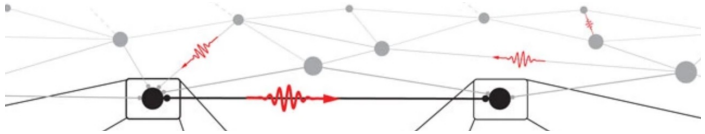
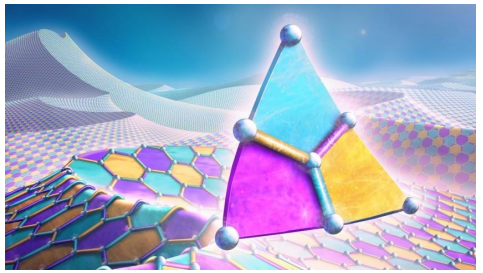


Ritter et al Nature (2012)



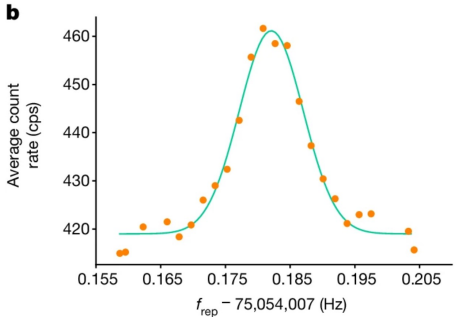
Nill et al, Science (2014)

Communication

Computing

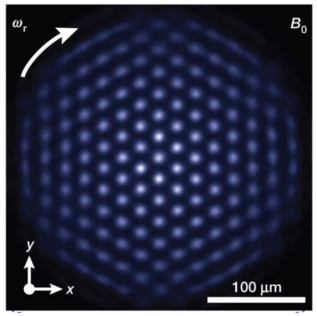
Quantum information processing

Metrology



Zhang et al Nature (2024)

Simulation



Britton et al Nature (2012)

Quantum speed-ups

Computing

Factoring relates to RSA encryption

E.g. Factoring a 2048 bit RSA key

Classical

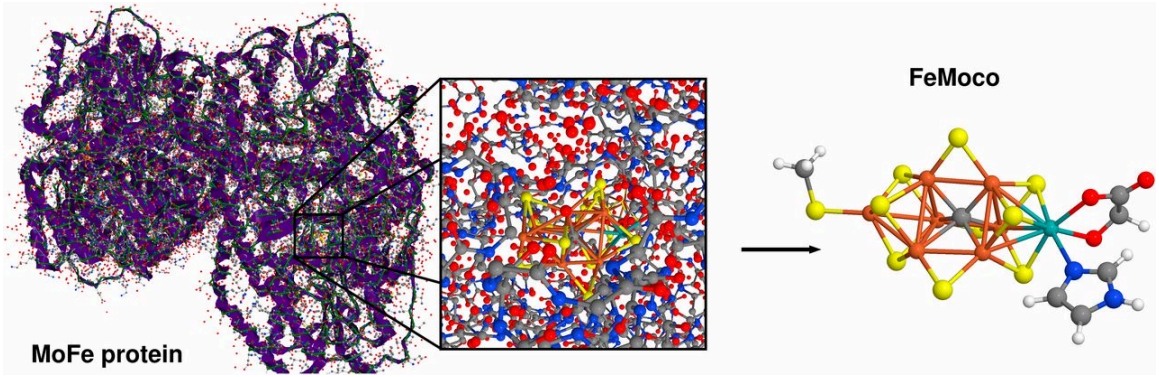
- Exponential scaling

Quantum

- Logarithmic scaling

Quantum Chemistry

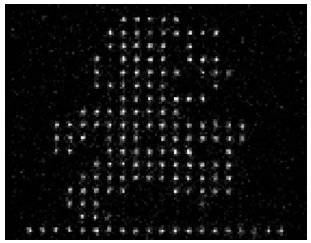
Better simulations of chemical properties and reaction mechanisms



