Atom-by-atom assembly of defect-free one-dimensional cold atom arrays

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Manuel Endres *et al.*, *Science* **354**, 1024-1027(2016). DOI:10.1126/science.aah3752

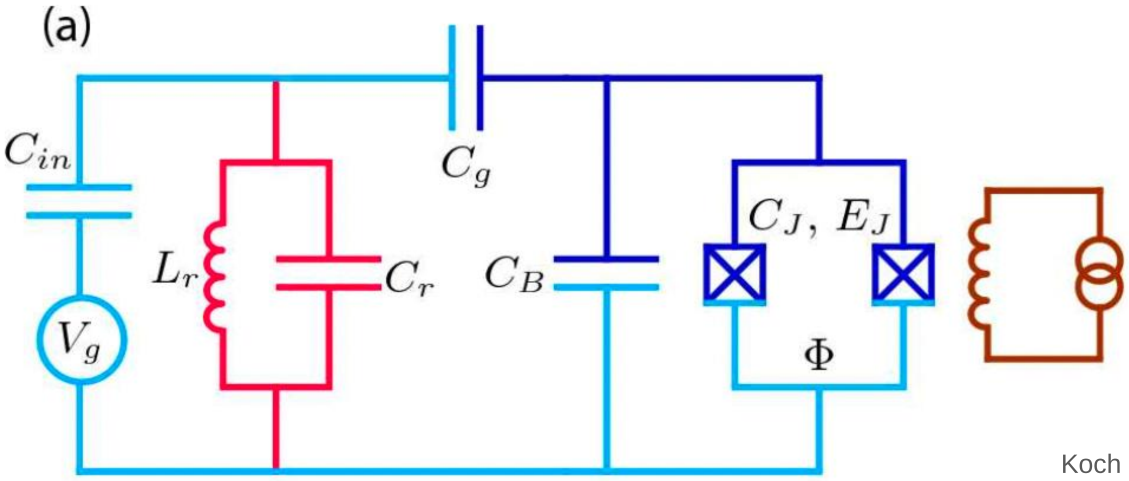
Challenges for realizing quantum computing

- Can we develop reliable, long-lasting qubits for scalable quantum computers?

- Common platforms for quantum computing
  - Transmons, flux qubits, phase qubits
  - Each suffer from various forms of sensitivity to noise

Common platforms for quantum computing

- Transmission line shunted plasma oscillation qubit (transmon)
  - Anharmonicity induced by magnetic flux across Josephson junction
  - Resistant to charge noise and relatively easy to fabricate
  - Susceptible to environmental noise



Koch et al., 2019

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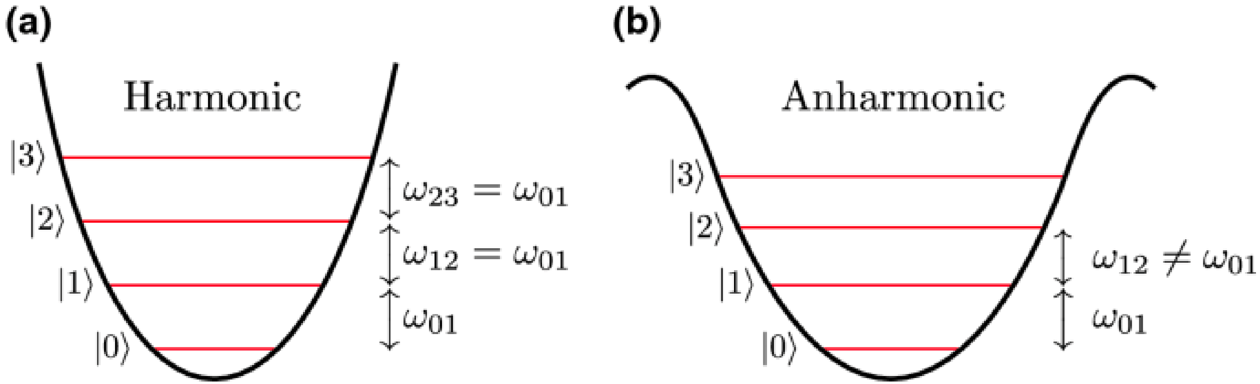
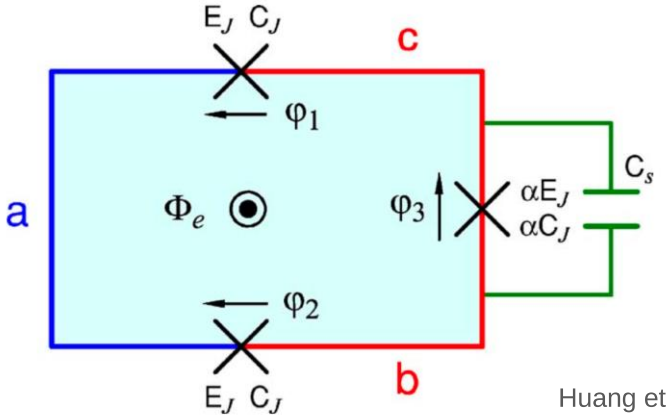
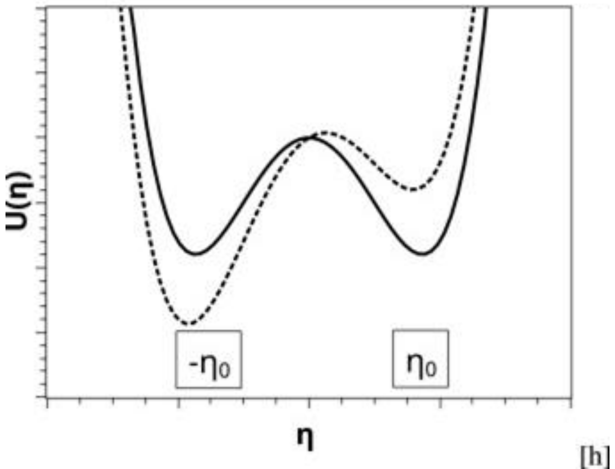


