The Road to Slovenia's First Quantum Computer

Pot do prvega slovenskega kvantnega računalnika

Nejc Blaznik
Atom Quantum Labs

2. Slovenski forum o kvantnem računalništvu · Novo mesto · 5 November 2026

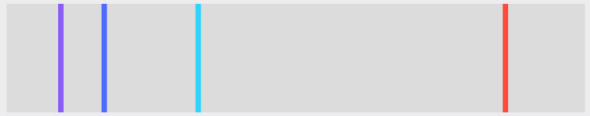


A hundred years of quantum.

Around 1900, nature at the smallest scales stopped following everyday rules. First we observed it and wrote down the theory.

I Discover

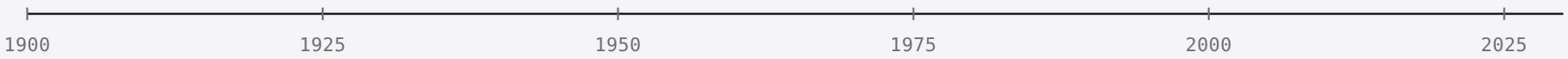
observe it, write the theory



hydrogen: light comes in sharp lines



an electron behaves as a wave

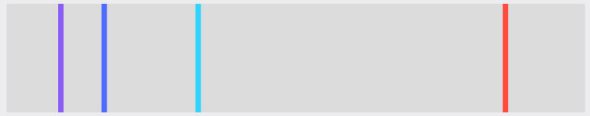


A hundred years of quantum.

Then we used it in bulk, without ever controlling a single quantum system: lasers, transistors, atomic clocks, MRI. The first quantum revolution.

I Discover

observe it, write the theory



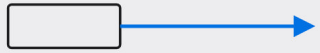
hydrogen: light comes in sharp lines



an electron behaves as a wave

II Use it in bulk

the first quantum revolution



laser



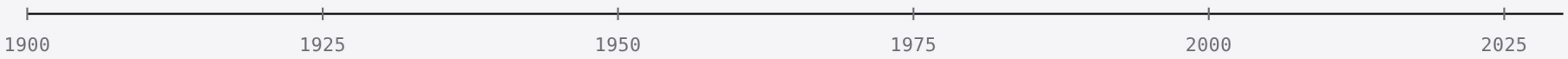
transistor



atomic clock



MRI

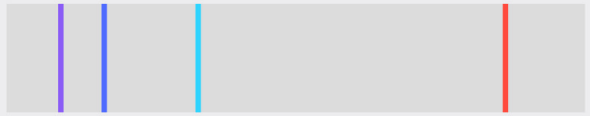


A hundred years of quantum.

Now we control single quantum systems, one at a time. The second quantum revolution: sensing, secure communication, computing.

I Discover

observe it, write the theory



hydrogen: light comes in sharp lines



an electron behaves as a wave

II Use it in bulk

the first quantum revolution



laser



transistor



atomic clock



MRI

III One by one

the second quantum revolution



atom photon electron

sensing

communication

computing

1900 1925 1950 1975 2000 2025

Why a quantum computer?

For some problems, a quantum algorithm changes what is possible, not just what is fast.

01

Molecules and materials

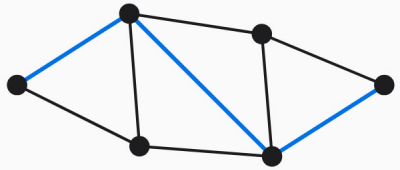
Simulate chemistry and new materials from first principles.



02

Optimisation

Some hard search and scheduling problems.



03

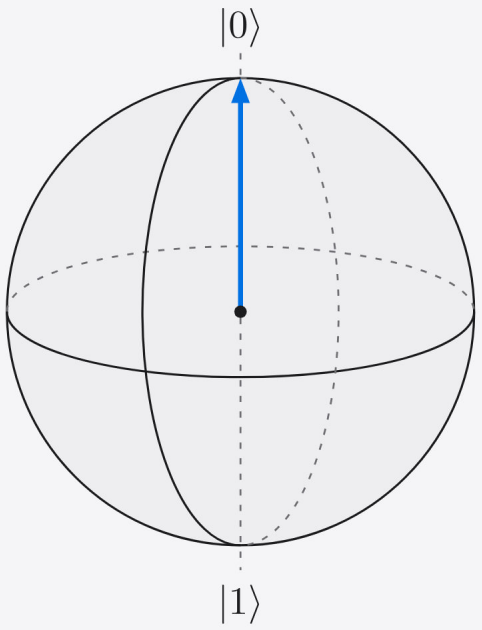
Cryptography

Factoring large numbers breaks some of today's encryption.

$$N = p \times q$$

The qubit.

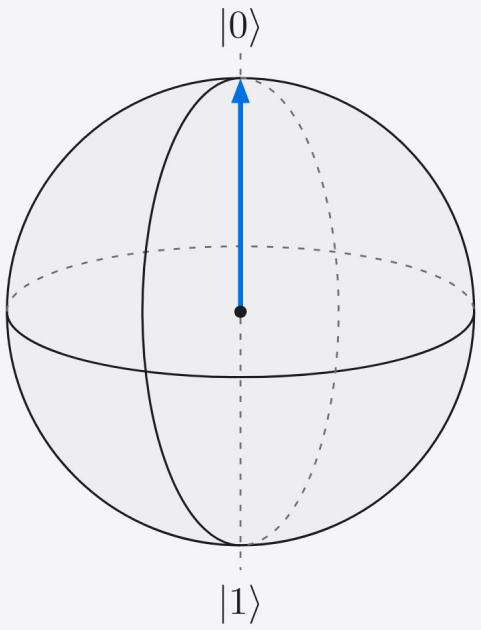
Every quantum algorithm needs the same ingredient: a quantum bit.
Simple on paper, hard to build reliably.



$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$$

The qubit.

Control: prepare it, rotate it, move it, read it out, and more. It has to do exactly what you say.



prepare
start the qubit in $|0\rangle$

rotate
a laser pulse turns the state

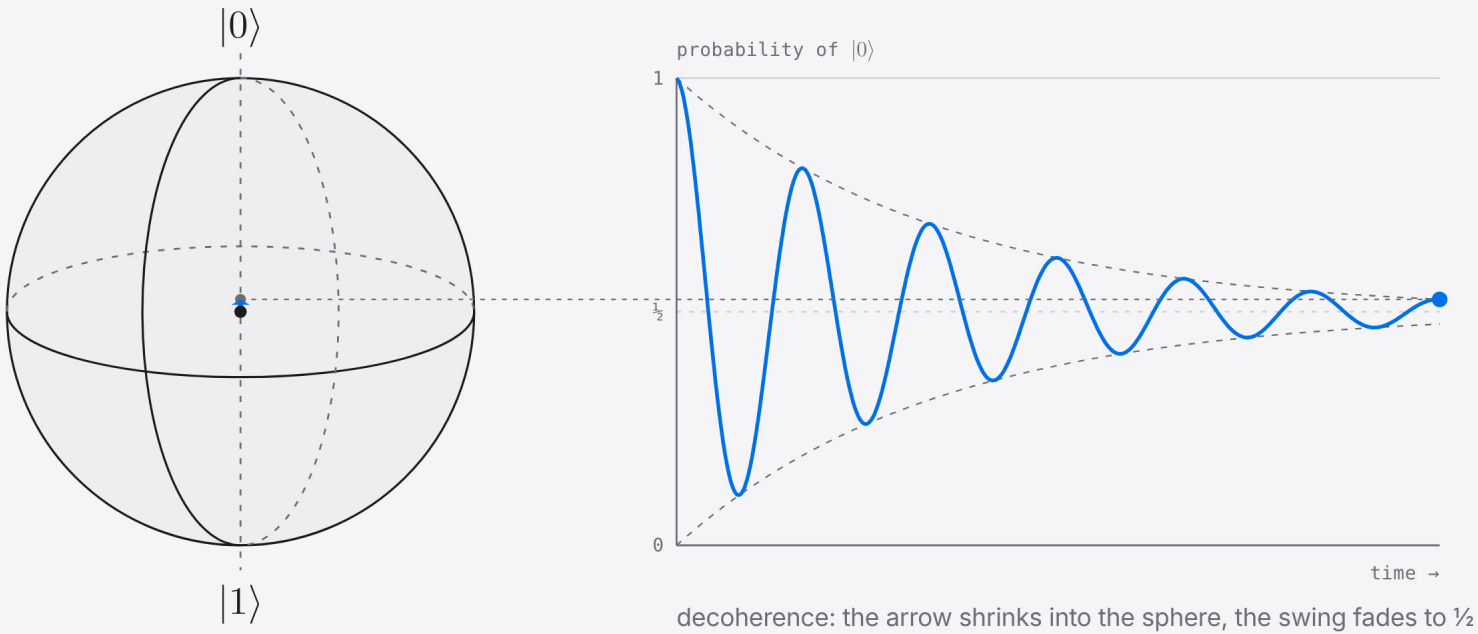
move
carry it to its partner

read out
a camera sees 0 or 1

The qubit.

Stability: drive it, and it swings between $|0\rangle$ and $|1\rangle$. A good qubit keeps swinging until the environment blurs it.

01 Control 02 Stability 03 Scale

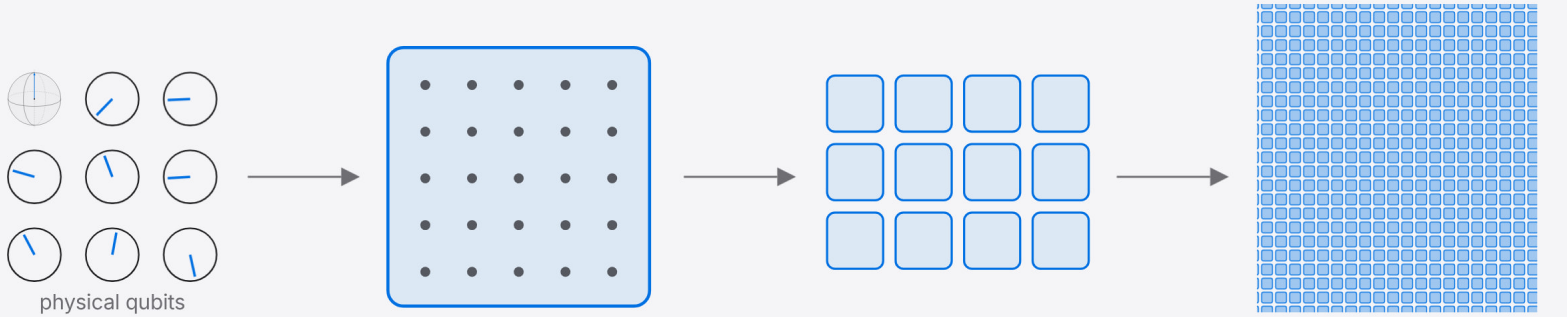


decoherence: the arrow shrinks into the sphere, the swing fades to ½

Not to scale: a real qubit oscillates far faster, and for many more turns before it fades.

The qubit.

Scale: many physical qubits make one logical qubit that corrects its own errors. A useful machine needs about a million.



dots: physical qubits · squares: logical qubits · [1, 2]: tens to thousands per logical qubit

[1] Bravyi et al., Nature 627, 778 (2024).
[2] Fowler et al., Phys. Rev. A 86, 032324 (2012).
[3] Gidney, arXiv:2505.15917 (2025): RSA-2048 with under a million noisy qubits.