PNAS July 18, 2017 114 (29) 7555-7560

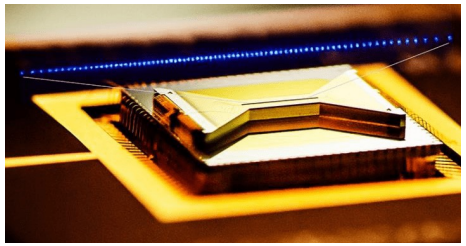
Scaling up quantum objects

Neutral atoms



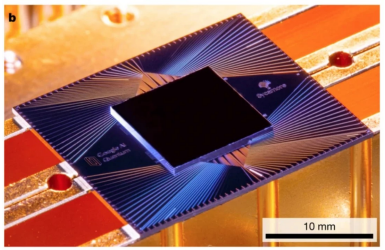
Img credit: Harvard

Trapped ions



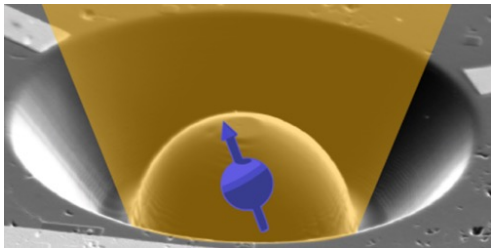
IONQ

SC qubits



Google

NV centers



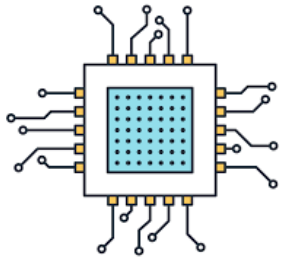
Delft

…

Lots of interesting physics and applications: optical atomic clocks, loophole-free Bell tests, etc…