Common platforms for quantum computing, cont.

- Flux qubits
  - Persistent current in superconducting circuit separated by Josephson junctions
  - Resistant to charge noise, relatively long coherence times
  - Precision control of magnetic field flux can be challenging

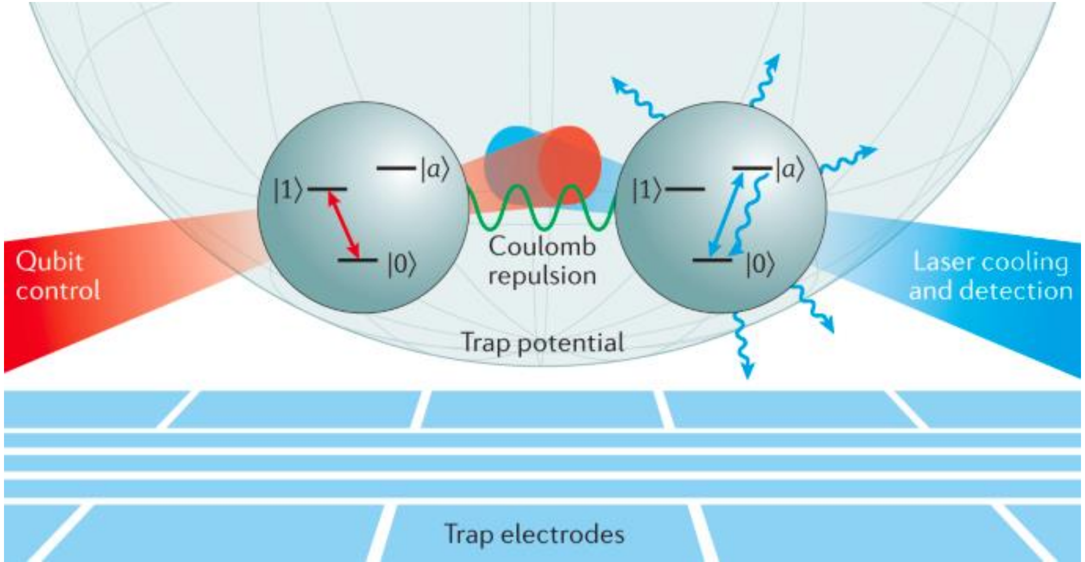


Huang et al., 2023



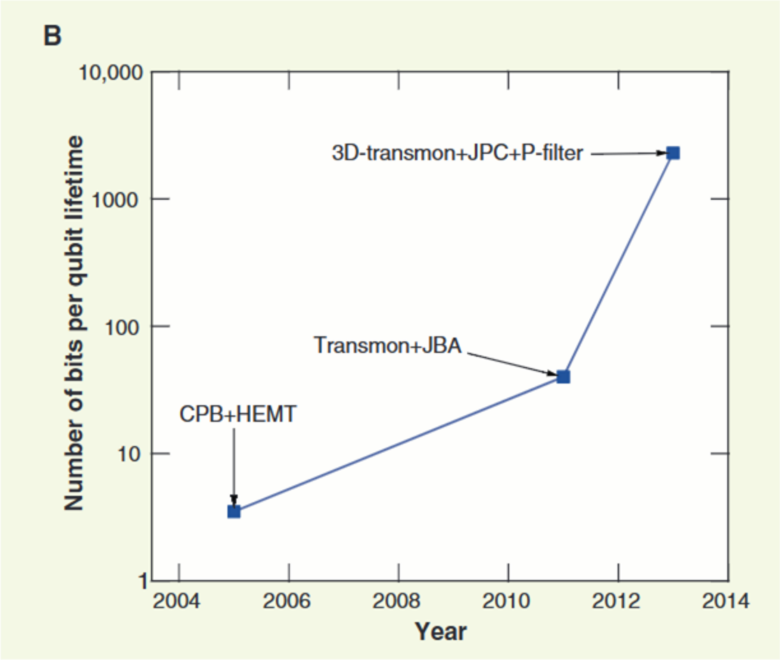
Enter trapped ion qubits

- Trapping ions in potential well formed by oscillating electric fields
- Relatively insensitive to environmental noise due to manipulation via lasers
    - Also implies long coherence times
- Defect free cold atom arrays provide reliable platform for trapped ion qubits