Seven ways to build a qubit.

Around the world, seven kinds of qubit are being built and tested.



Superconducting circuits



Trapped ions



Neutral atoms



Photons



Spins in silicon



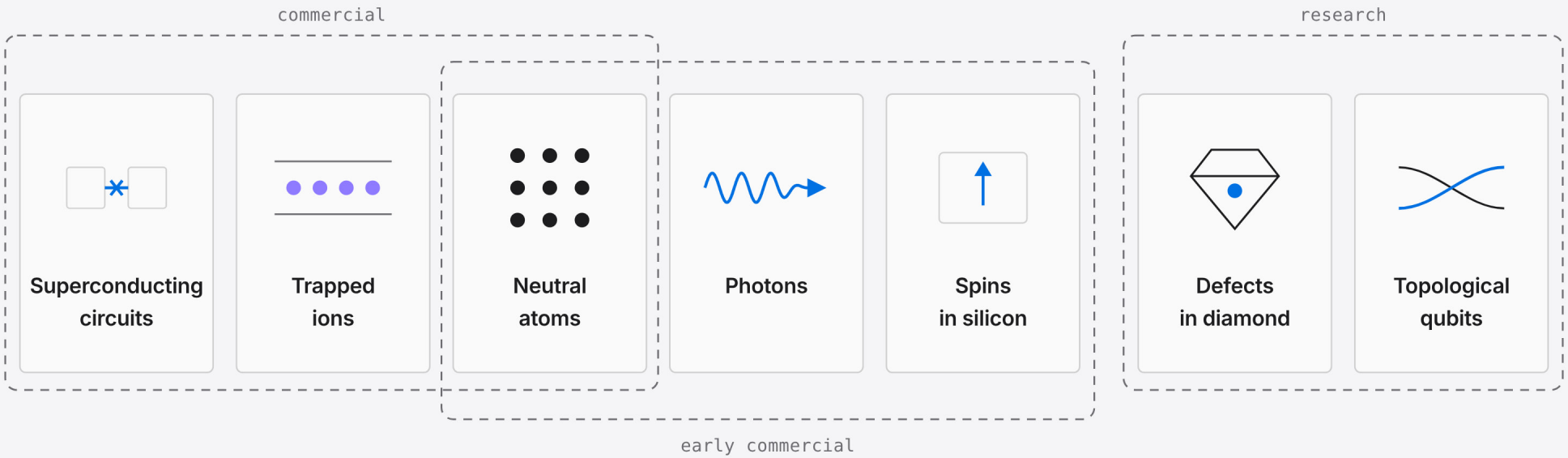
Defects in diamond



Topological qubits

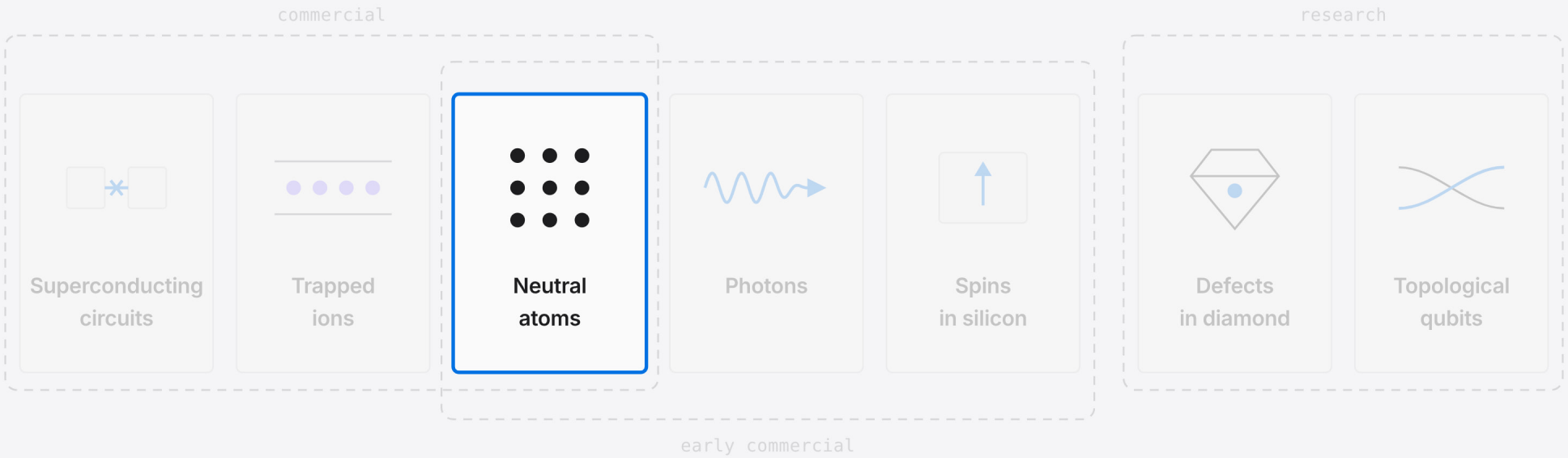
Seven ways to build a qubit.

Some you can already use, some are early products, some are still in the lab.



Cold atoms.

The latest comer, and the one we are betting on, especially if you want to build it in Slovenia.



From the oven.

Strontium is heated until it evaporates. A beam of atoms leaves the oven at a few hundred metres per second.



Slow them with light.

A laser points straight at the oncoming atoms. Each photon an atom absorbs takes away a little momentum, and tens of thousands of them bring it almost to a stop.



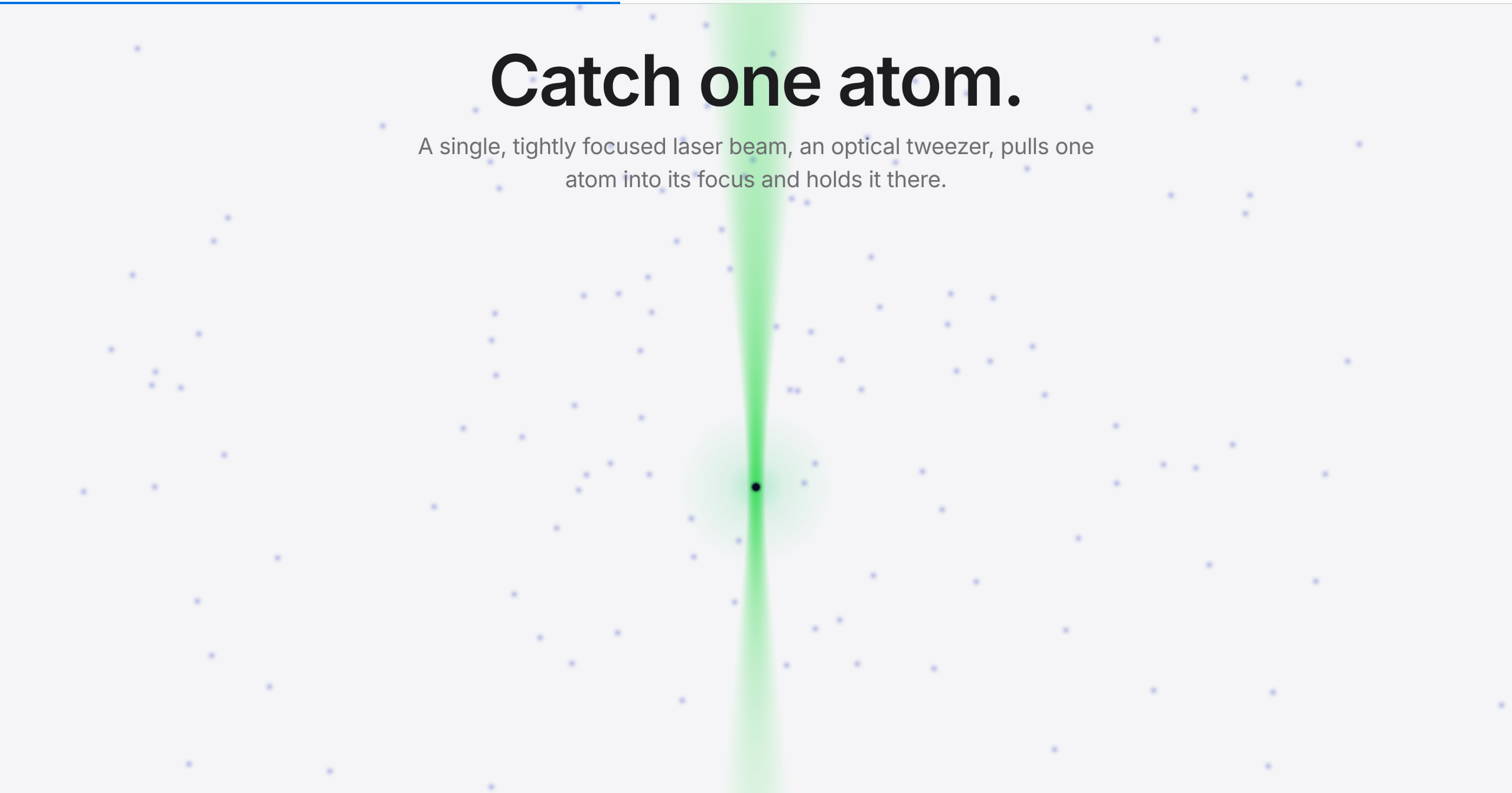
Trap and cool.

Laser beams from three directions and a weak magnetic field push the slow atoms into one spot. The cloud cools to a small fraction of a degree above absolute zero.



Catch one atom.

A single, tightly focused laser beam, an optical tweezer, pulls one atom into its focus and holds it there.



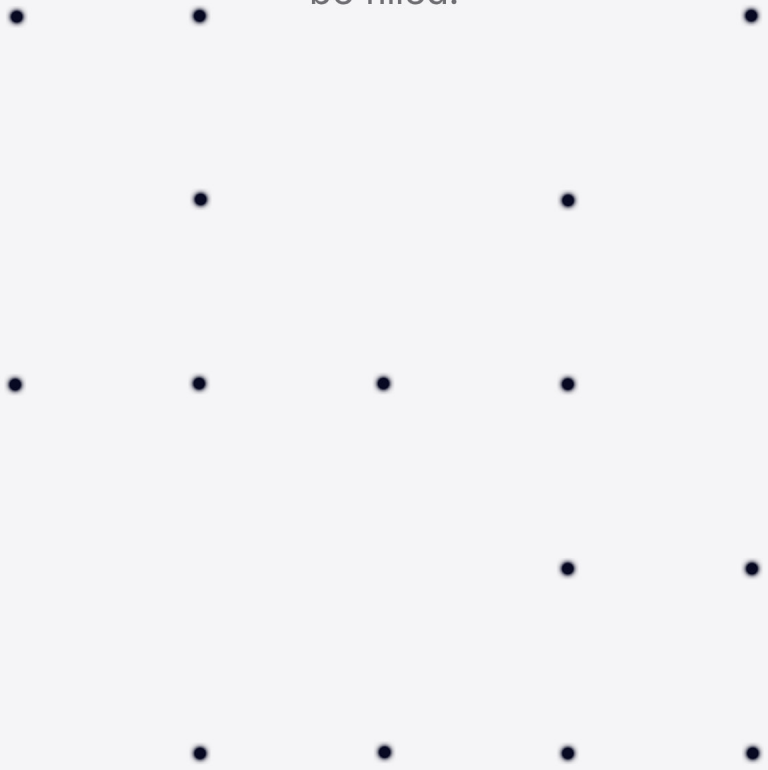
Then many.