Scaling is hard! Race is open but no need for only one winner

Charge encoding

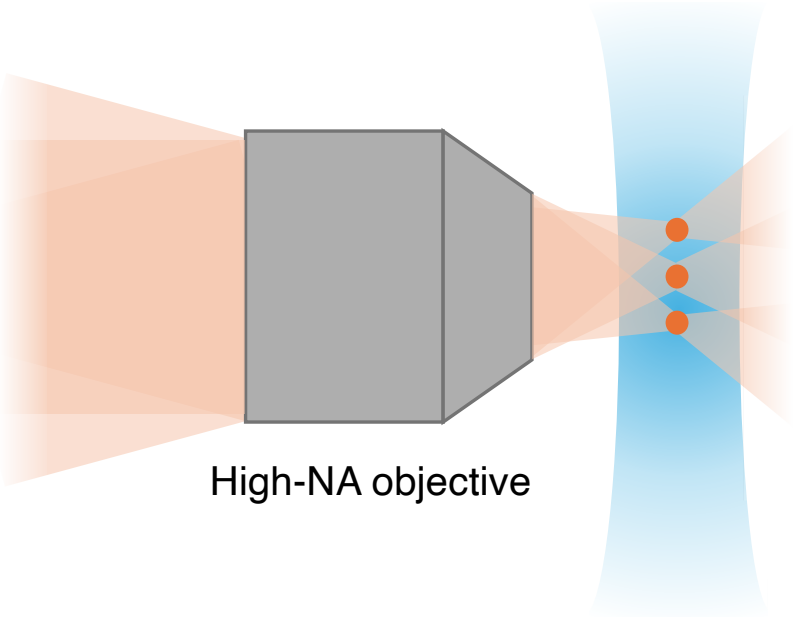


Magnetic encoding

QIP with optical tweezers

Atoms are trapped by virtue of light-matter interaction

Laser beams are used to manipulate atoms and for fluorescence detection

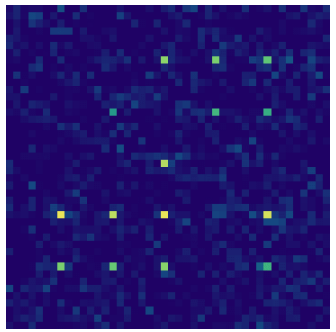


High-NA objective

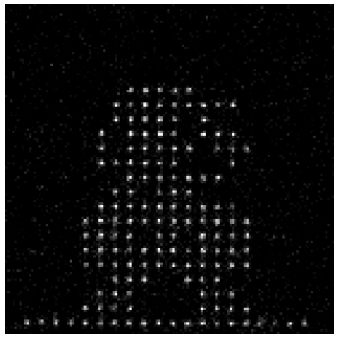
20 x 10 atom array

5 μm

JILA



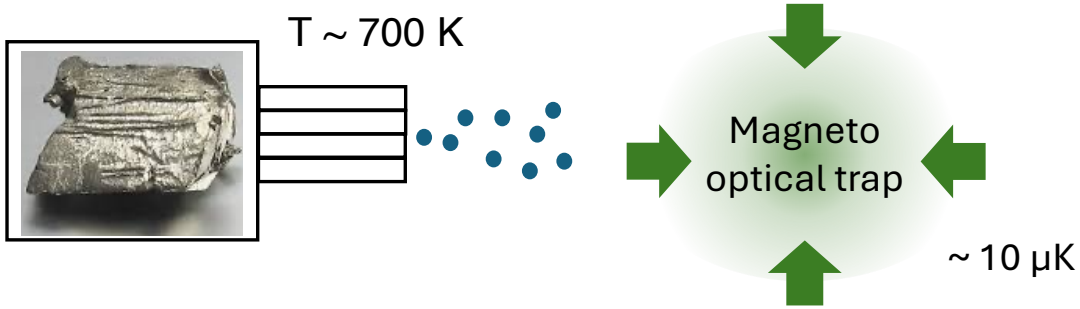
Harvard

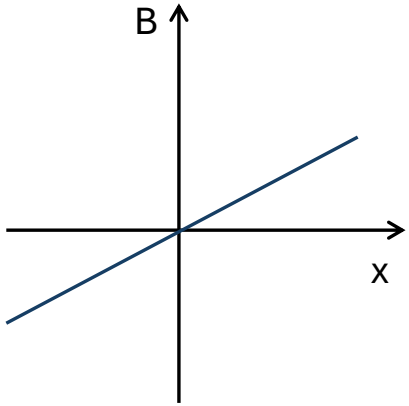


Pioneering technology from Grangier group

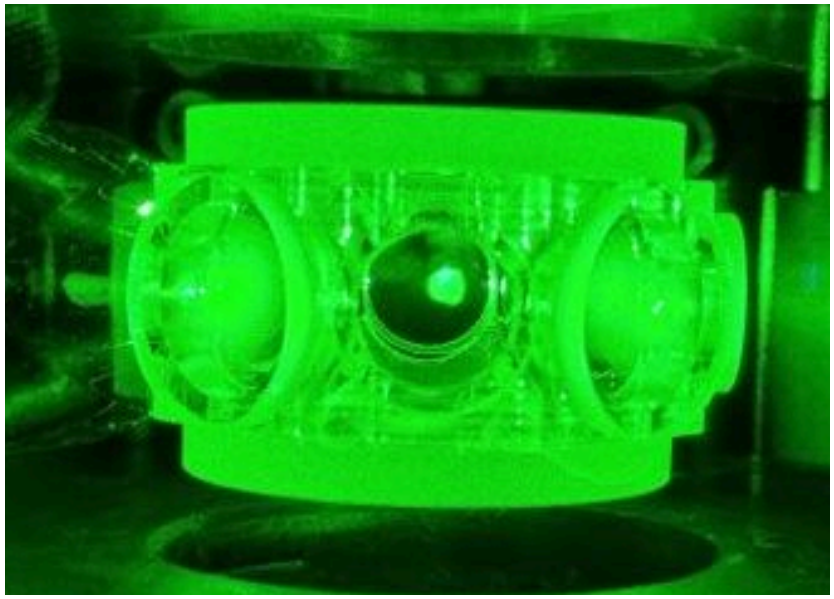
Trapping atoms in tweezers

Tweezers are shallow traps (~1 mK). Atoms need to be cold! 🥶



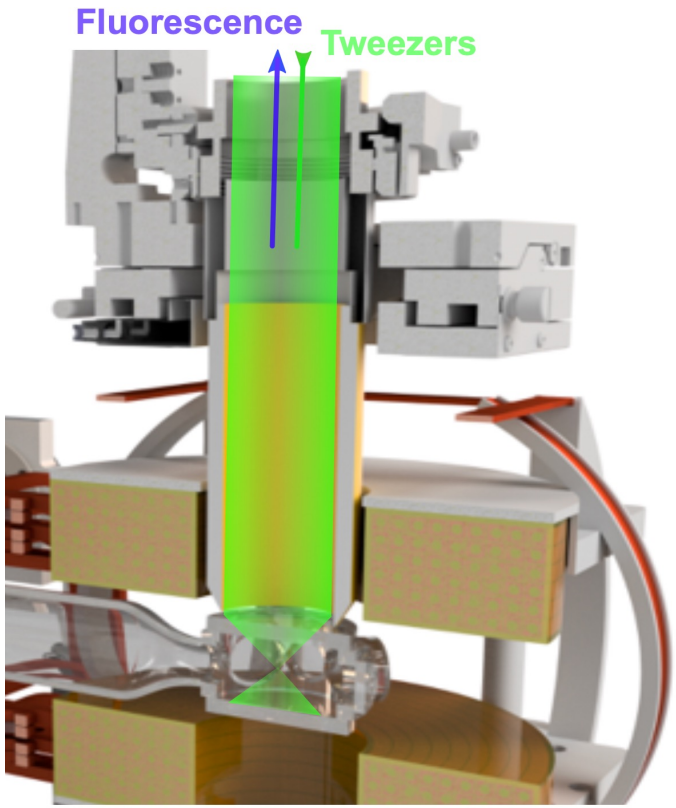


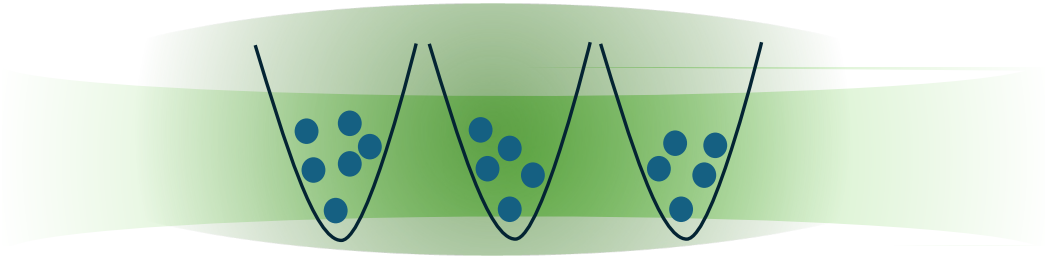
The magnetic gradient makes the atoms resonant with the laser propagating against the motion direction -> cooling