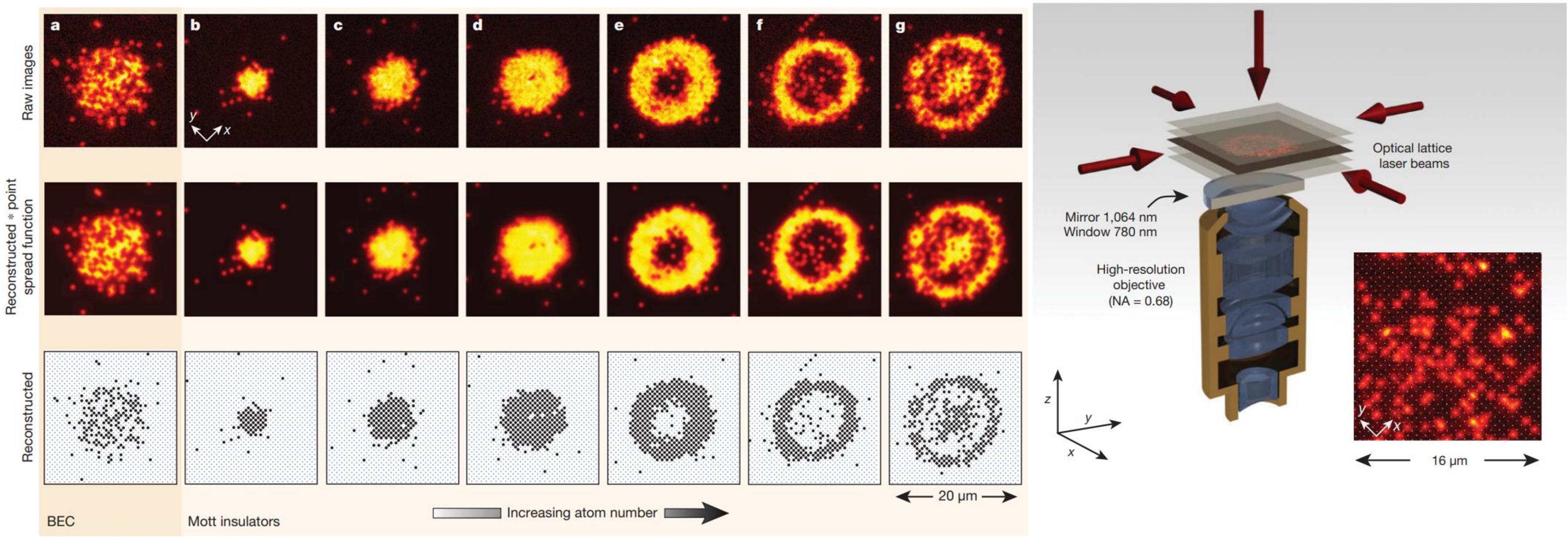
Motivations for atom-by-atom assembly

- The detection and manipulation of individual quantum particles
- Major efforts: scaling up ion-trap and superconducting platforms



M. H. Devoret, et al. Superconducting Circuits for Quantum Information: An Outlook.*Science* **339**,1169-1174(2013).

Recent-year individual particle detection and control

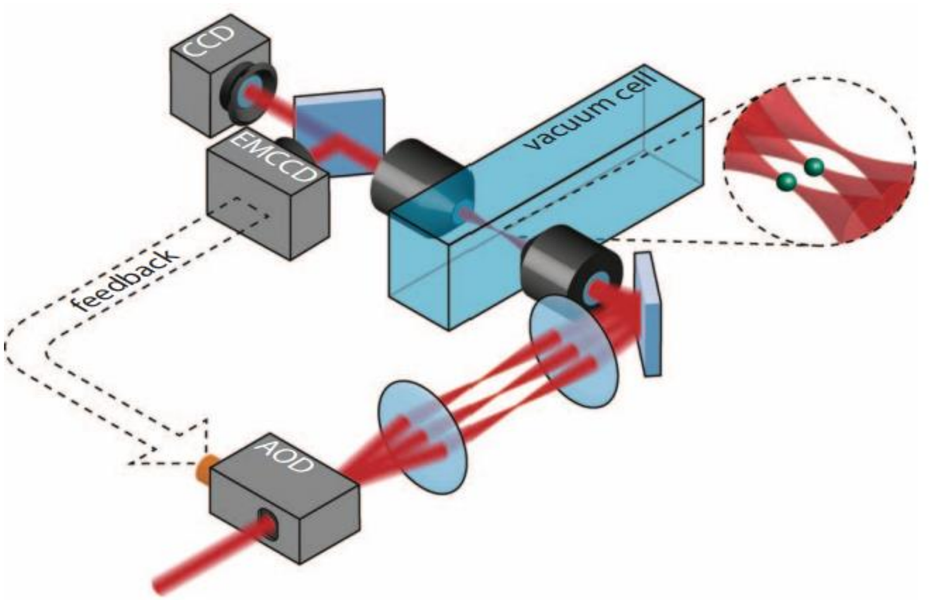


Sherson, J., Weitenberg, C., Endres, M. *et al.* *Nature* 467, 68–72 (2010)

Create deflected arrays of cold atoms

- Employ acousto-optic deflector driven by a multitone radiofrequency (RF) signal

