Quantum Computing with Neutral Atoms

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Atom Computing

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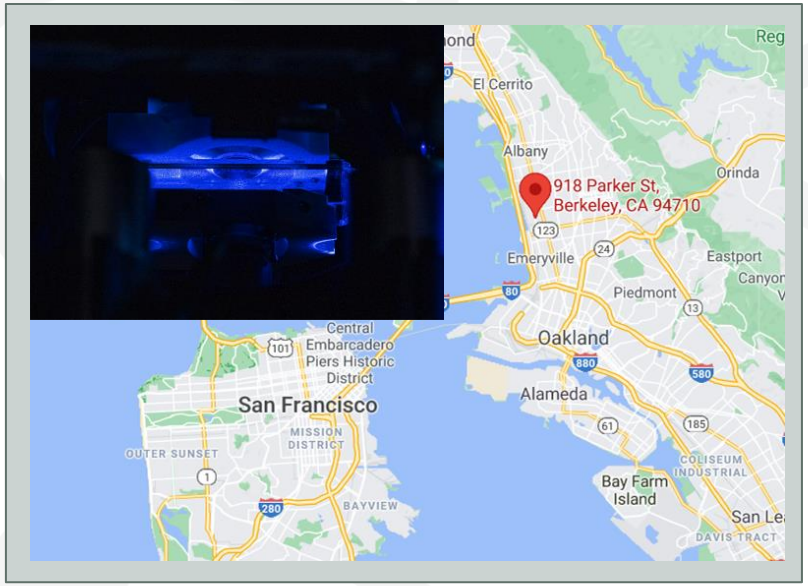
Atom Computing

Neutral Atom Startup Founded in 2018

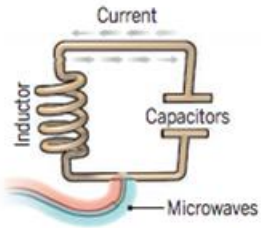
- Based in **Berkeley, CA**

Our goal: to develop neutral atoms trapped in light as a highly-scalable, externally-accessible platform for quantum computing

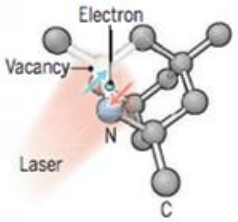


- Pursuing gate-based, near-neighbor couplings
- Focused on achieving capabilities and qubit numbers compatible with known error correction schemes

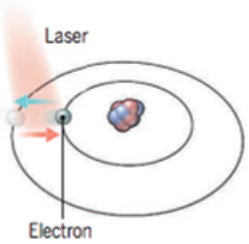
Quantum computing architectures



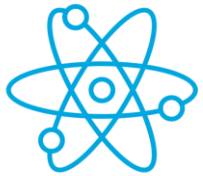
Superconducting loops



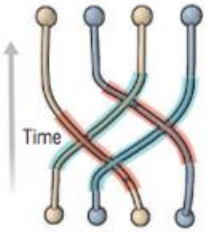
Diamond vacancies



Trapped ions



Neutral atoms

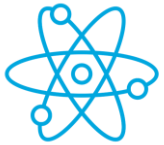


Topological qubits

Silicon quantum dots

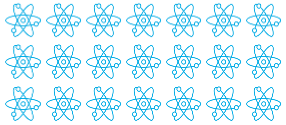
Quest for Qubits by Gabriel Popkin
Science 354, 1090 (2016)

Common ingredients regardless of underlying platform



HIGH-QUALITY QUBITS

- Long coherence times
- High-efficiency readout



SCALABLE TO MANY QUBITS

- Wireless control

UNIVERSAL GATE SET

- Tunable Rydberg-mediated interactions

Relevant work includes: Browaeys, Endres, Greiner, Kaufman, Lukin, Pichler, Regal, Saffman, Thompson, Vuletic, Weiss

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SCALABLE QUANTUM COMPUTING

2018

Founding and build out of facility in Berkeley, CA

100Q

Neutral atom QC with 100 qubits demonstrated

40s

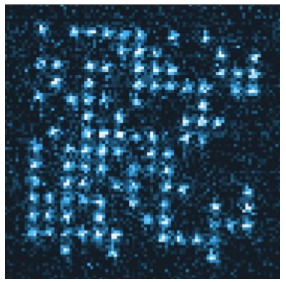
World-record coherence time achieved

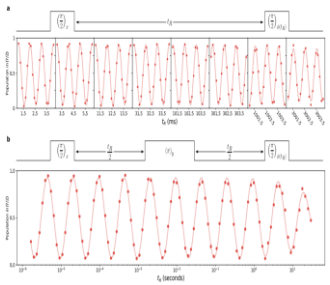
$60M

Series B funding for $80M in total funding to date

50+

Scientists and Quantum Engineers





THIRD POINT VENTURES venrock

Prelude VENTURES Prime Movers Lab

innovation endeavors

2018	Jul'21	Aug'21	Jan'22	2022

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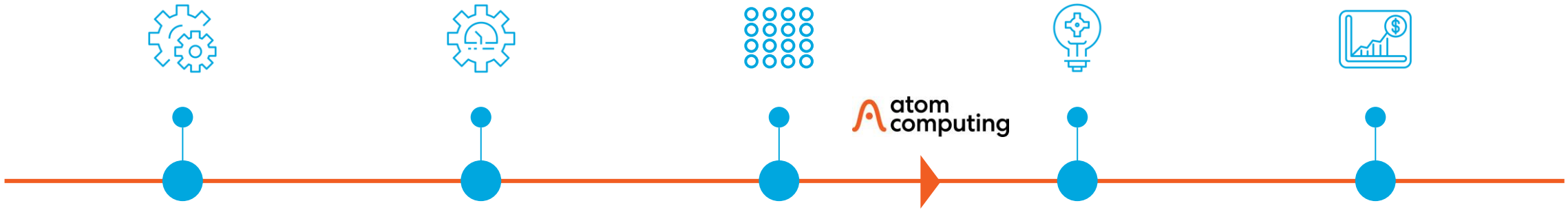
Quantum Industry Journey