Split the light into a grid of tweezers. Each one catches at most one atom, and loading is random, so only about half of the sites end up filled.



Gaps in the array.

Seen from above, the random loading leaves holes. A quantum computer needs a complete, regular array, so the holes have to be filled.



Fill the gaps.

A movable tweezer picks up atoms one at a time and carries them into the empty sites, leaving a defect-free block.



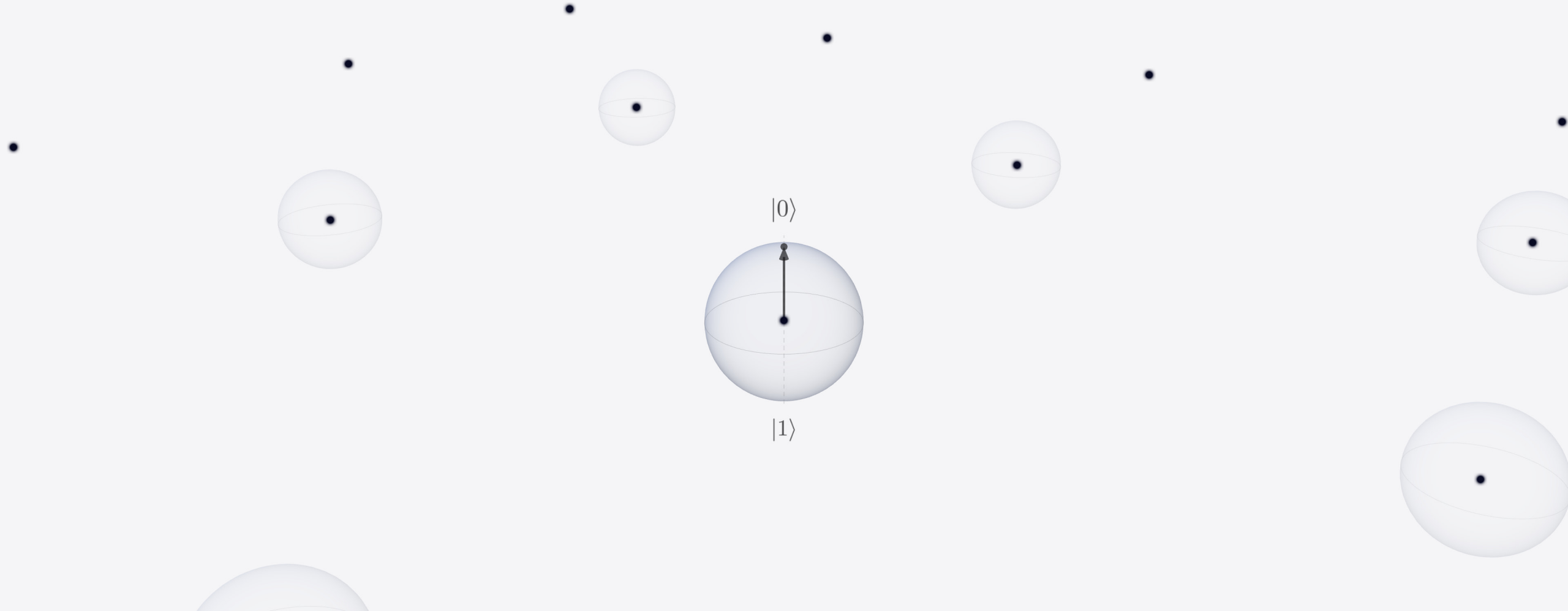
Top up from a reservoir.

Spare atoms wait in reservoir tweezers next to the array. They fill the remaining sites, and when an atom is lost, a spare takes its place.



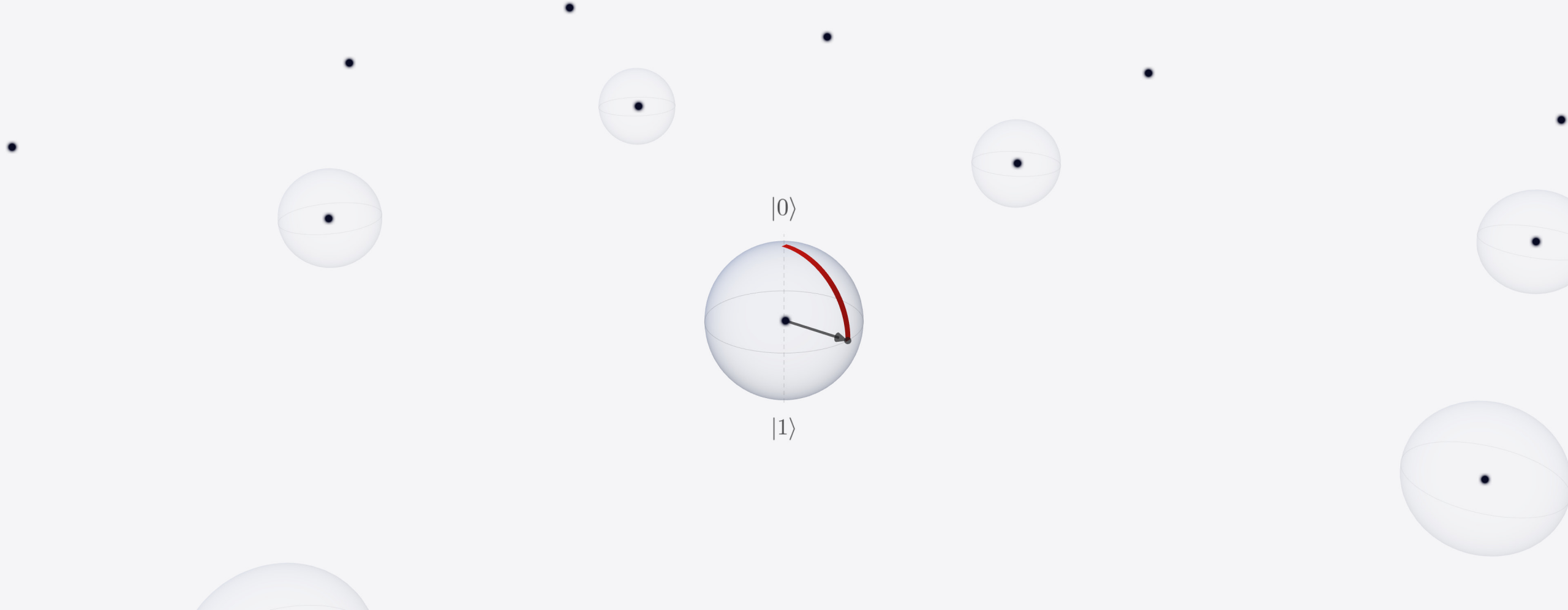
One atom, one qubit.

The qubit is two long-lived states of the atom, drawn as the poles of a sphere. This atom starts in $|0\rangle$.



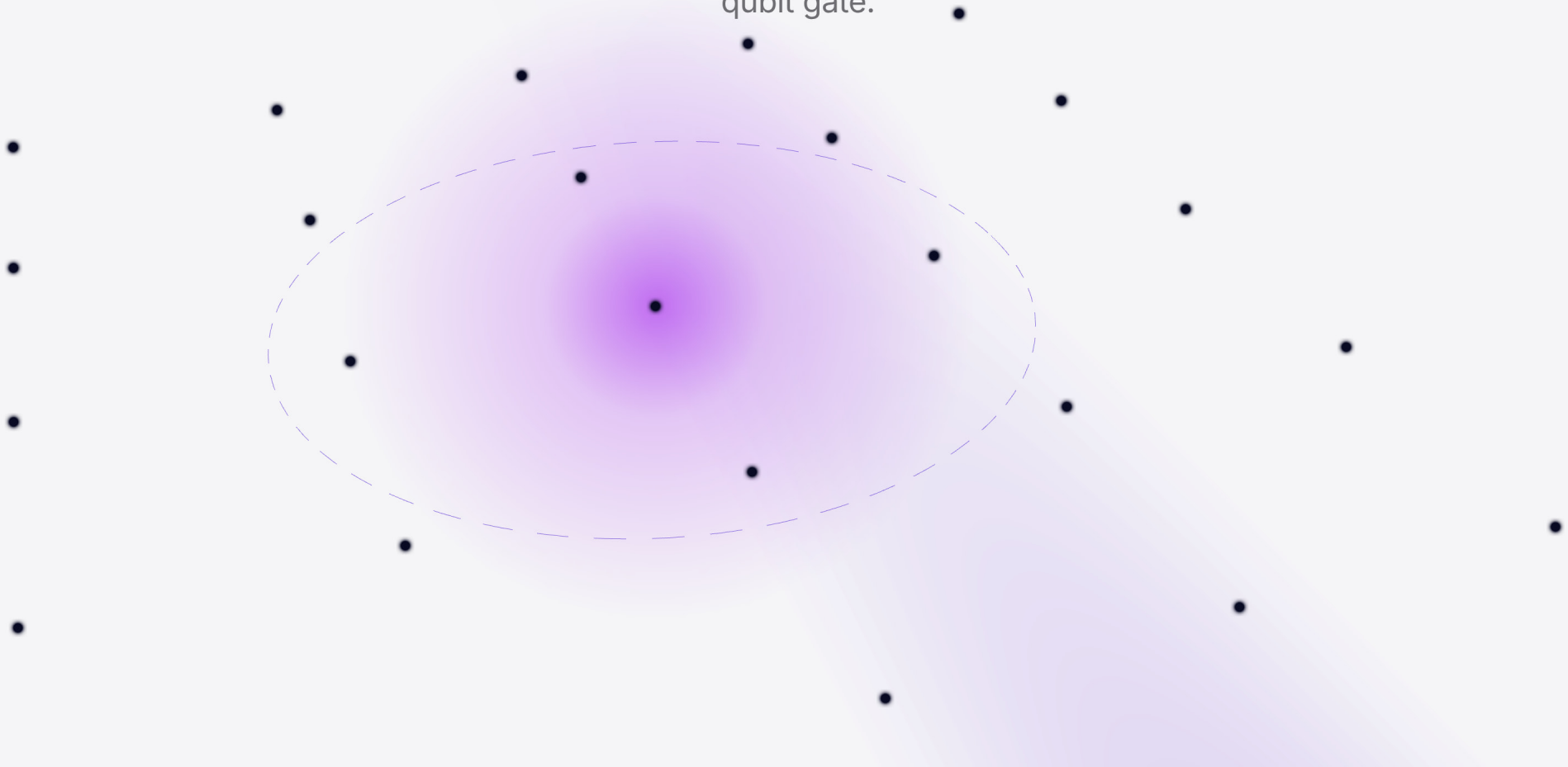
Rotate it with light.

A short laser pulse, aimed at this atom alone, rotates the state.
This pulse stops halfway, in an equal superposition of $|0\rangle$ and $|1\rangle$.