- Form optical tweezer either empty or carrying single atom

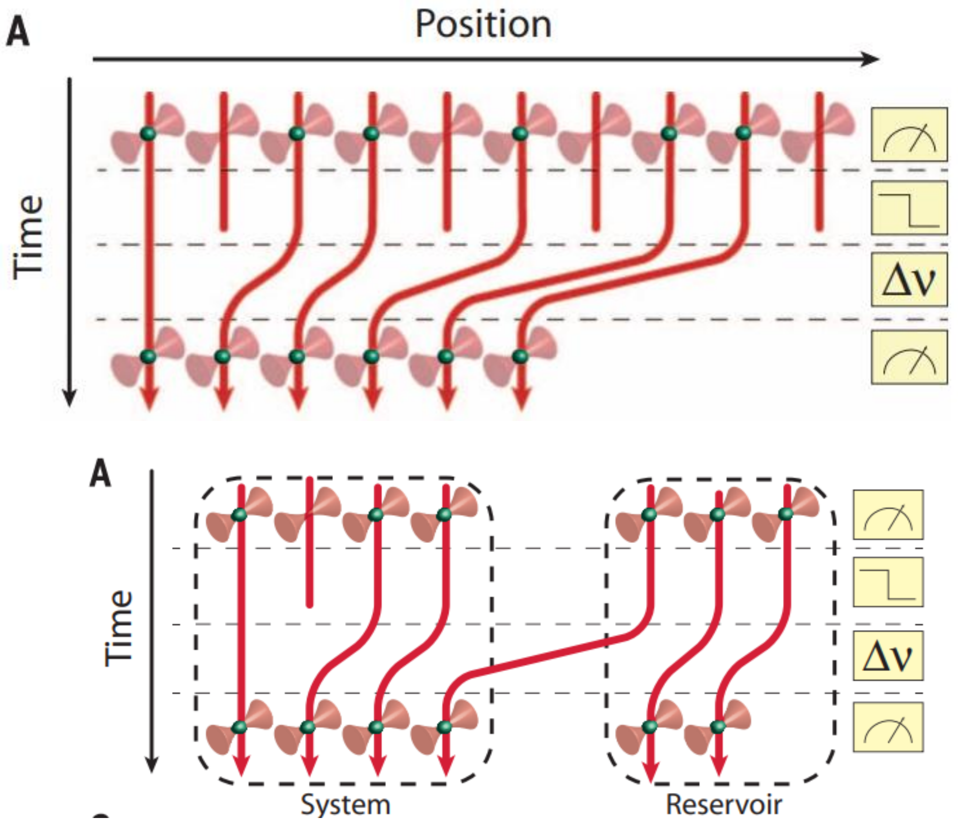


Rearrange tweezers to get defect-free arrays

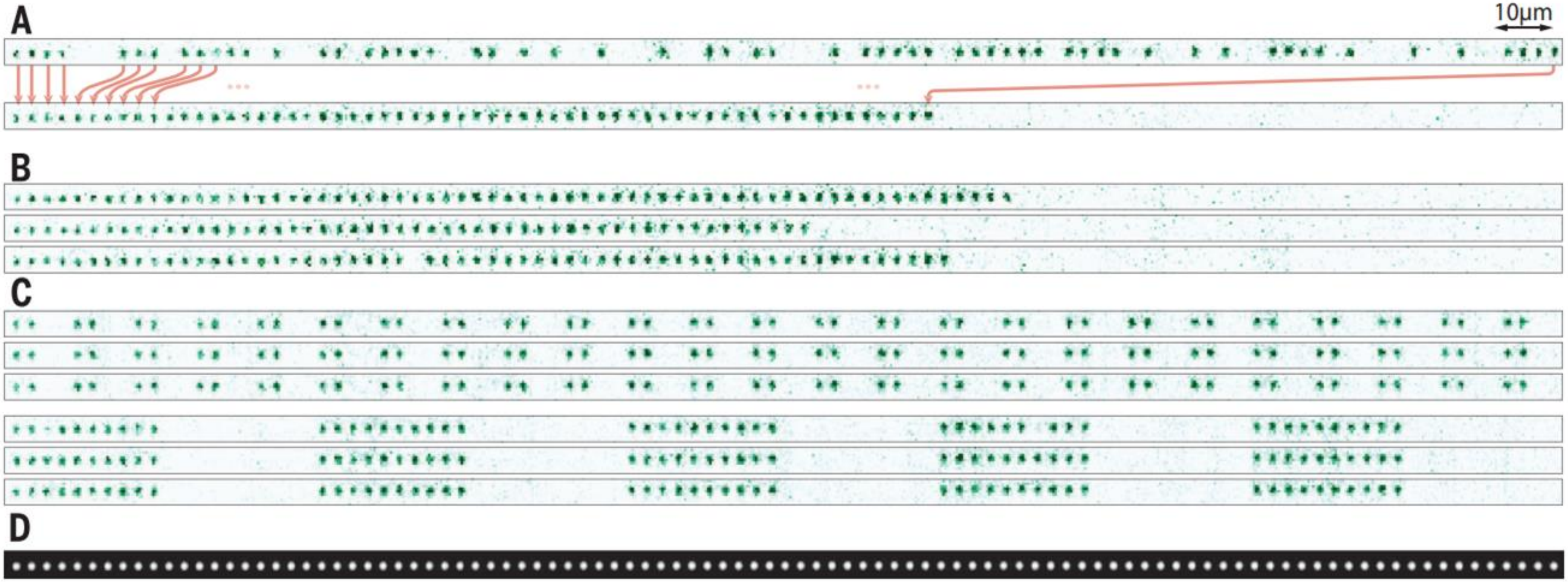
- Switch off unoccupied tweezers by setting the corresponding RF amplitudes to zero