UNITS

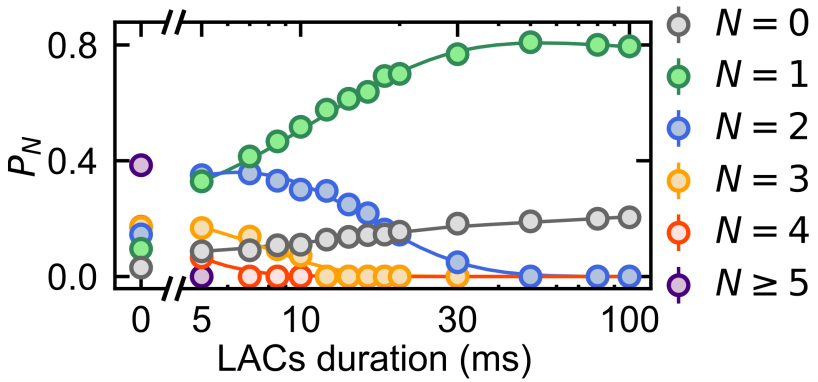
Trapping atoms in tweezers





Optical tweezer load atoms from the MOT

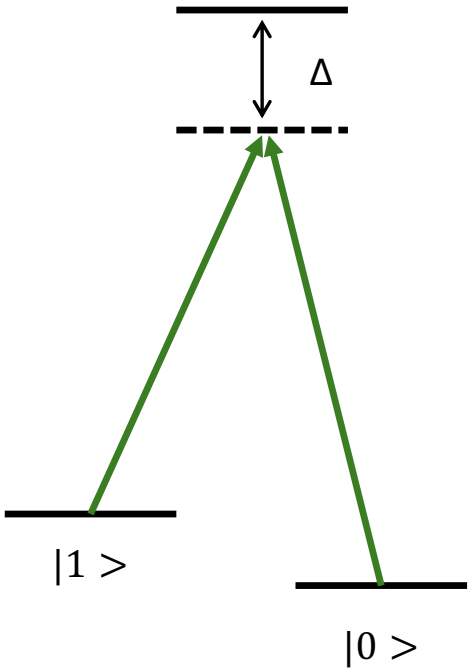
Light-assisted collisions ejects atoms leaving either 1 o 0 atoms trapped

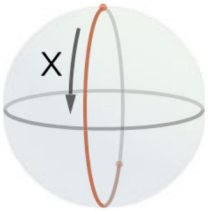


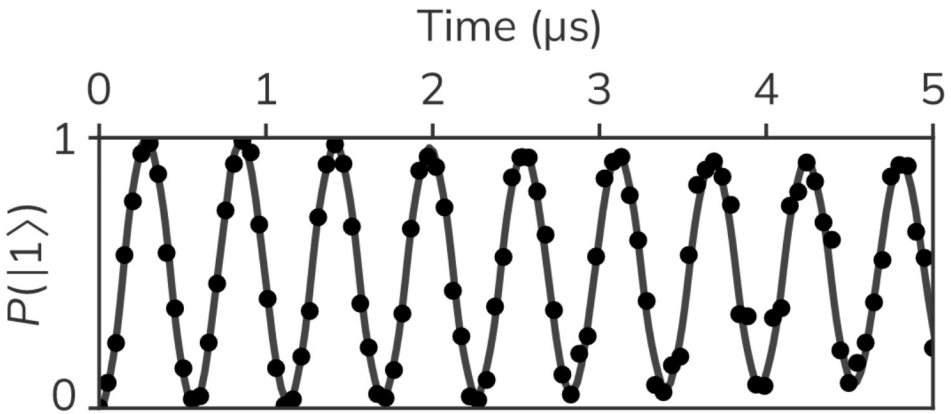
Muzi Falconi et al., arXiv:2507.01011 (2025)

Single qubit operations with atoms

The qubit is defined either between two hyperfine states or two different electronic states. Single qubit operations are achieved either with Raman beams or resonant laser beams