RAPID PROGRESS TOWARD FULL QUANTUM IMPACT



Systems Exist

Initial system development proved that quantum computers could be built

Systems Perform

Follow-on systems demonstrated a path to error correction thresholds

Systems Scale

Approaches emerge to rapidly scale qubits while maintaining quality

Applications Explored

Scaled resources will bring new insights on valuable use cases

Applications Proliferate

True operational advancements deliver on the vision for quantum advantage

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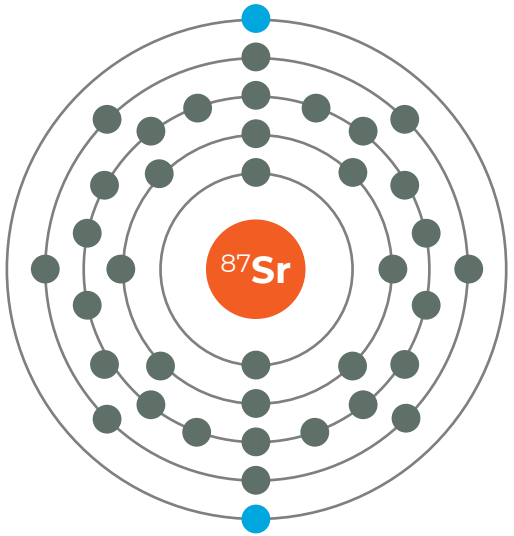
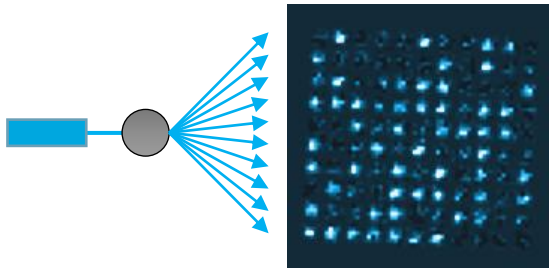
Atom's Technology

NEUTRAL ATOMS MAKE IDEAL QUBITS

- Qubits encoded in the nuclear spin of inherently identical atoms
- Alkaline-earth(-like) metals have a closed shell which protects the nuclear spin from environmental perturbation
- Enables long coherence times and other favorable qubit properties
- Atoms are trapped in an optical tweezer array where they are manipulated with laser pulses and read out with a camera