- Move occupied tweezers to the left by sweeping the RF tones to change the deflection angles of the AOD

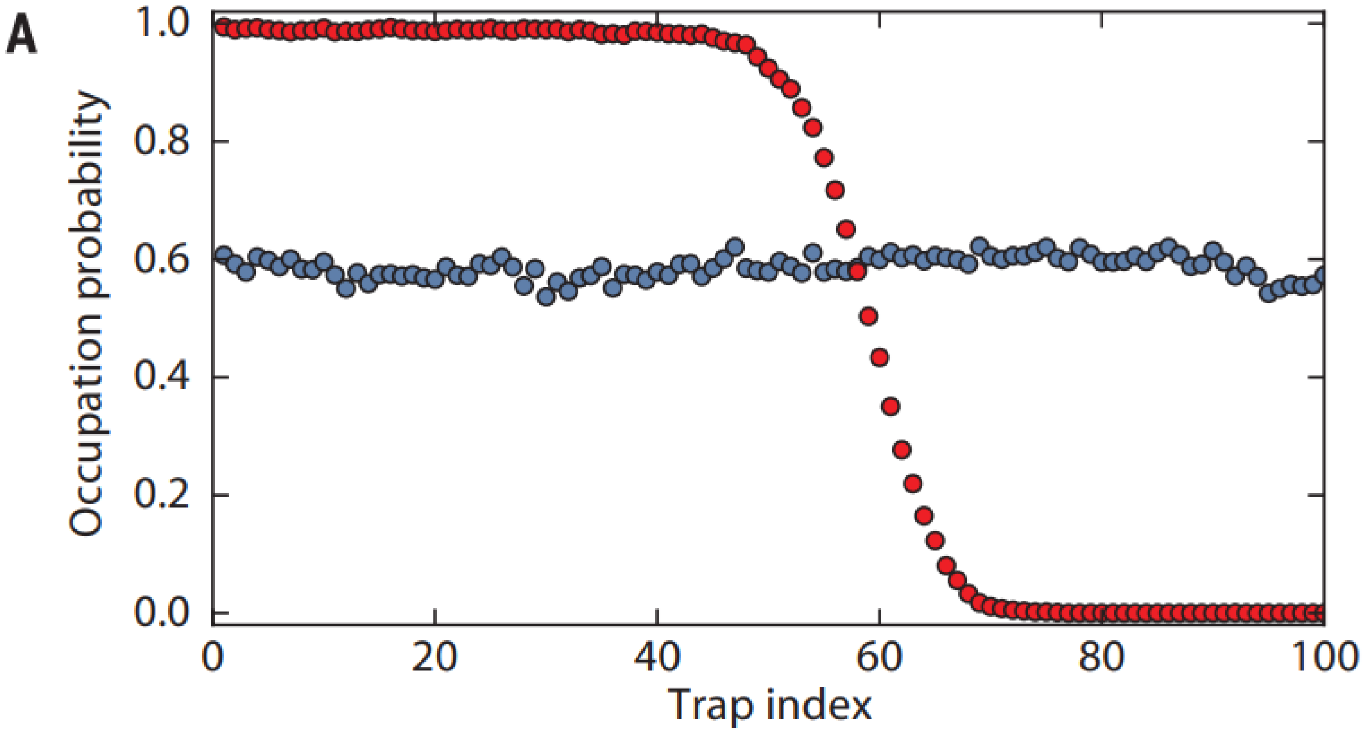
- Store surplus atoms for repetitive reloading of the array