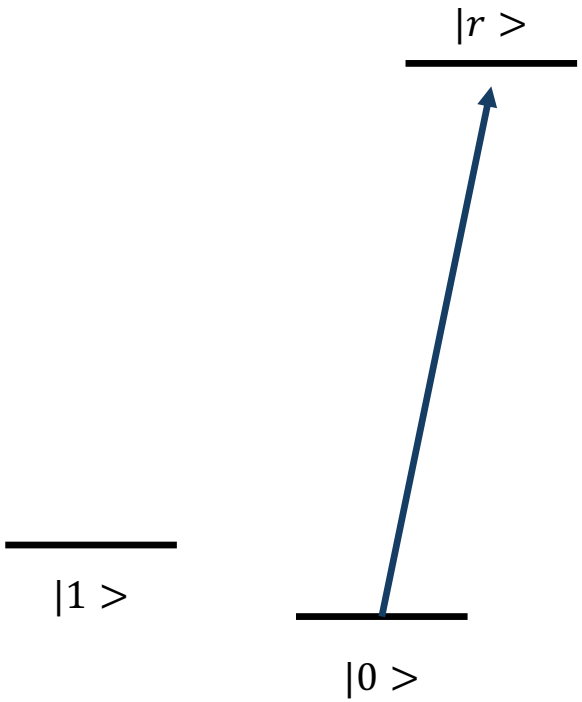


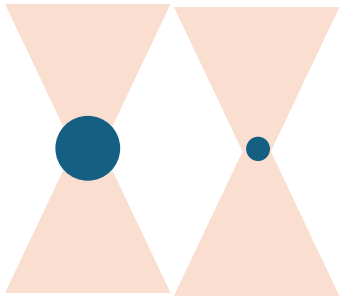


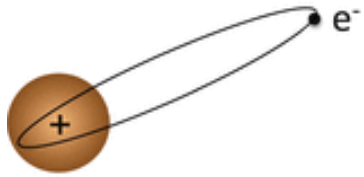
Jenkins et al., PRX 12, 021027(2022)

Two qubit operations with atoms

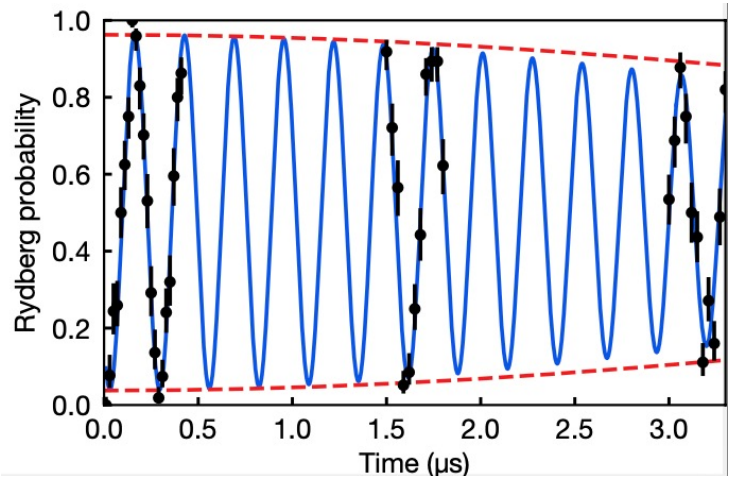
Two-qubit gates are mediated by dipole-dipole interaction through Rydberg states