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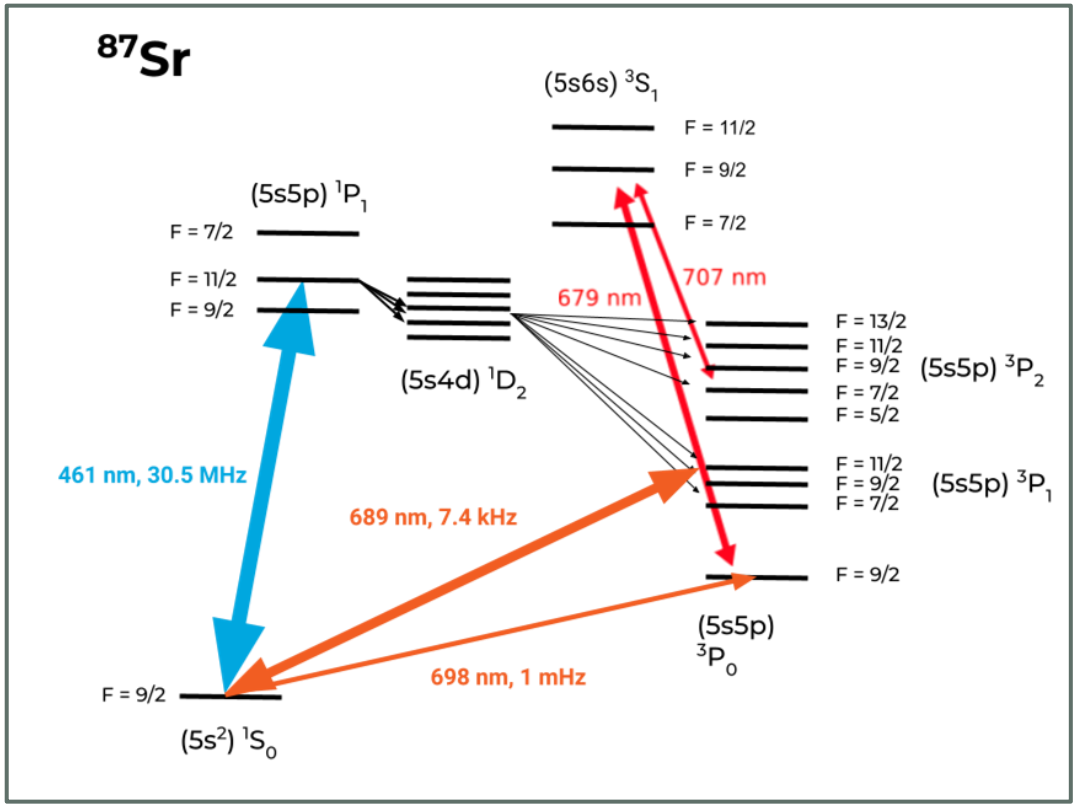
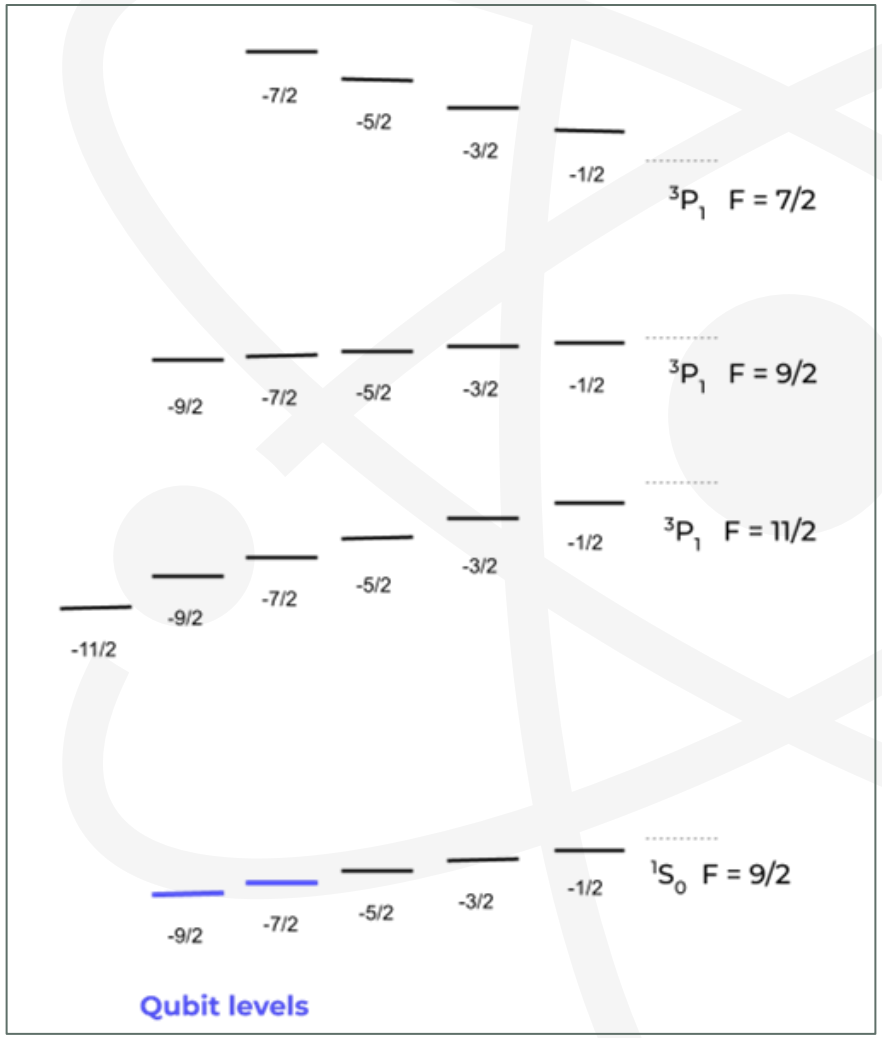
The Qubit is “Inside” the Atom

Benefits of alkaline earth atoms (2-valence electron atoms):

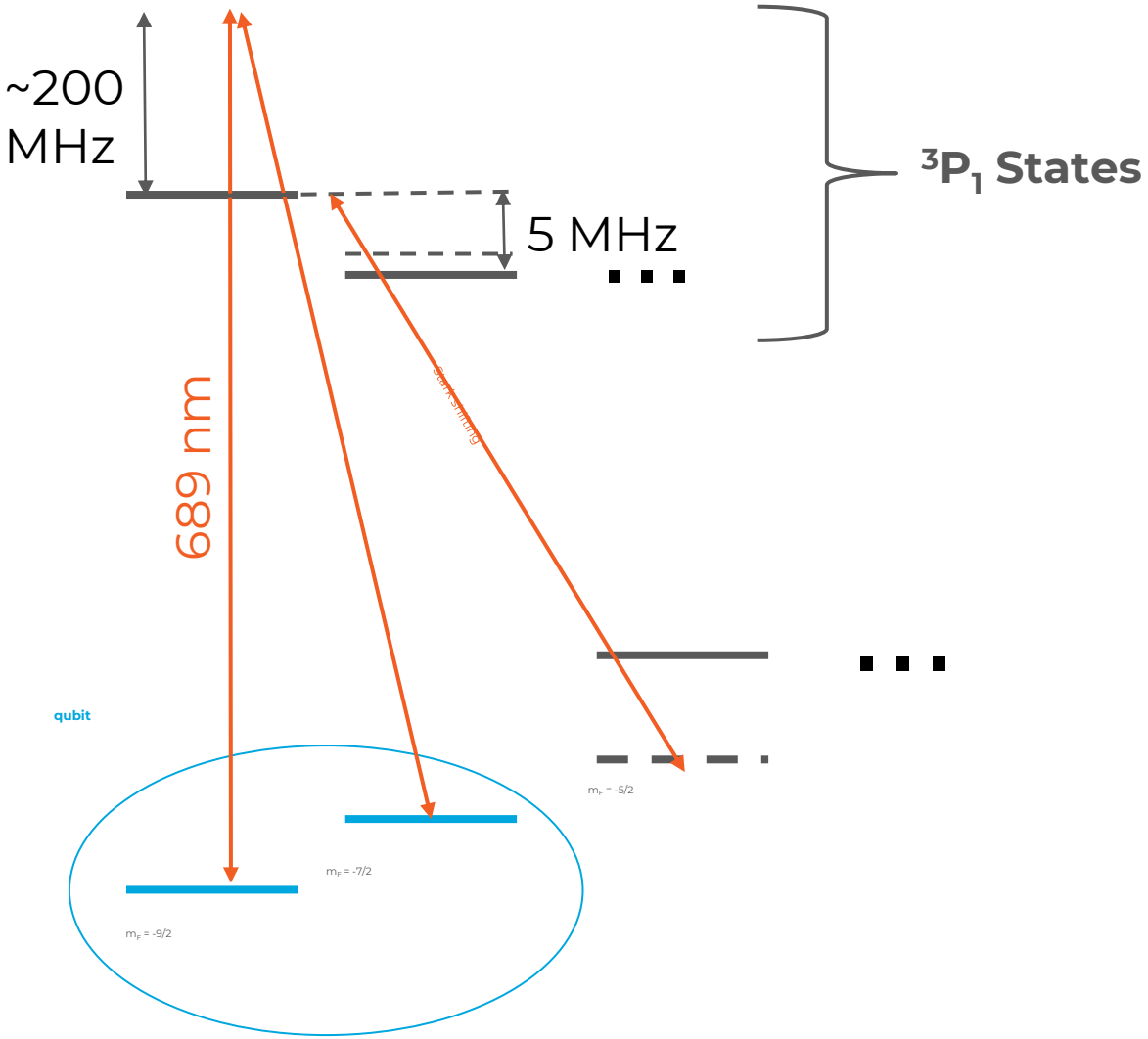
- Rich level structure: multiple long-lived excited states, variety of optical transitions & variety of linewidths
- Trapped Rydberg states