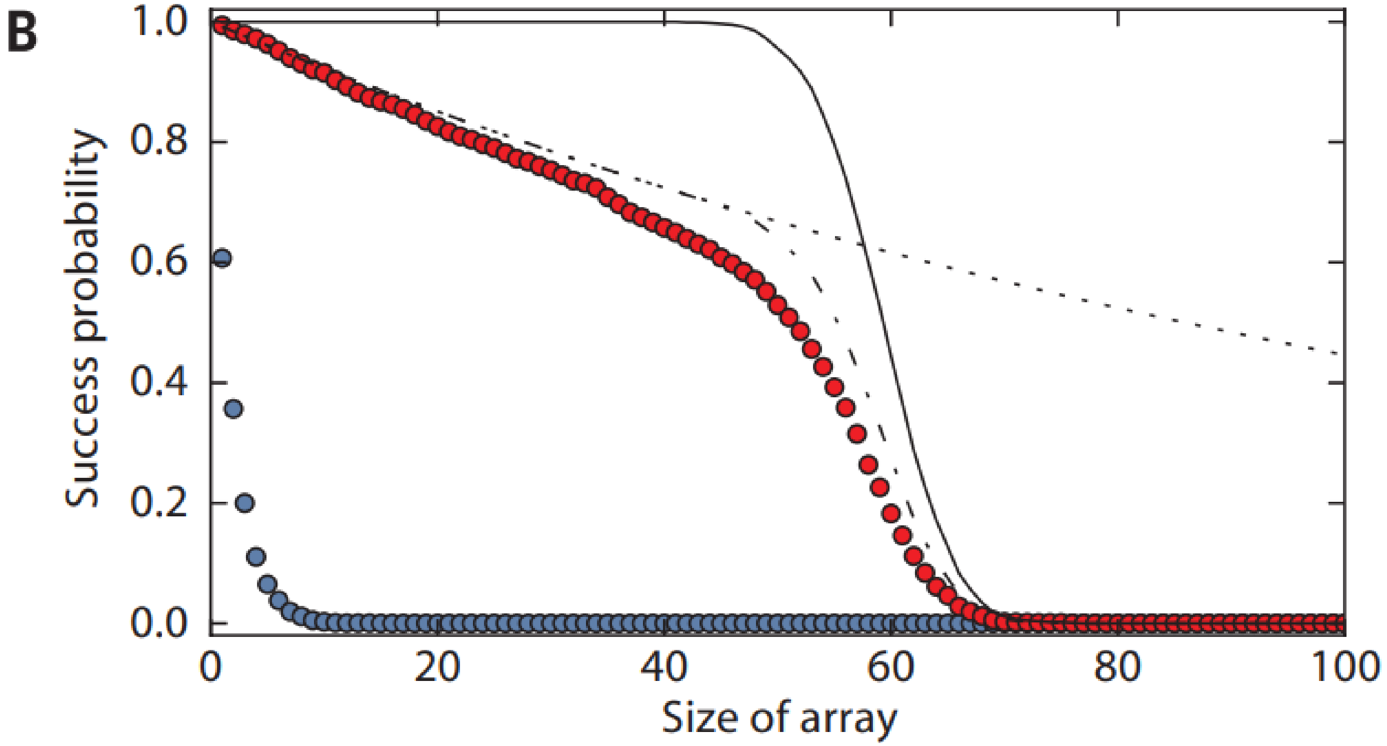
Results: configurable trapped atoms arrays



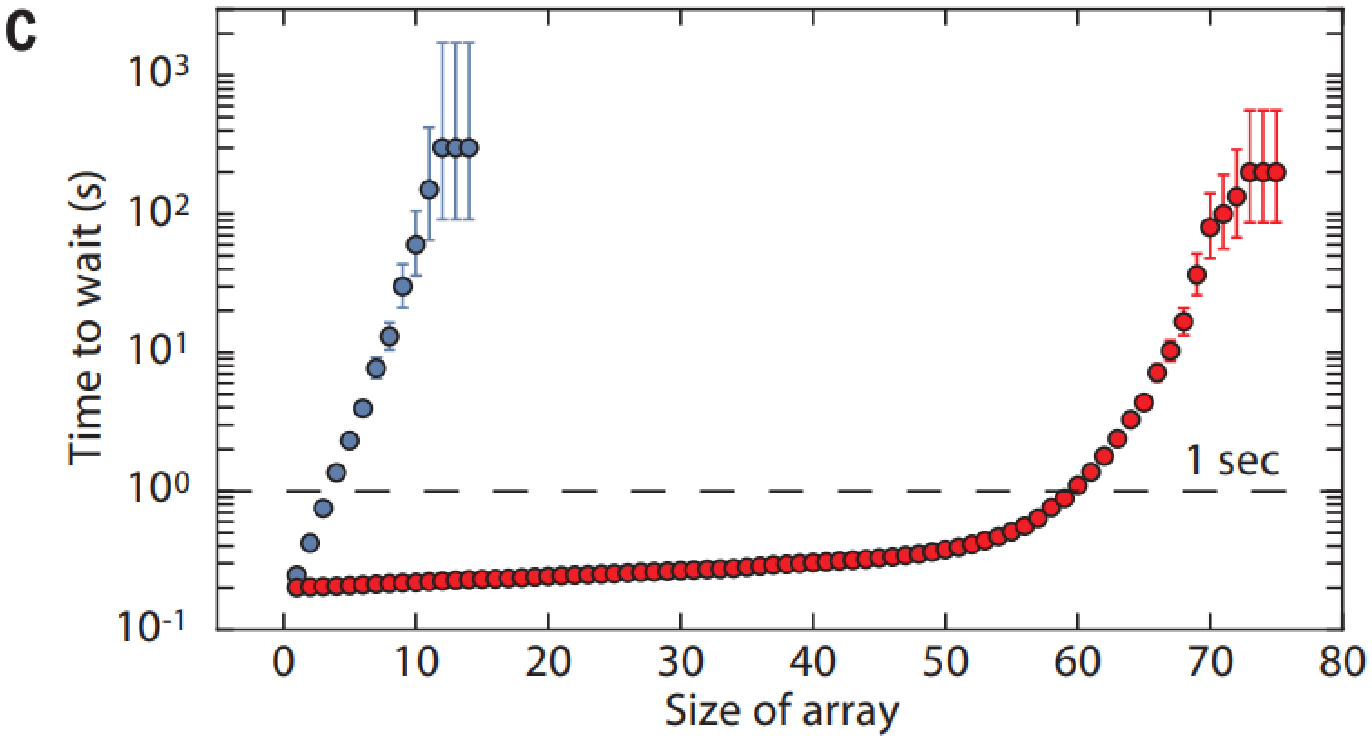
Results: array occupation before and after assembly