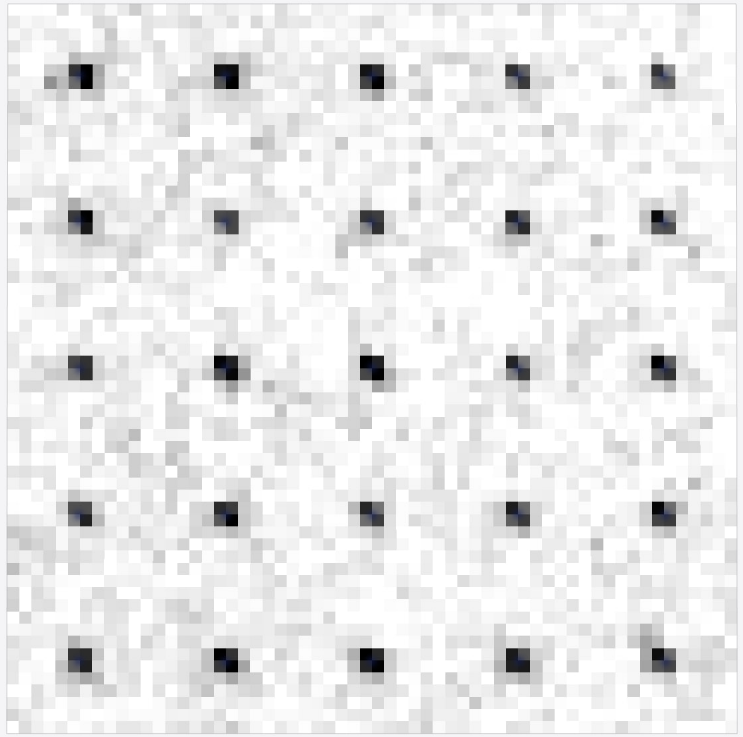
Rydberg blockade.

An ultraviolet laser lifts an atom into a Rydberg state, hundreds of times its normal size. Inside the dashed circle, a second atom cannot be excited as well. That rule is what makes a two-qubit gate.



Read out.

Switch the blue light back on and photograph the array from above. Each atom shows up as a bright spot. An empty site stays dark.



Camera image: a 5 × 5 section of a fluorescence image of an atom array, Jožef Stefan Institute (IJS).

Why we bet on neutral atoms.

01 Identical

Nature makes every qubit the same.

02 Coherent

They hold their state for seconds.

03 Flexible

Traps made of light can be rebuilt.

04 Scalable

Thousands of atoms, and counting.

Why we bet on neutral atoms.

01 IDENTICAL

Every atom is the same.

A strontium atom in Ljubljana is identical to one on Jupiter, **to every decimal place**. Nobody fabricates it, so there is no bad qubit on the chip. It is why the second is defined by an atom.

9,192,631,770

oscillations of a caesium atom define one second [1]

8×10^{-19}

uncertainty of a strontium atomic clock [2]

[1] BIPM, The International System of Units (SI Brochure), 9th ed. (2019).
[2] Aeppli et al., Phys. Rev. Lett. 133, 023401 (2024).

02 Coherent

03 Flexible

04 Scalable



Why we bet on neutral atoms.

01 Identical

02 COHERENT

Atoms keep their state.

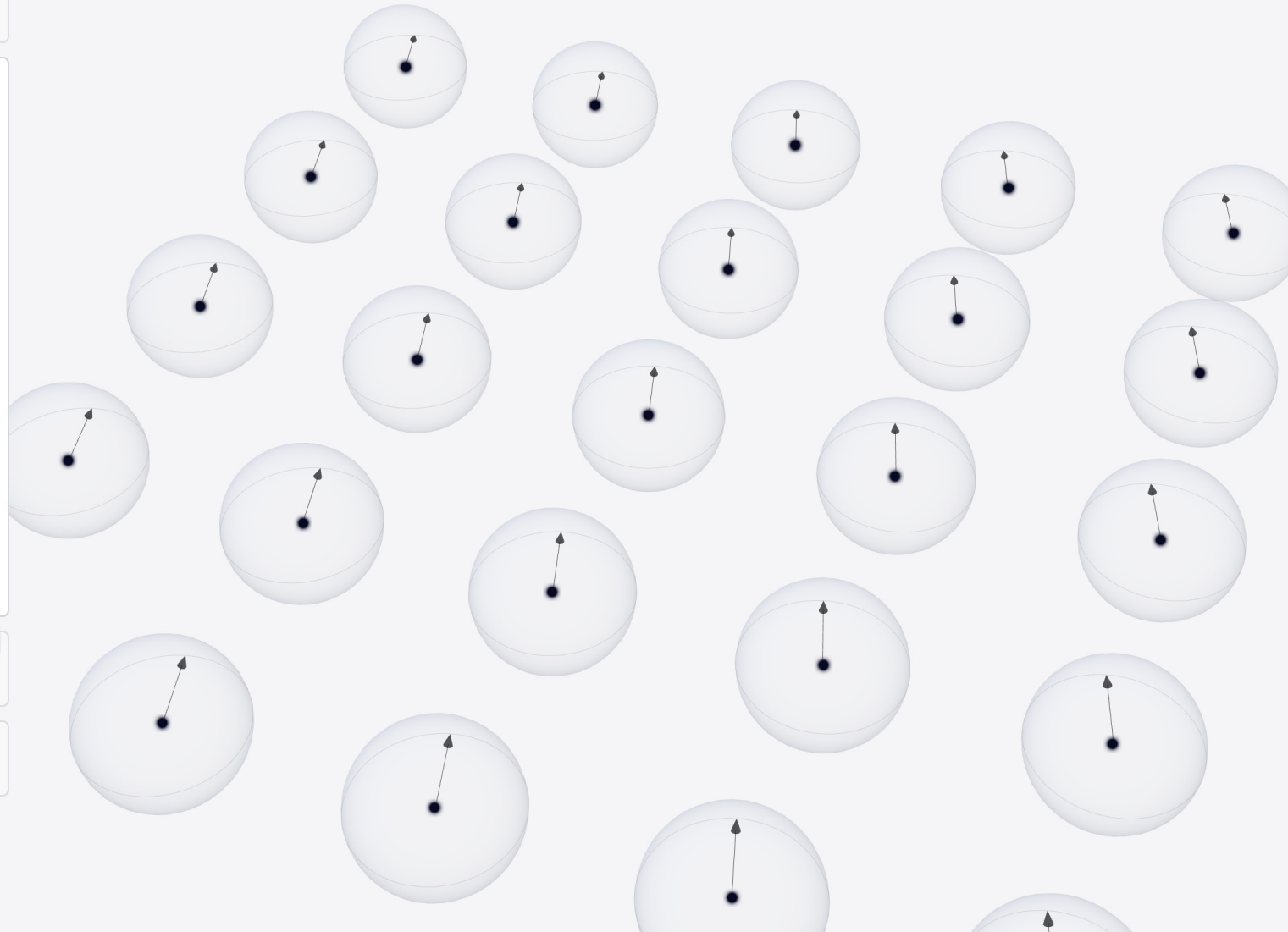
Tens of seconds is an eternity when a gate takes a fraction of a microsecond [4]. Lost atoms can be replaced without stopping.

40 s	qubit coherence, strontium [1]
23 min	atom lifetime in a tweezer [2]
2 h+	continuous run, 3,000 qubits [3]

[1] Barnes et al., Nat. Commun. 13, 2779 (2022).
[2] Manetsch et al., Nature 647, 60 (2025).
[3] Chiu et al., Nature 646, 1075 (2025).
[4] Evered et al., Nature 622, 268 (2023).

03 Flexible

04 Scalable



Why we bet on neutral atoms.

01 Identical

02 Coherent

03 FLEXIBLE

Traps made of light.

Move whole groups of atoms at once. A group can **encode one logical qubit**, and sliding two groups together entangles them in a single step [1]. All at room temperature.

48

logical qubits,
entangled by moving
atom blocks [1]

[1] Bluvstein et al., Nature 626, 58 (2024).



04 Scalable

Why we bet on neutral atoms.

01 Identical

02 Coherent

03 Flexible

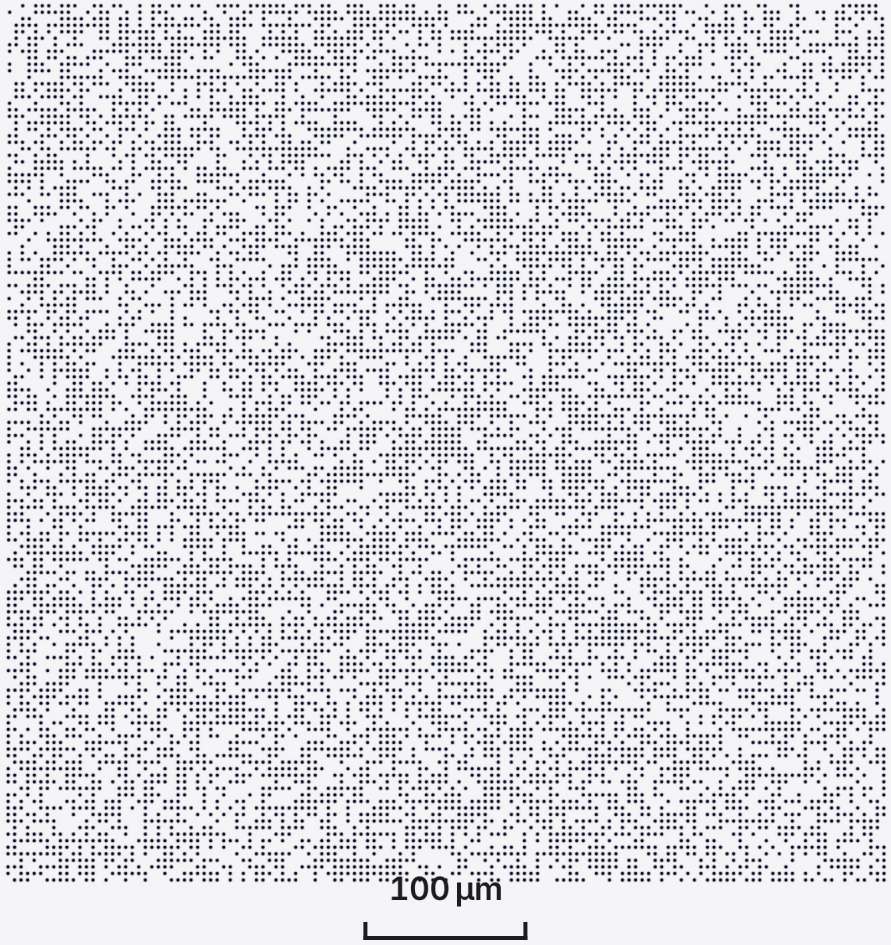
04 SCALABLE

Bigger arrays.

Every error-corrected logical qubit is built from many physical ones: about two dozen with the newest codes [2], hundreds with the standard surface code [3]. So **bigger really is better**.

11,022
atoms, loaded at random, not yet qubits [1]

18,225
optical tweezers in one array [1]

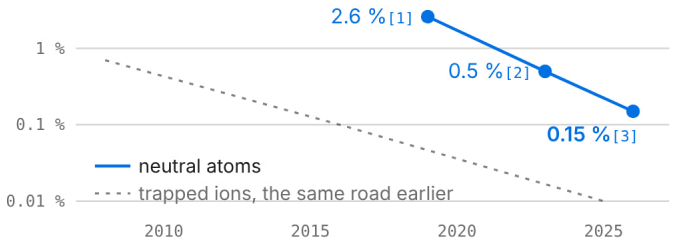


[1] Wang et al., arXiv:2606.02715 (2026, preprint).
[2] Bravyi et al., Nature 627, 778 (2024).
[3] Fowler et al., Phys. Rev. A 86, 032324 (2012).

The open problems.

01 Gate fidelity

Error per two-qubit gate, falling year by year.