m_F levels for $^1S_0$ and $^3P_1$



Single-Qubit Manipulations in ^{87}Sr



- Qubit encoded in m_F = -9/2, -7/2 nuclear spin in ground state.
- 1Q gates actuated by 2-photon transition.
- Avoid “leakage” to other nuclear spin states using a Stark shift beam.

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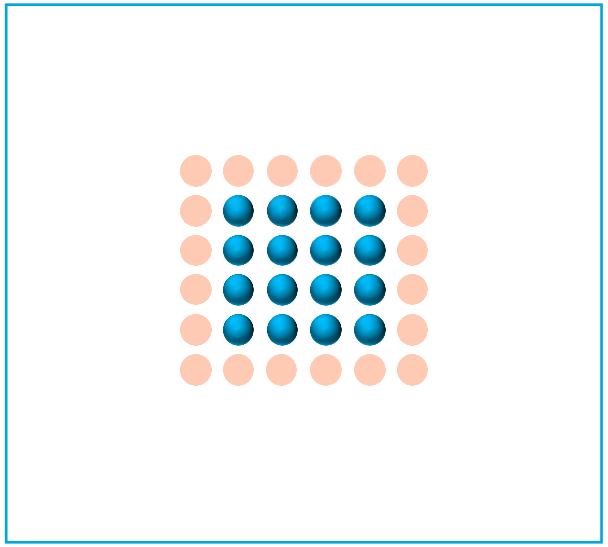
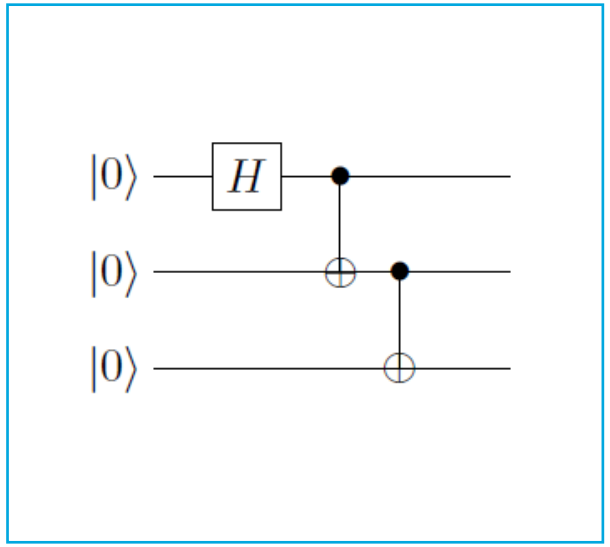
Realizing a Neutral Atom Quantum Computer