Results: odds of creating a perfect array with and without assembly

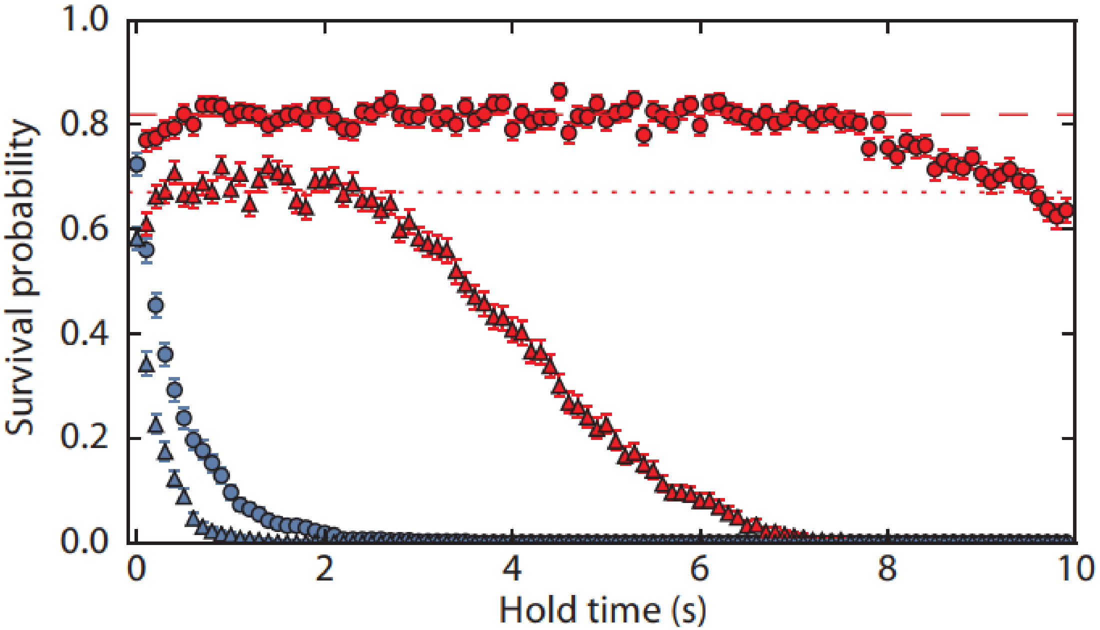


Results: time to create a perfect array with and without assembly

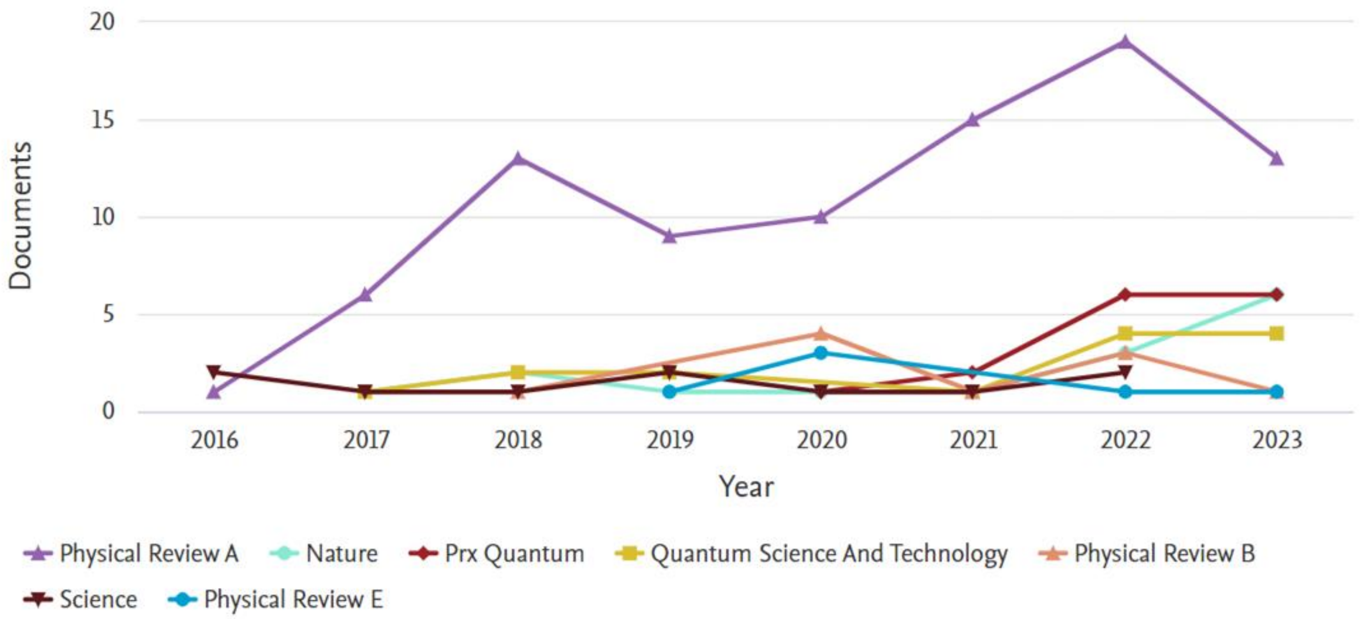


Results: array lifetimes and reloading

- Maintain a reservoir to replace lost atoms
- As long as the reservoir remains full, the probability of observing a perfect array remains roughly flat over time