Rydberg decay	→ more laser power
laser noise	→ filter cavities
uneven beams	→ beam shaping
hidden errors	→ errors that flag themselves[4, 5]
qubit overhead	→ better gates, or more atoms

[1] Levine et al., PRL 123, 170503 (2019)
[2] Evered et al., Nature 622, 268 (2023)
[3] Evered et al., arXiv:2604.25987 (2026)
[4] Wu et al., Nat. Commun. 13, 4657 (2022)
[5] Scholl et al., Nature 622, 273 (2023): erasure conversion with strontium
Trapped ions: Benhelm et al., Nat. Phys. 4, 463 (2008); Ballance et al., PRL 117, 060504 (2016); IonQ / Oxford Ionics, arXiv:2510.17286 (2025)



The open problems.

Rydberg decay	→ more laser power
laser noise	→ filter cavities
uneven beams	→ beam shaping
hidden errors	→ errors that flag themselves
qubit overhead	→ better gates, or more atoms

02 Cycle time

270 ns[1]	~200 µs[1]	~1 ms[1]
a gate	a move	a readout

moving atoms	→ deeper traps
imaging	→ better optics, cameras[2]
mid-circuit readout	→ separate zones
reloading	→ continuous reloading[3]
slow rounds	→ parallel gates[1]

[1] Bluvstein et al., Nature 626, 58 (2024)
[2] Muzi Falconi et al., arXiv:2507.01011 (2025)
[3] Chiu et al., Nature 646, 1075 (2025)



The open problems.

uneven beams	→	beam shaping
hidden errors	→	errors that flag themselves
qubit overhead	→	better gates, or more atoms
moving atoms	→	deeper traps
imaging	→	better optics, cameras
mid-circuit readout	→	separate zones
reloading	→	continuous reloading
slow rounds	→	parallel gates

03 Atom loss

seconds to minutes[1]

before an atom is lost from its trap

background gas	→	better vacuum
untrapped during gates	→	flag the loss[2]
heating	→	continuous reloading[3]

[1] Manetsch et al., Nature 647, 60 (2025)
[2] Wu et al., Nat. Commun. 13, 4657 (2022)
[3] Chiu et al., Nature 646, 1075 (2025)



The open problems.

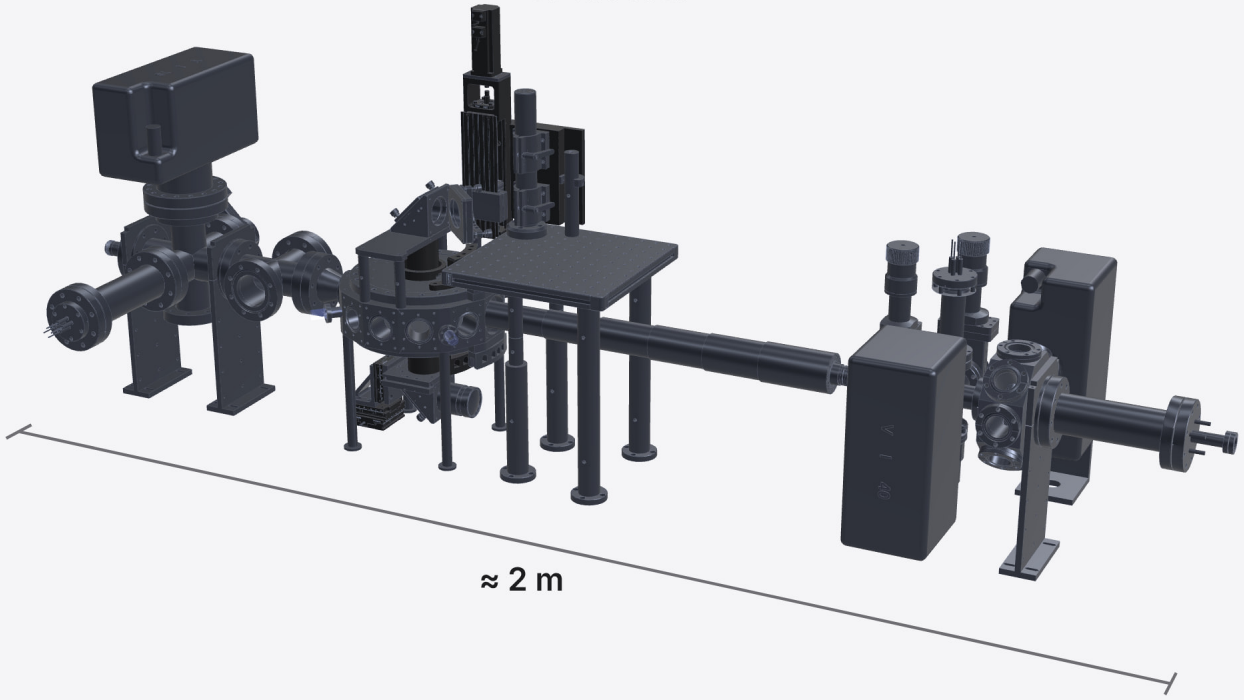
Rydberg decay	→ more laser power
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background gas	→ better vacuum
untrapped during gates	→ flag the loss
heating	→ continuous reloading

Every one of these is an engineering lever, not a missing law of physics.



This is what it takes.

The cold-atom machine at the Jožef Stefan Institute in Ljubljana: an oven, a Zeeman slower, a vacuum chamber, and tables full of lasers.



CAD model of the caesium setup at IJS, Ljubljana. The atom array is drawn at its real size at the centre of the chamber.

Built and run in Ljubljana.

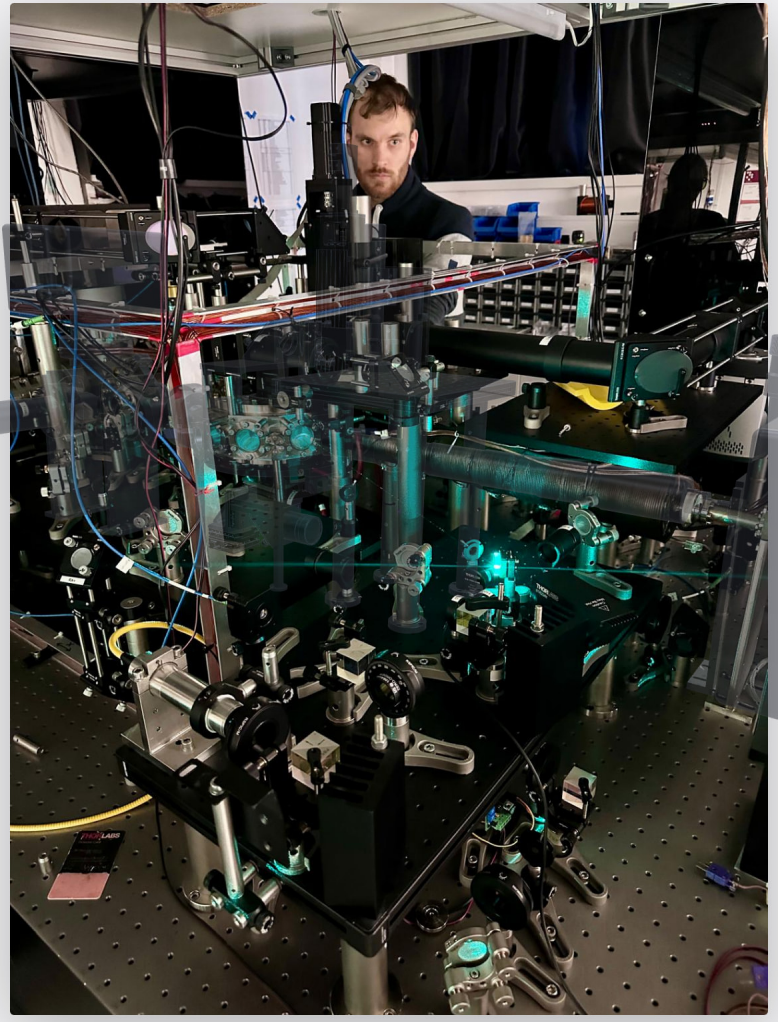
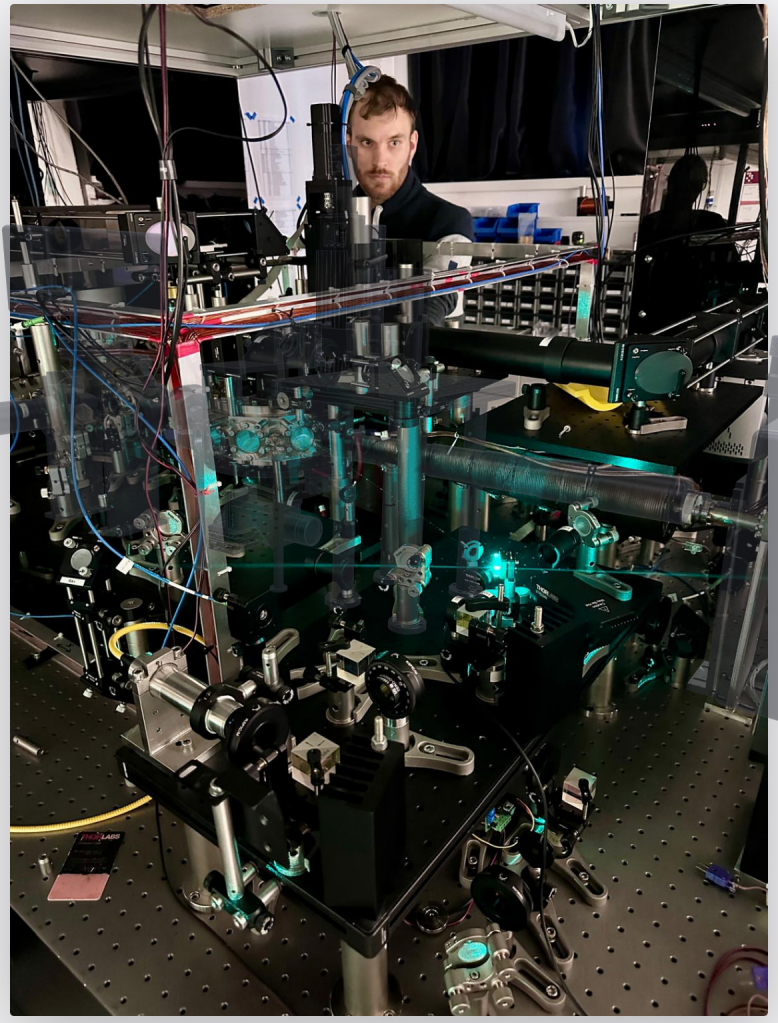
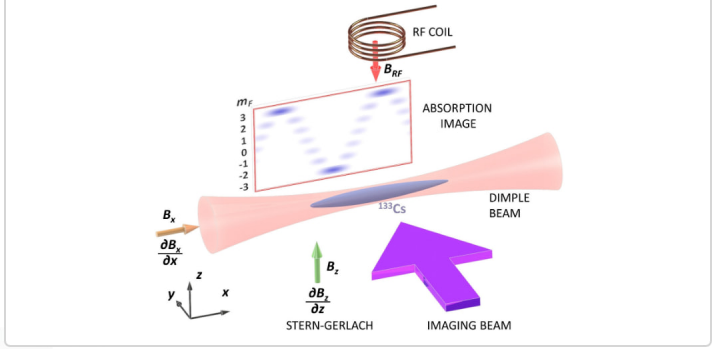


Photo: the setup at the Jožef Stefan Institute, Ljubljana, with the CAD model lined up behind it. Images: Jožef Stefan Institute.