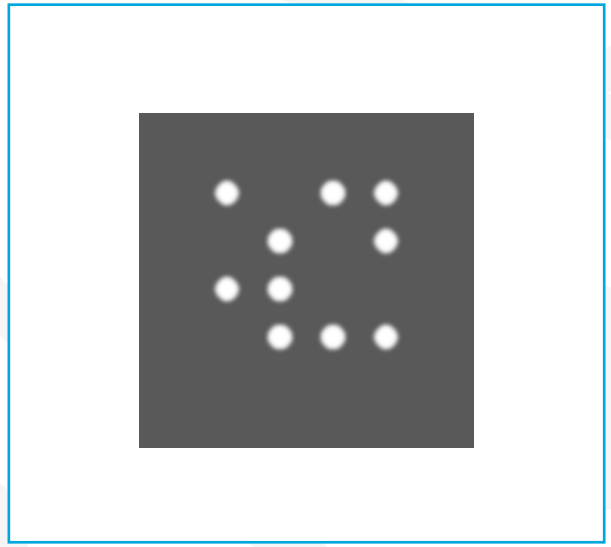
PREPARING THE ATOMS

A hot stream of atoms is cooled and optically trapped in a 2D array



QUANTUM PROCESSING

Quantum gates are performed with sequences of laser pulses



RESULTS READOUT

A camera watches glowing qubits to identify zeros and ones

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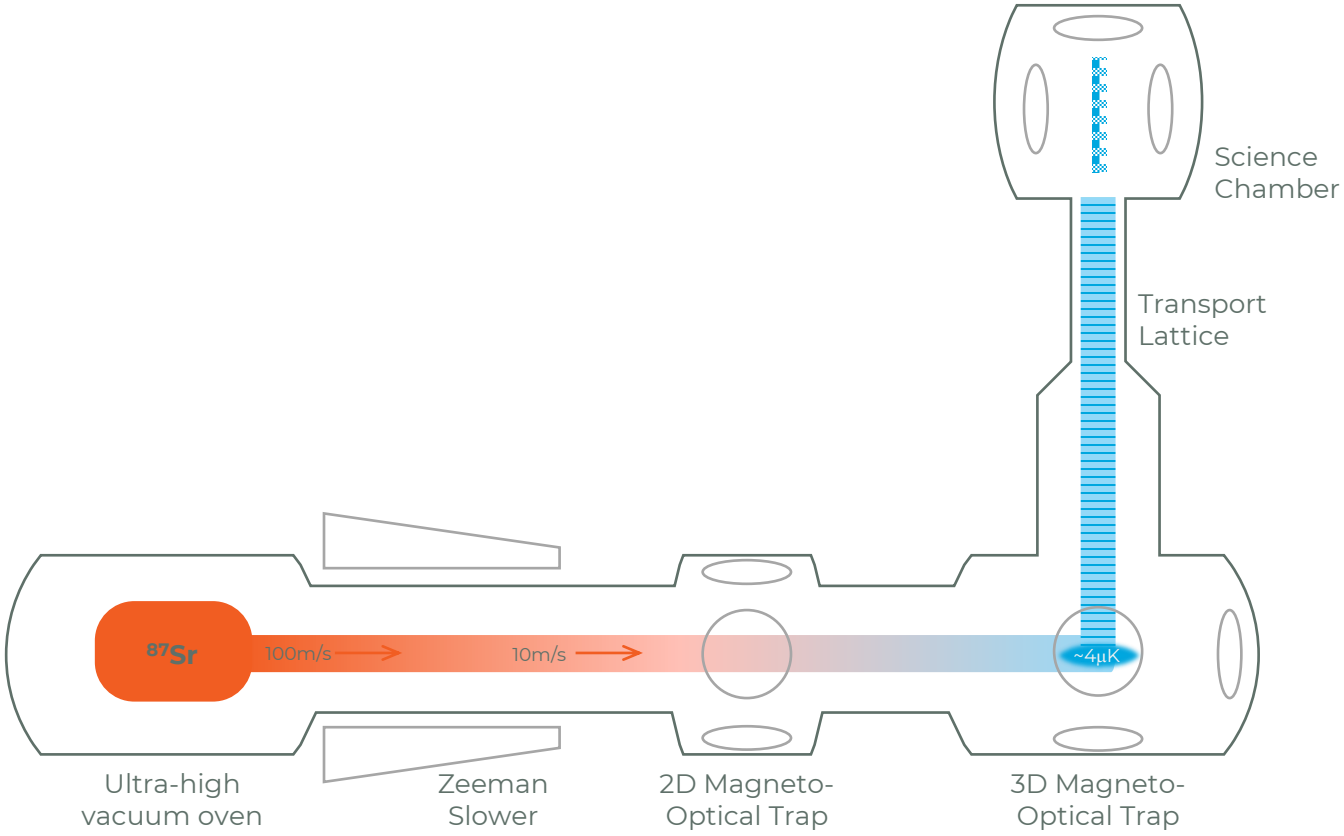
Preparing the Atoms

- Metal is heated in an ultra-high vacuum oven to release a stream of energetic atoms
- The atoms are progressively slowed using magnet fields and lasers
- A cloud of cold atoms is held in a reservoir to be delivered into the science chamber for trapping and computing



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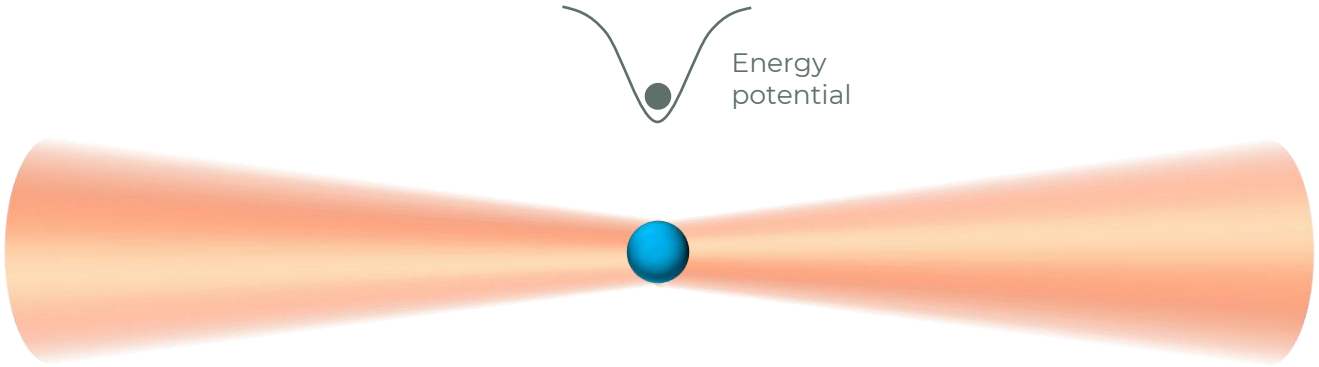
Optical Tweezers