Future Works
Selected Document per year per source



Outlooks

- Defect-free arbitrary **two**-dimensional atomic arrays (D. Barredo *et al.* 2016)
- Logic Quantum processor based on reconfigurable atom arrays (Bluvstein *et al.* 23)

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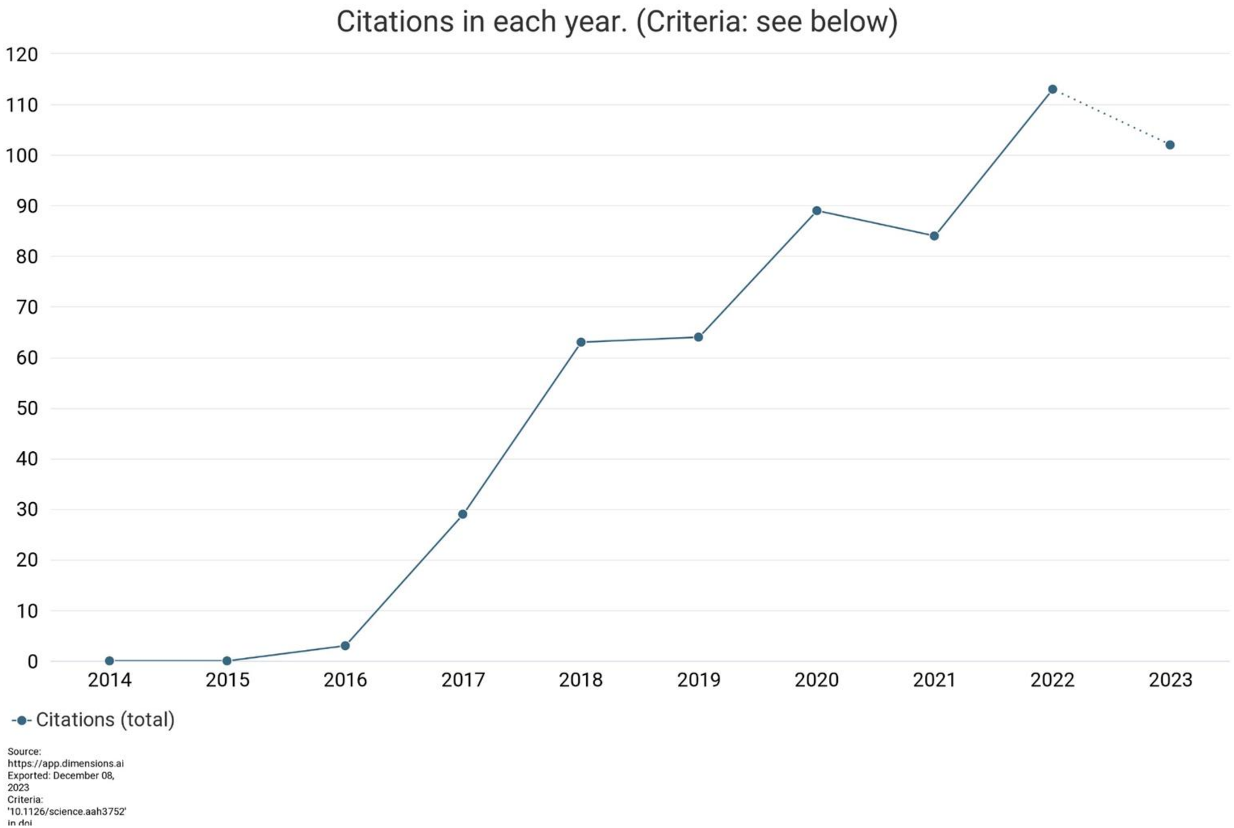
Multiquibit experiments and studies of quantum many-body effects:

- **High-Fidelity Multiqubit Gates** (H. Levine *et al.* 2019)
- **Quantum technologies** (C. Adams *et al.* 2019)
- **Quantum phases of matter** on quantum simulators (Ebadi *et al.* 20; Bernien *et al.* 17)
- **2D antiferromagnets** quantum simulations (P. Scholl *et al.* 2020)
- Observation of a **SPT phase of interacting bosons** (S. de Léséleuc *et al.* 2019)

Citation analysis



Contribution to the field

- Choi, Joonhee, et al. **"Preparing random states and benchmarking with many-body quantum chaos."** *Nature* 613.7944 (2023): 468-473.
- Eckner, William J., et al. **"Realizing spin squeezing with Rydberg interactions in an optical clock."** *Nature* 621.7980 (2023): 734-739.
- Ma, Shuo, et al. **"High-fidelity gates and mid-circuit erasure conversion in an atomic qubit."** *Nature* 622.7982 (2023): 279-284.
- Kumar, Aishwarya, et al. **"Quantum-enabled millimetre wave to optical transduction using neutral atoms."** *Nature* 615.7953 (2023): 614-619.

Questions?

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