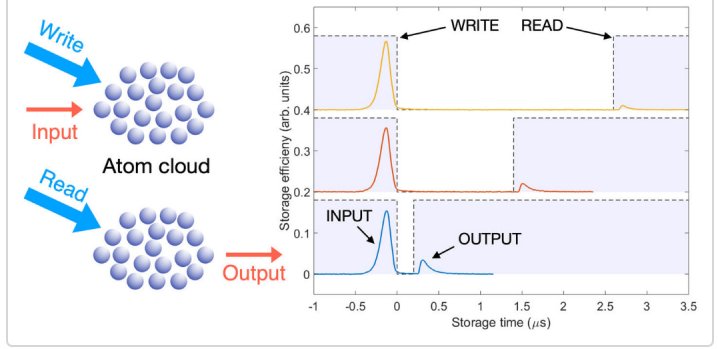
Built and run in Ljubljana.





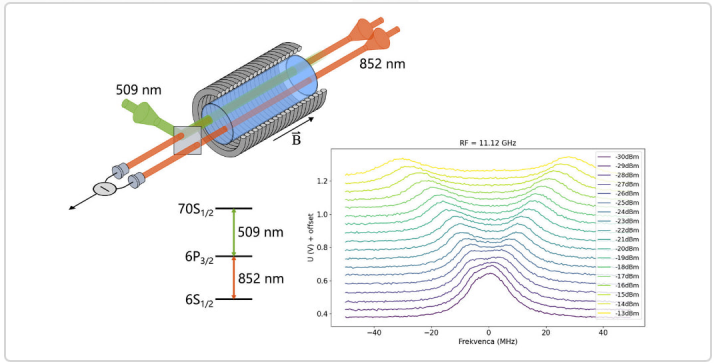
Magnetic gradiometry with cold caesium

Gosar et al., Phys. Rev. A 103, 022611 (2021)



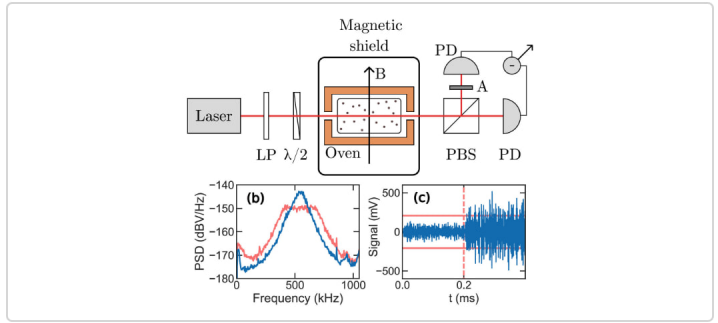
Storing light in a cold atom cloud

Gosar et al., Phys. Rev. A 108, 032618 (2023)



Detecting microwaves with Rydberg atoms

Pirman et al., submitted



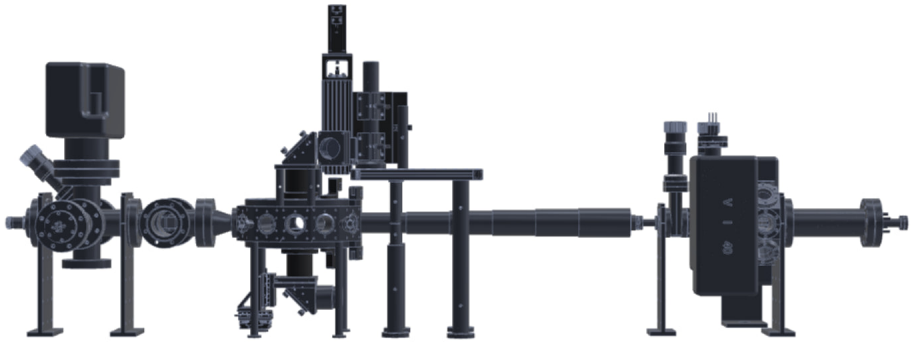
Quantum random numbers from atomic spin noise

Koterle et al., EPJ Quantum Technol. 11, 11 (2024)

Images: Jožef Stefan Institute, Ljubljana.

Big, heavy, and a lottery.

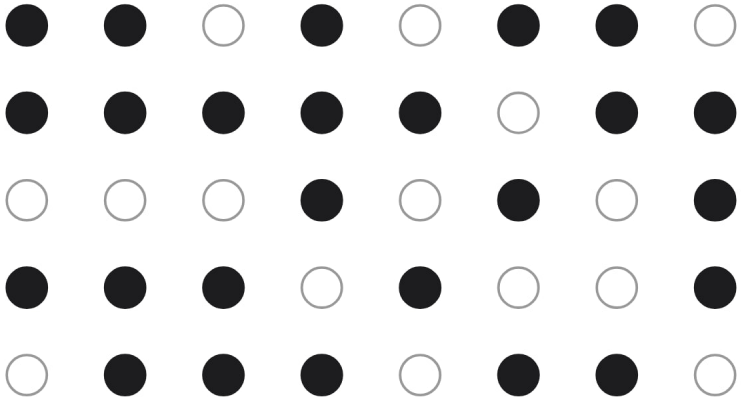
01 Big and heavy



≈ 2 m

Two metres of vacuum, coils and optics, on tables full of lasers.

02 A lottery



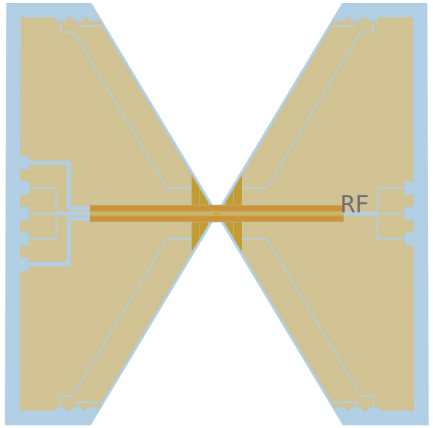
Each tweezer catches an atom about half the time[1].

[1] Schlosser et al., Nature 411, 1024 (2001).

From a room to a chip.

At Atom Quantum Labs we want to take this machine and make it small,

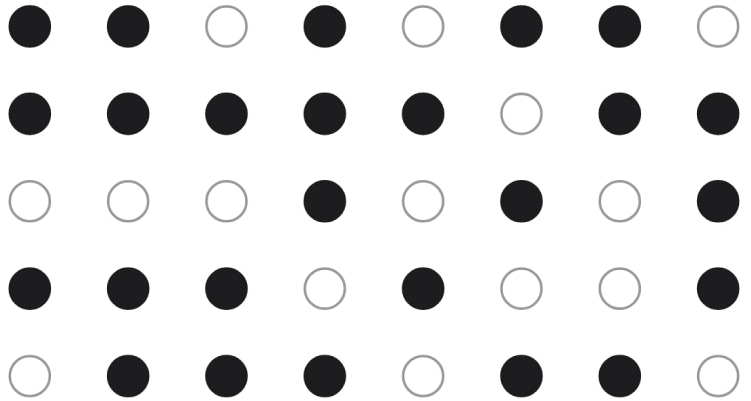
01 On a chip



one chip

No oven, no slower: an ion-trap chip, with a port in the middle for the tweezer.

02 A lottery



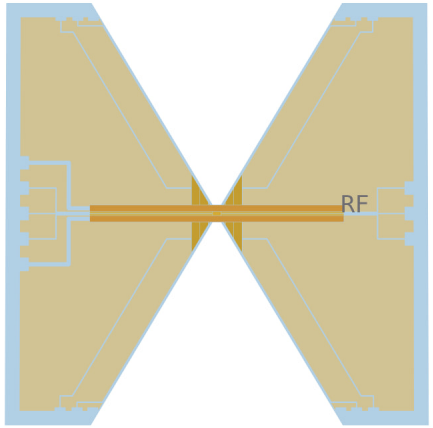
Each tweezer catches an atom about half the time[1].

[1] Schlosser et al., Nature 411, 1024 (2001).

From a room to a chip.

and replace the lottery with a factory. The route goes through ions.

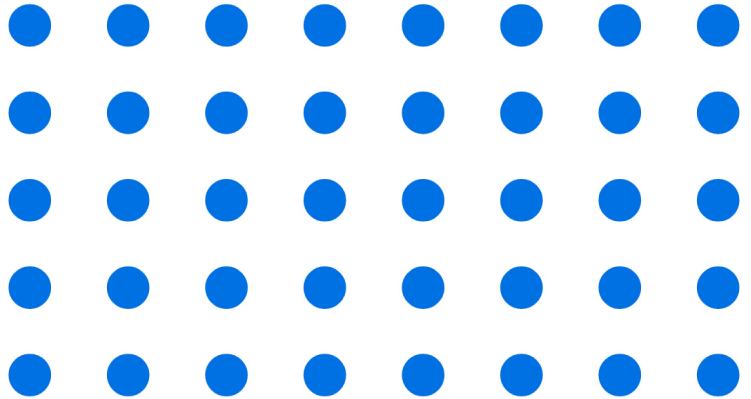
01 On a chip



one chip

No oven, no slower: an ion-trap chip, with a port in the middle for the tweezer.

02 On demand

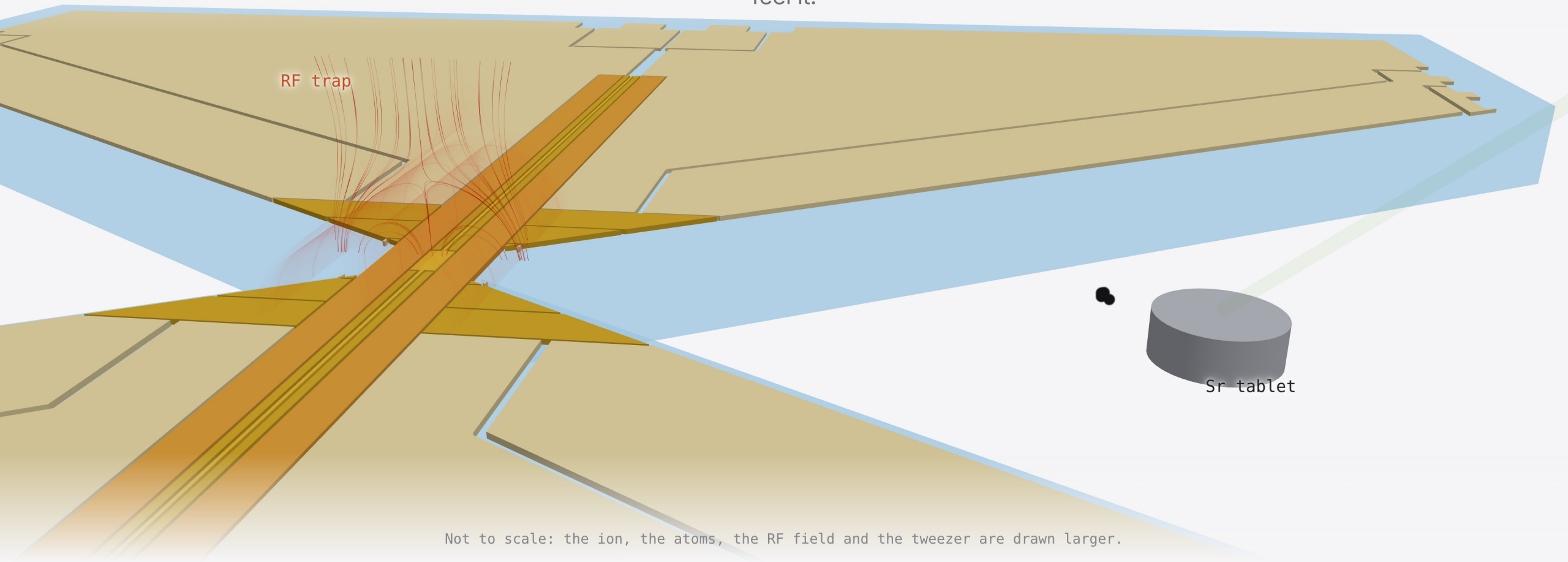


One atom at a time, into every tweezer.