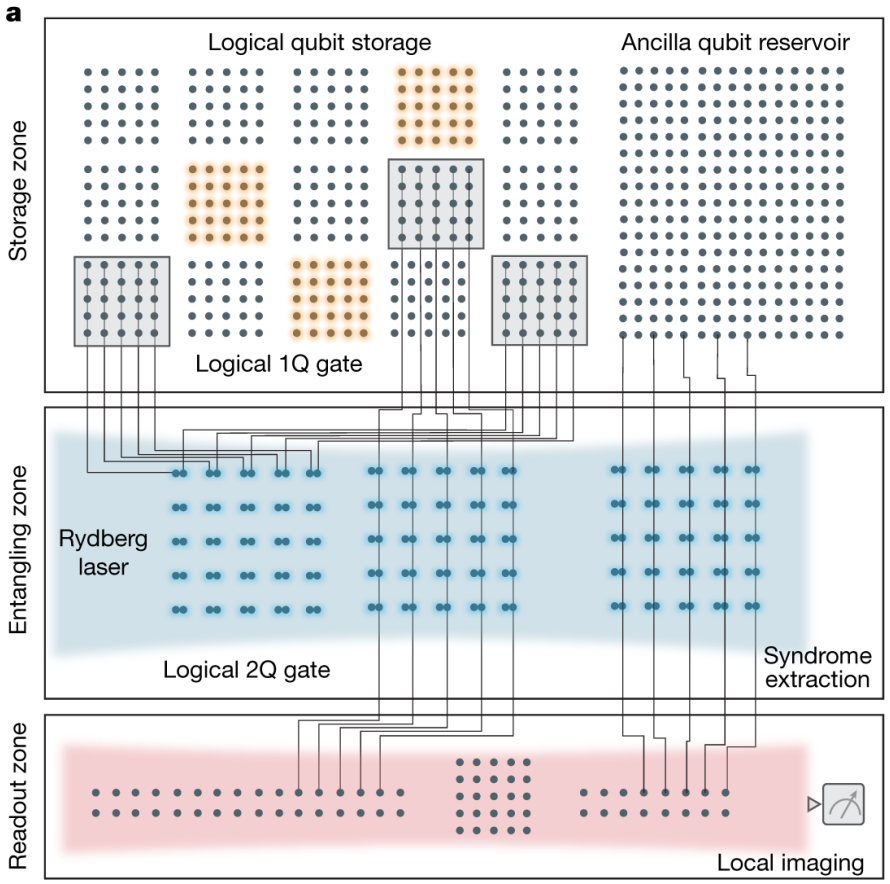


Rydberg blockade: only one atom can be in the Rydberg state

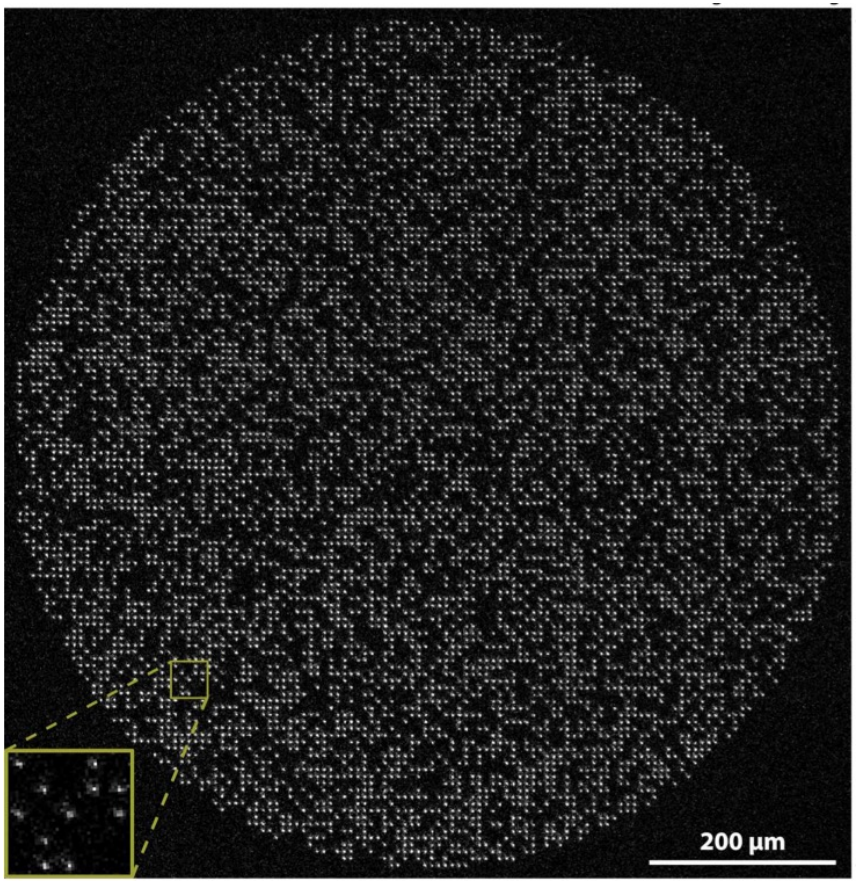


Zhang et al., PRX Quantum 6, 020337 (2025)

State of the art architectures

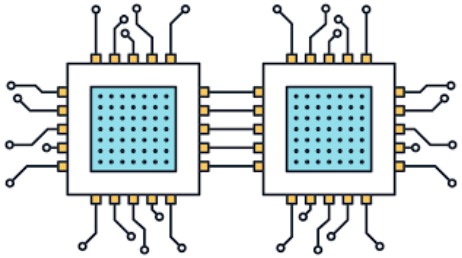


Bluvstein et al., Nature 626, 58-65 (2024)