- A tightly focused laser beam is used to induce a “dipole moment” in an atom
- The electric fields from the atom and laser interact such that the atom settles into a region of lowest potential energy: it is “trapped”



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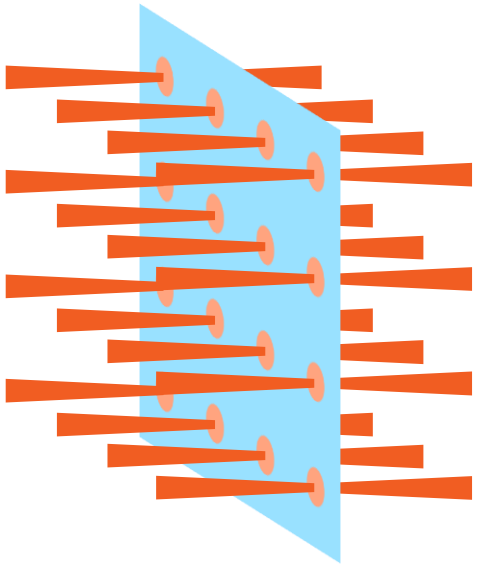
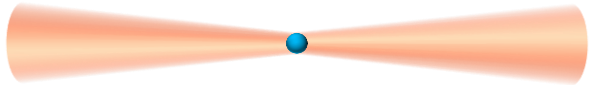
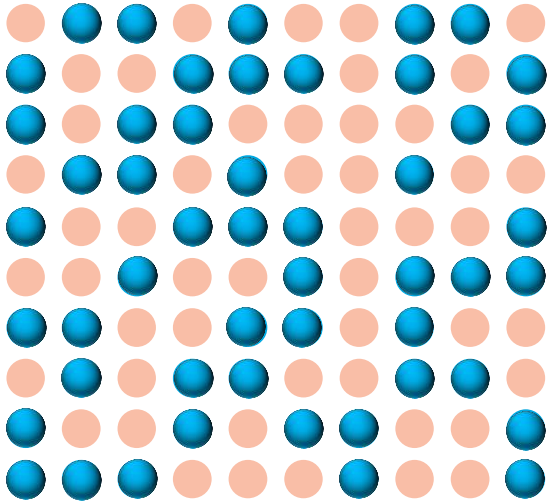
Trapping an Array of Atoms

- Inside the Science Chamber, an array of optical tweezers is generated
- In one scheme, a single laser beam is shaped into a grid of high-intensity spots (tweezers) where atoms become trapped
- Initially, atoms fill the traps randomly, filling about 50% of the traps







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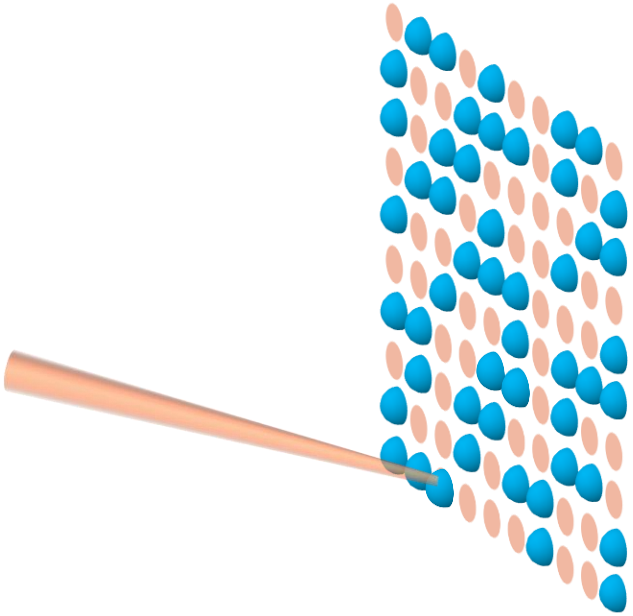
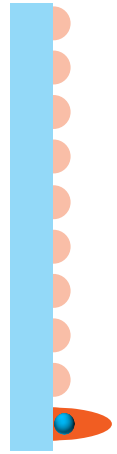
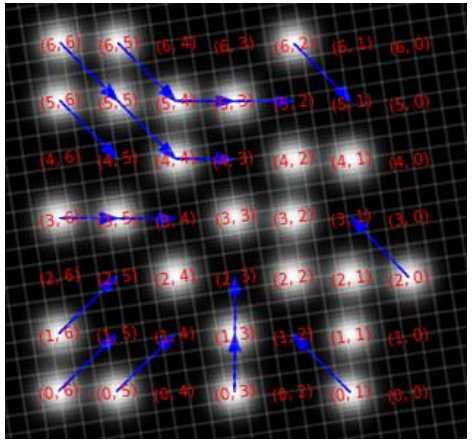
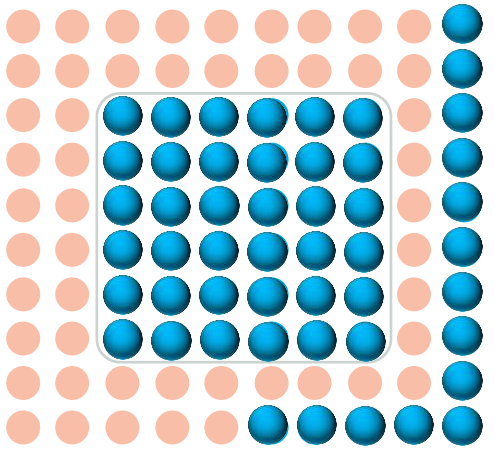
Rearranging the Atoms