[1] Schlosser et al., Nature 411, 1024 (2001).

Ablate.

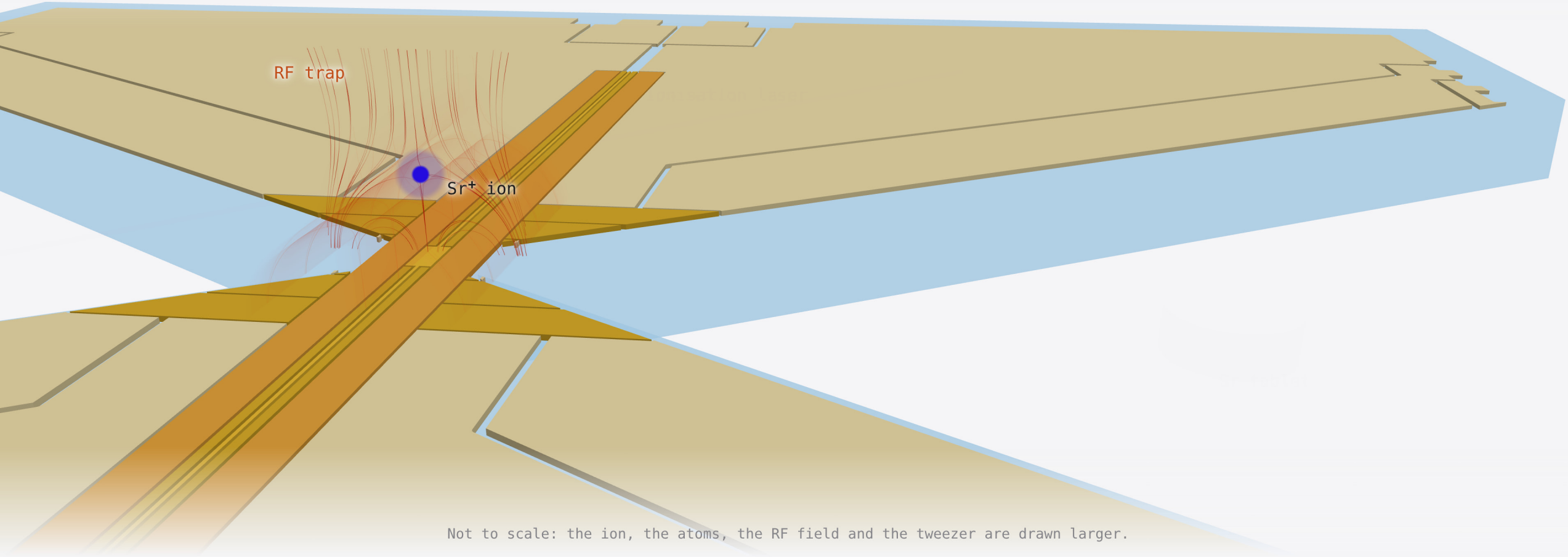
A short laser pulse hits a strontium tablet and knocks out a puff of atoms. They fly straight through the chip's RF trap: neutral atoms do not feel it.



Not to scale: the ion, the atoms, the RF field and the tweezer are drawn larger.

Ionise.

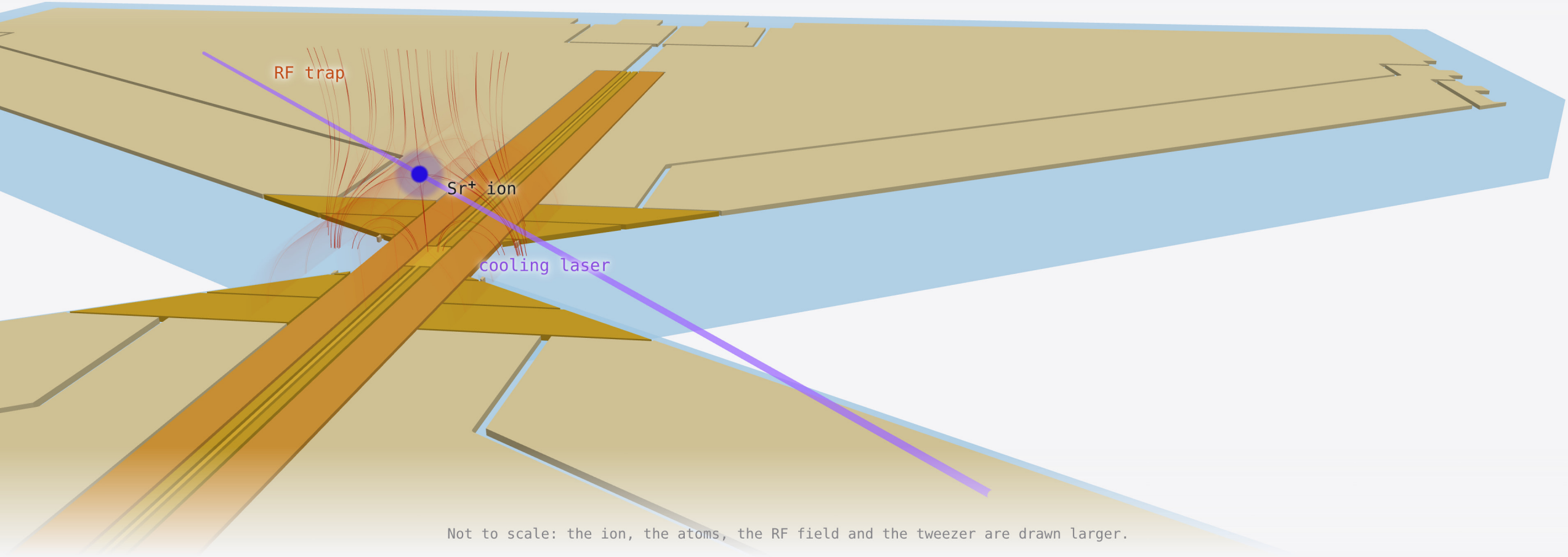
A laser tuned to strontium takes an electron from the atom crossing the centre. Now charged, it is caught by the trap, and the ablation stops.



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Cool.

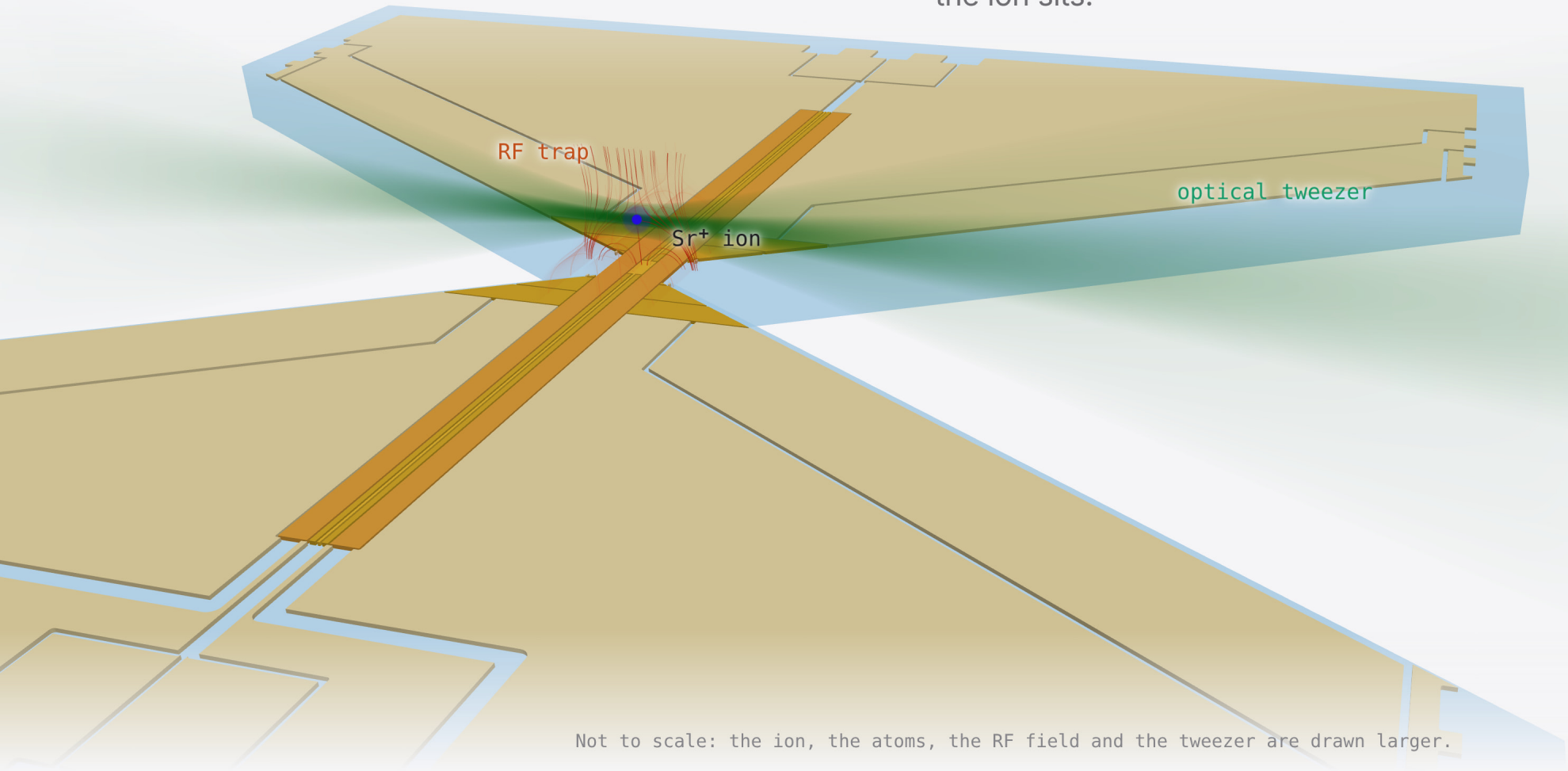
A second laser slows the ion down until it sits still at the centre of the trap. Exactly one, counted on a camera.



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Tweezer.

