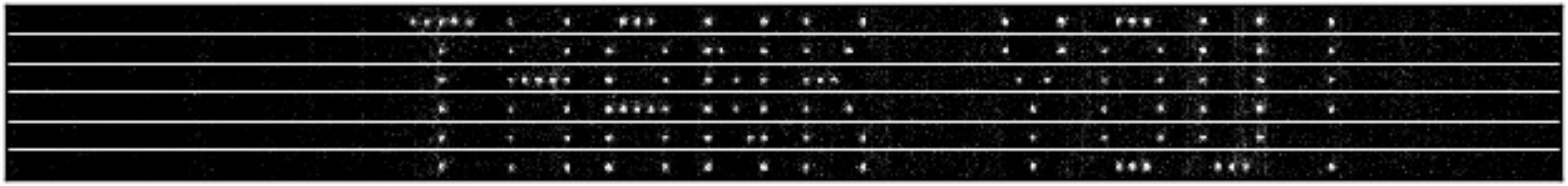
Going the distance:

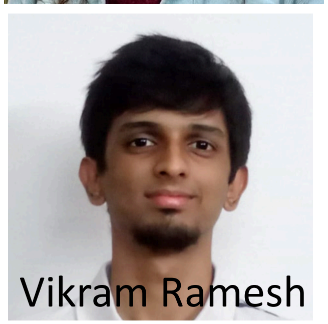


~50km of fiber UChicago – ANL

Entanglement rate:

$$\Gamma_{ent} = \frac{1}{2}\gamma_{attempt}\,\eta^2_{coll.}\,\eta^2_{detect}\,\eta_{fiberatt.} \sim 10\,\mathrm{Hz}$$





Collaborators:
Alan Dibos (ANL), Johannes Borreegaard (TU Delft),
Hannes Pichler (Innsbruck), Bill Fefferman (UChicago)

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