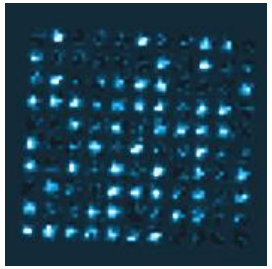
- A steerable laser forms a dynamic tweezer that individually rearranges atoms to fill the array
- Once a full grid has been organized, quantum computation can begin











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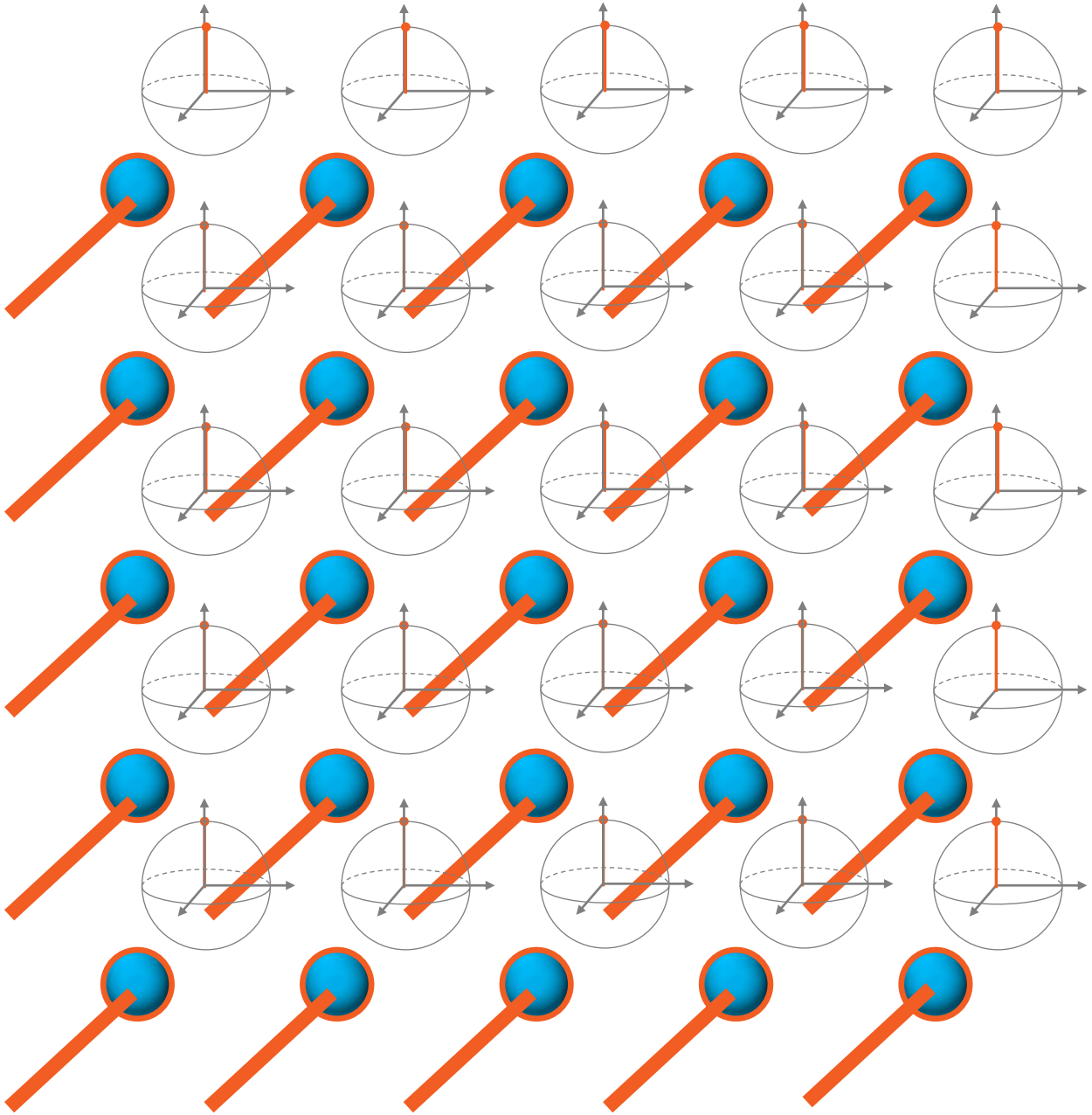
Quantum Processing

- Single qubit gates are performed with tuned laser pulses
- The operation can be performed in parallel across rows for higher circuit throughput



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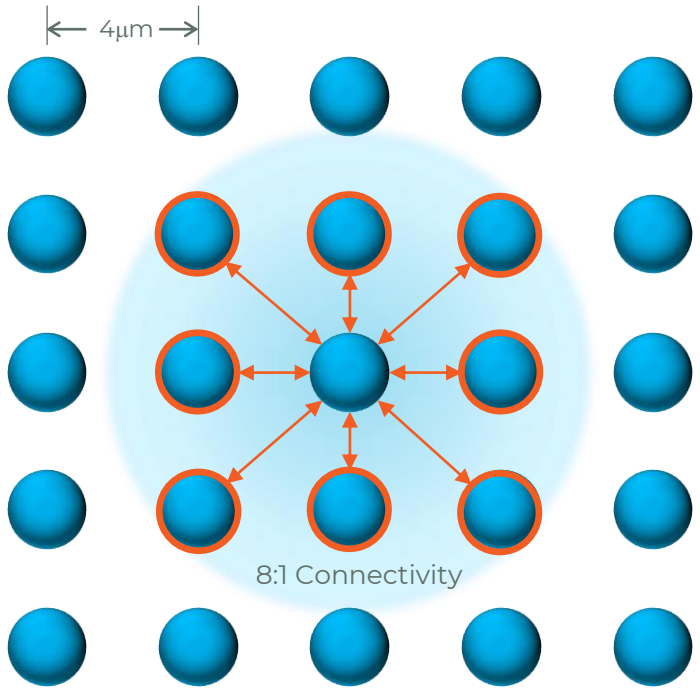
Quantum Processing