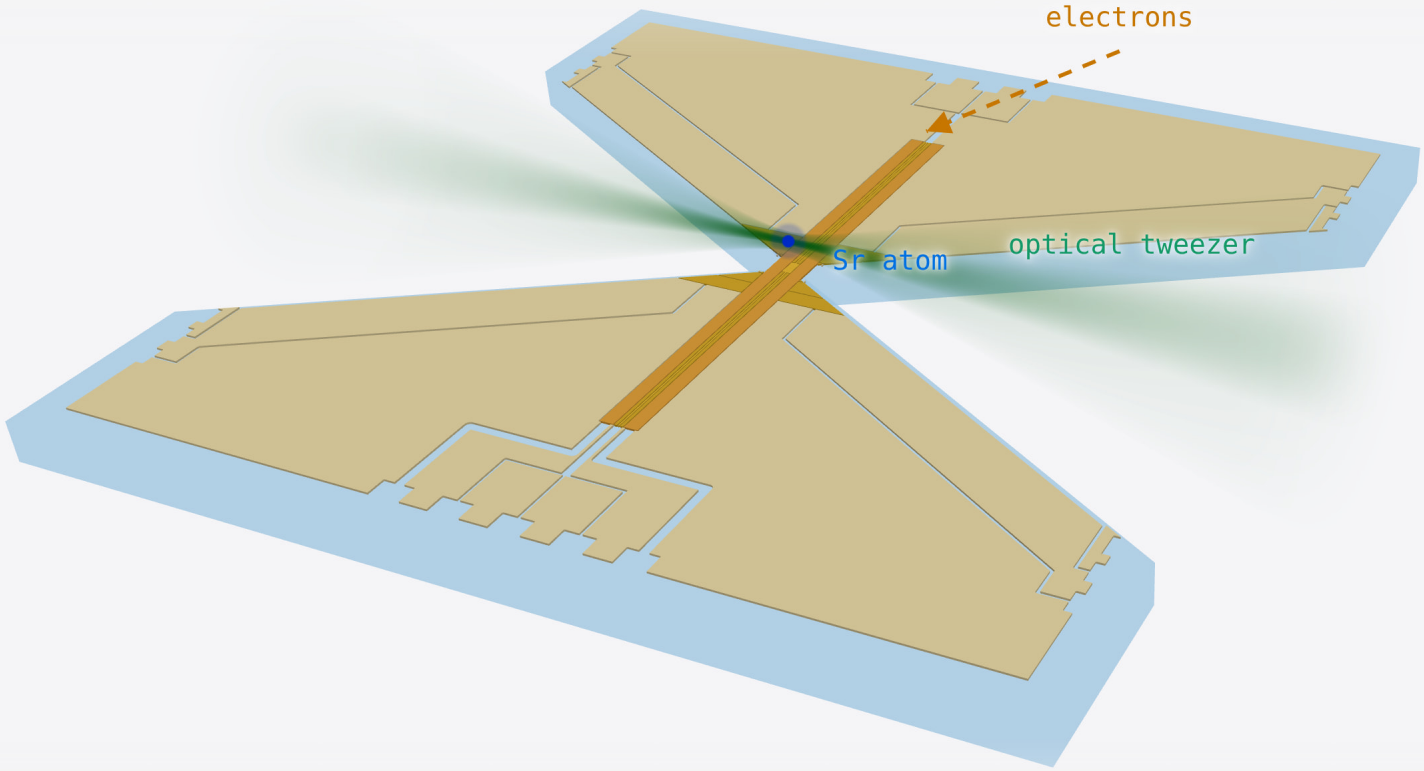
The optical tweezer comes up through the port in the chip, right where the ion sits.



Not to scale: the ion, the atoms, the RF field and the tweezer are drawn larger.

Neutralise.

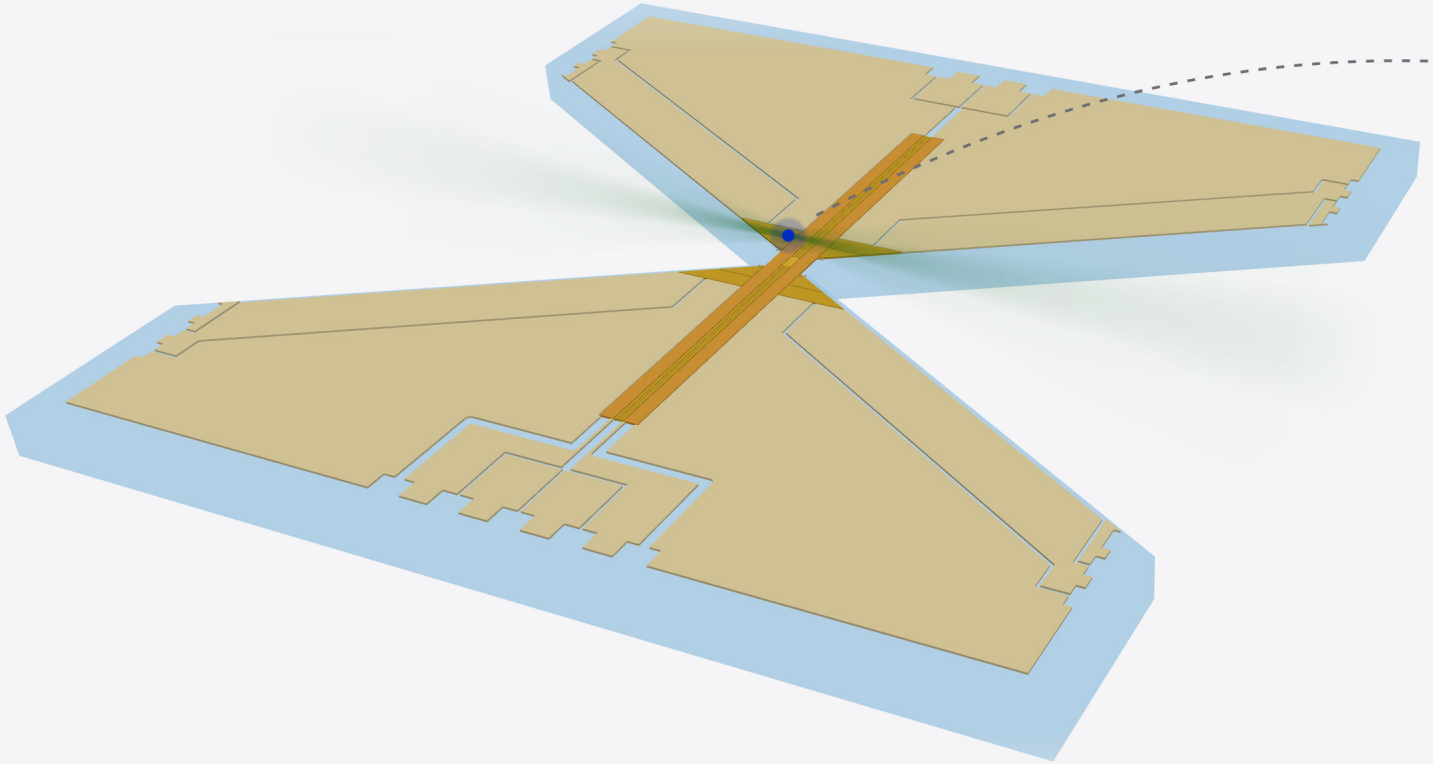
The RF is switched off: the tweezer alone holds the ion. Then one electron is sent in and caught, and it is a neutral atom again.



Not to scale: the ion, the atoms, the RF field and the tweezer are drawn larger.

On demand.

Repeat, and place the atoms one by one: a deterministic source for a neutral-atom array.



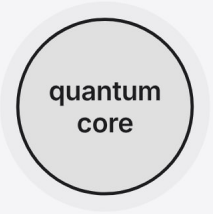


one atom at a time
no oven · no slower · no lottery

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The Road to Slovenia's First Quantum Computer

A quantum computer is not all quantum. At its centre sits a quantum core, and making that core work takes much more.



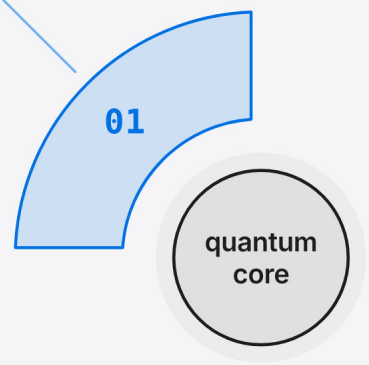
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Science & people

Internationally recognised researchers, strong theory, and labs for cold atoms and other quantum systems.

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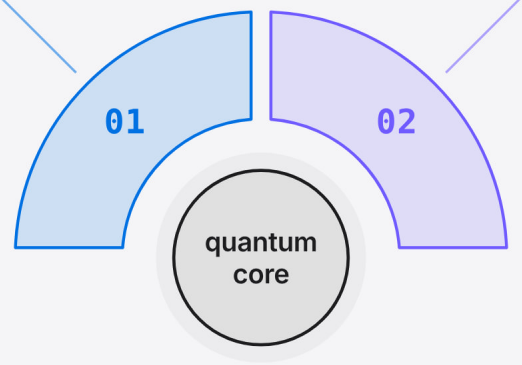
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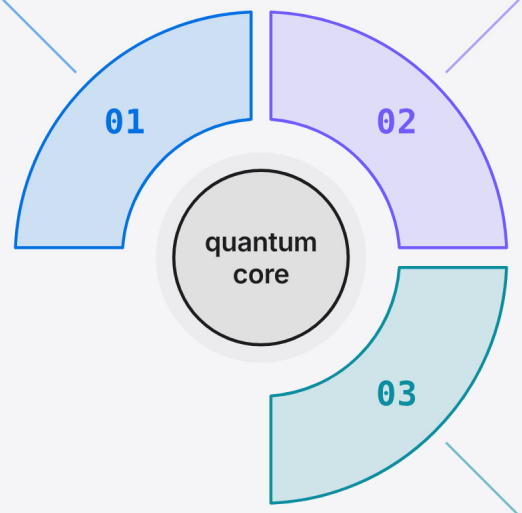
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An idea

A patented approach that we believe can address some of the fundamental problems of scaling quantum computers.

Atom Quantum Labs

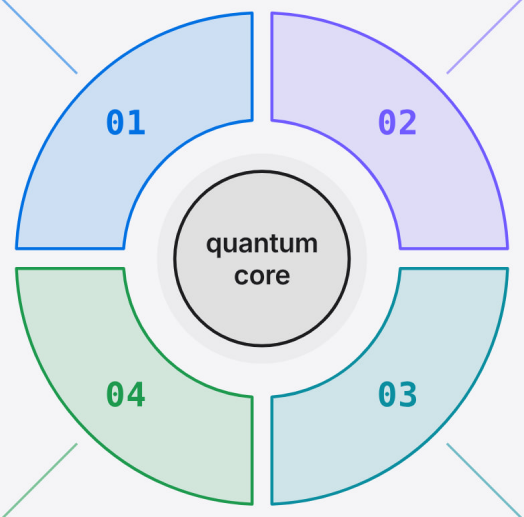
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room for Slovenian know-how and companies

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We don't need to build the whole quantum computer here. The road itself is worth taking.

Science & people

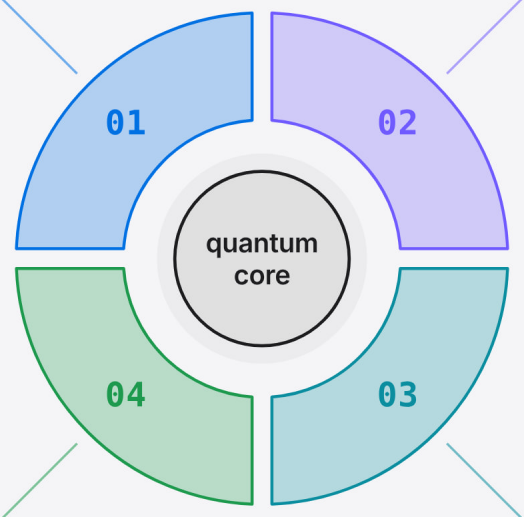
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