Manetsch et al., ArXiv 2403.12021

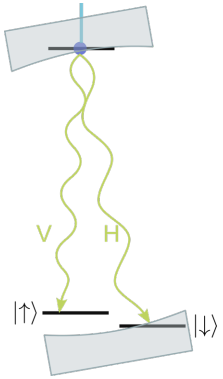
Scaling up: modular architecture



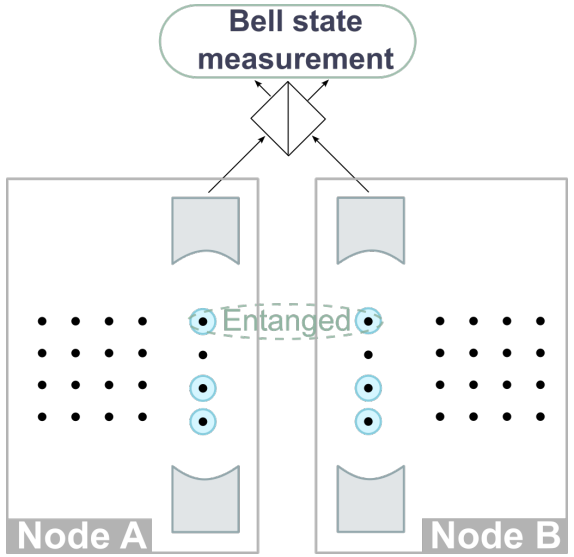
Similar approach to classical parallel computing: small computing modules connected to each other.

Remote entanglement

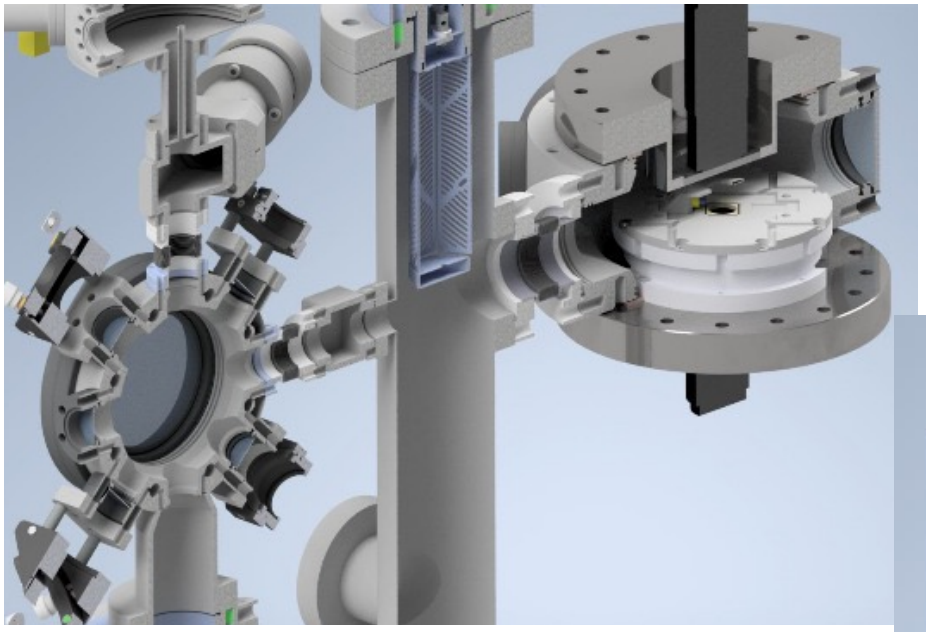
Qubits in each processor are entangled with photons.