- Two qubit gates are also performed with laser pulses, through a “Rydberg” excitation and interaction
- Normally, neutral atoms spaced microns apart do not interact with each other
- An excited atom has a larger radius of interaction such that it can reach surrounding atoms
- The state of one atom can be used to control the state of another atom, creating the basic building block for quantum circuit execution



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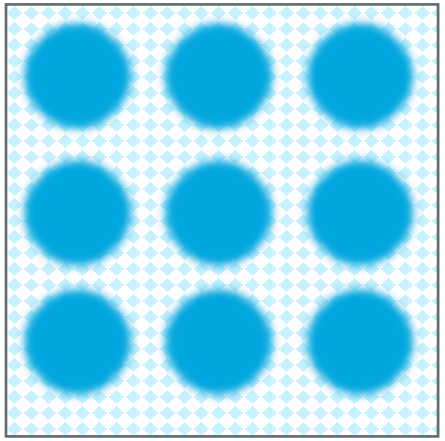
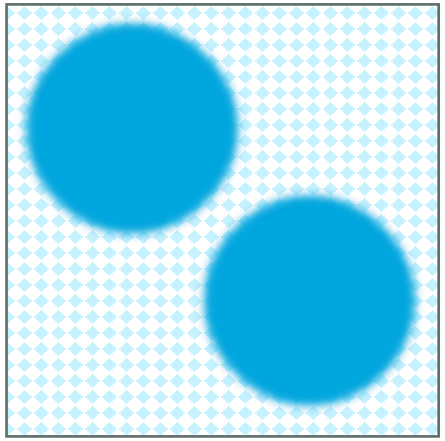
Quantum Processing

- Multiple two-qubit gates can be performed in parallel by spacing the islands of interaction apart from each other
- The radius of interaction can be increased for greater connectivity with a tradeoff of fewer parallel zones





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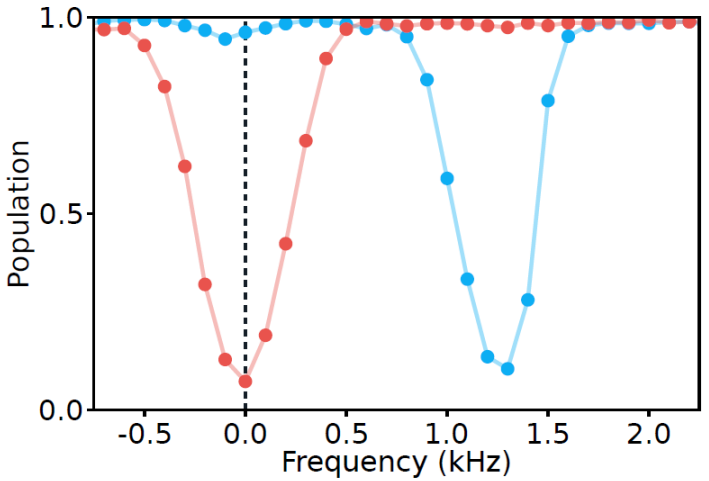
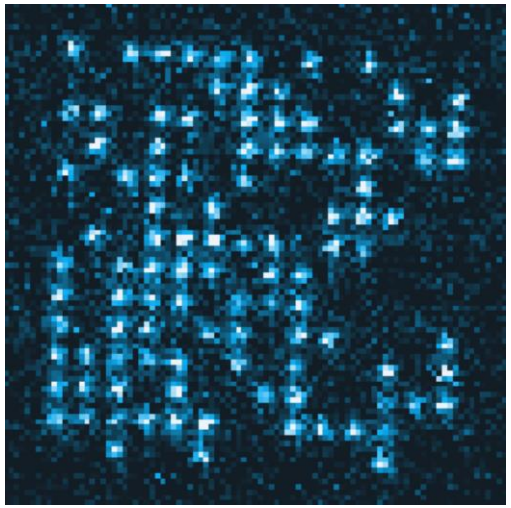
Results Readout

- After quantum circuit completion, results are readout optically
- To distinguish between spin states (qubits that are ones or zeros), a “shelving” technique is used
- Qubits which are zeros are temporarily “hidden” in a different energy level so that only the remaining qubits (ones) are caused to fluoresce from a laser pulse
- A sensitive camera measures the glowing qubits, and the results of the computation are reported





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SUMMARY

SCALABLE TECHNOLOGY

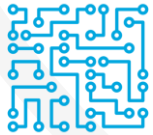
Leveraging neutral atoms held in an optical tweezer array

Rapidly scalable to millions of qubits in 1mm^3

EXPERT TEAM

Diverse group of ~50 scientists and engineers

Experience from the top global quantum institutions



ADVANCED SYSTEMS

100Q system operating now, with larger commercial systems in ’23

Custom control system to drive performance

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Thank you!

Contact us:

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