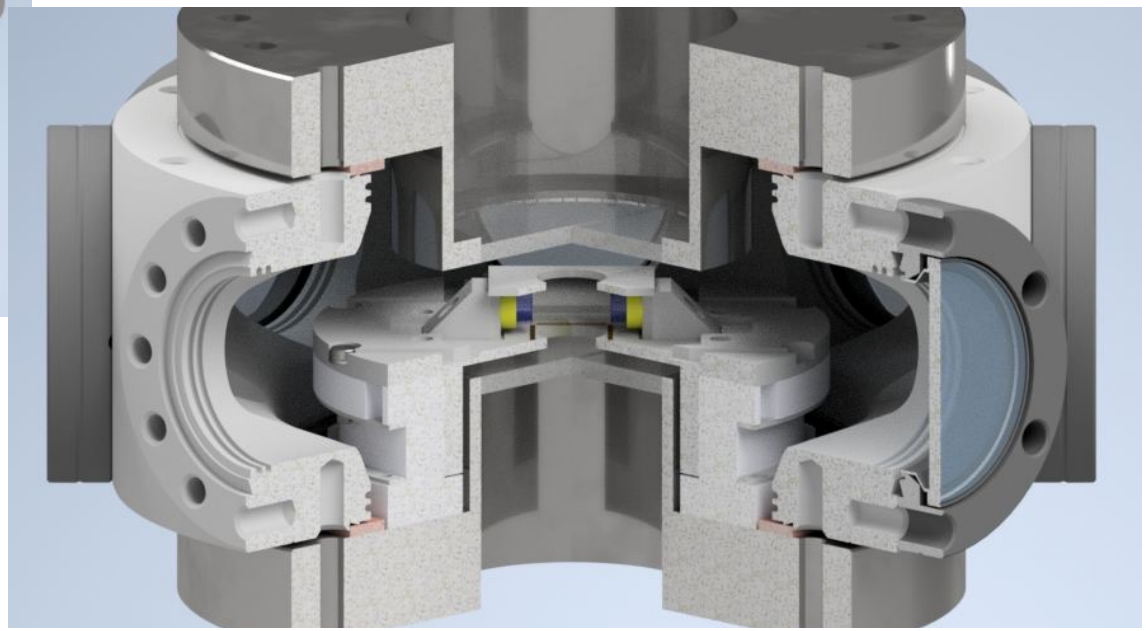


Photons interfere and are measured to swap entanglement leaving qubits in two different chambers entangled

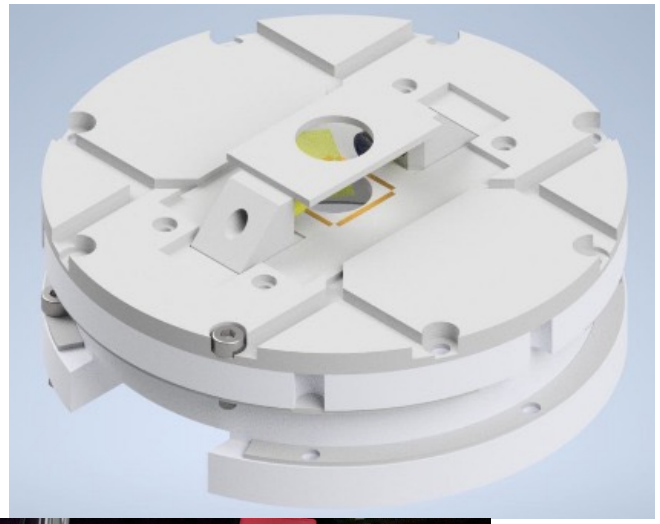


Scaling up: modular architecture @ UNITS

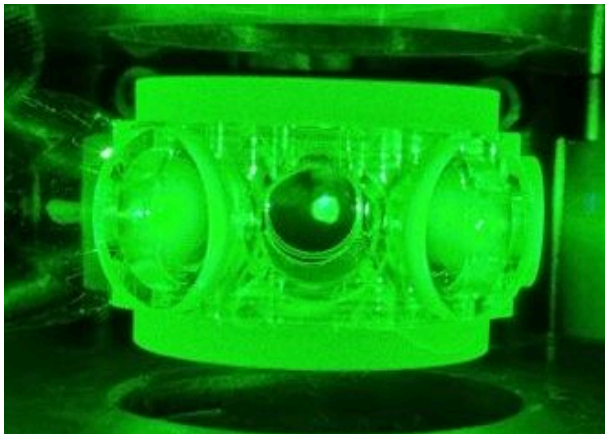


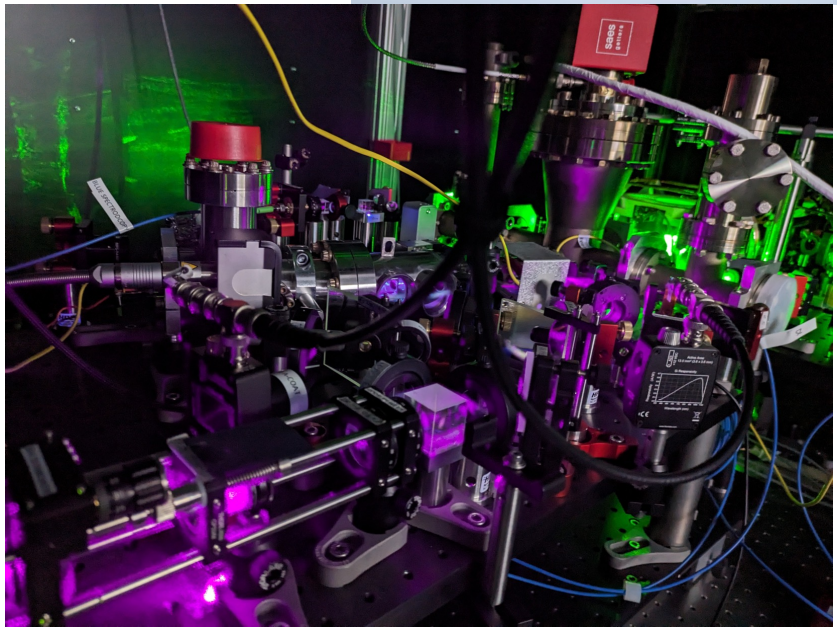


Conclusions



- Necessary ingredients to build a quantum computer
- Trapping single atoms
- Basic operations with atoms in tweezers
- How to scale atomic systems: modular architectures





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Thank you for the attention!

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