A tweezer array with 6,100 highly coherent atomic qubits

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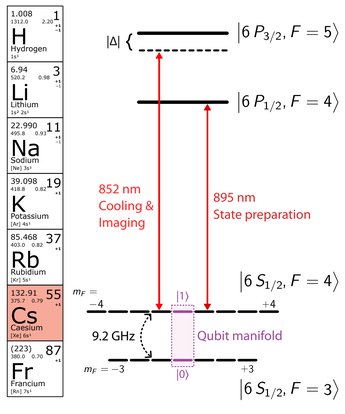
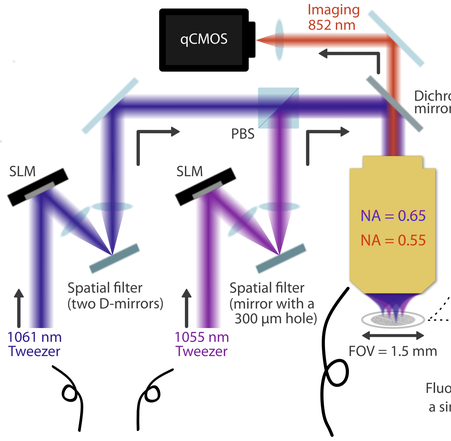
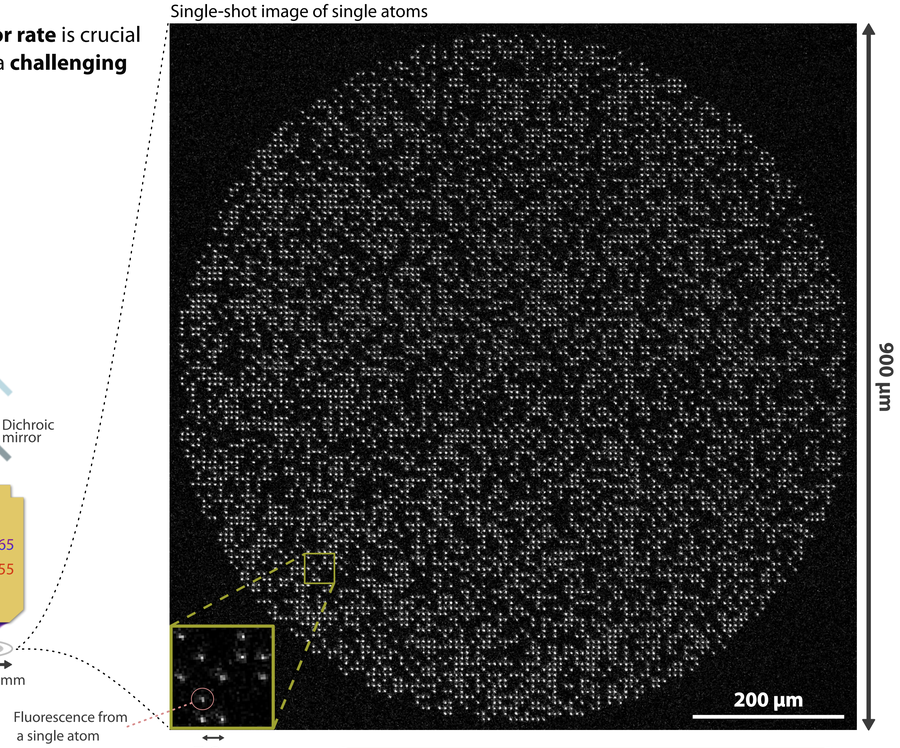
6,100 single ^{133}Cs atoms in 12,000 optical tweezers

Scaling up the fully programmable quantum system while preserving **low error rate** is crucial for quantum simulation, metrology, and computation. However, this still remains a **challenging problem** across all the platforms.

Here we demonstrate
- generation of **12,000 optical tweezers** using SLMs
- over 50% loading probability, trapping **6,100 single ^{133}Cs atoms** on average
- high imaging fidelity **> 0.9999**
- high imaging survival **> 0.99989**
- long vacuum-limited lifetime of **23 min**
- long coherence time of T_2 **= 12.6(1) s** with dynamical decoupling







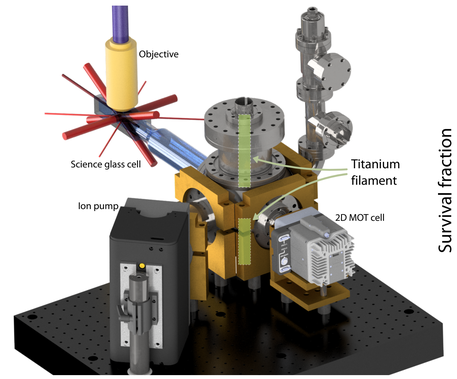
- 120 W output fiber-amplifier for each tweezer path.
(Only around 8.5 W is currently used for 1055 nm path*)
- Large numerical-aperture (NA)
- Large field-of-view (FOV)

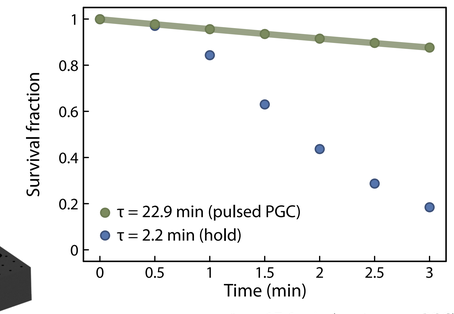
*1055 nm path makes only 4 rows of tweezers in the middle of the array

Current limitation
- Aberration caused by the heating of the objective
- Degradation of diffraction efficiency of the SLM

Long vacuum-limited lifetime

- Long trapping time is essential for large-size tweezer arrays
- Vacuum-limited lifetime of around **23 min with a room-temperature apparatus**
- 10 ms polarization-gradient cooling is applied every 2 s
- **Titanium sublimation pump** coats wide range of surface of the vacuum parts

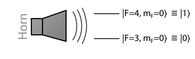


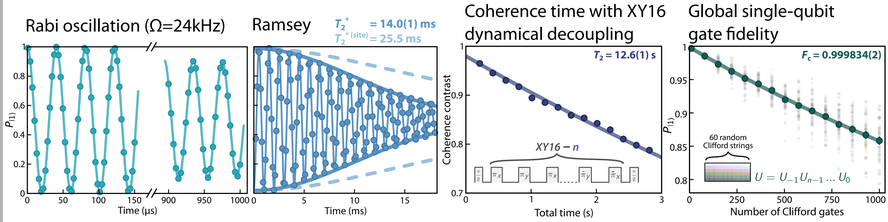


* τ = 17.6 min (continuous PGC)

Highly coherent hyperfine-qubits

- Hyperfine-qubit (6 $S_{1/2}$): $|0\rangle \equiv |F=3, m_F=0\rangle$, $|1\rangle \equiv |F=4, m_F=0\rangle$
- Global microwave single-qubit control
- T_2^* **= 14.0(1) ms** and **25.5 ms** for averaged and single-site, respectivey
- T_2 **= 12.6(1) s** with dynamical decoupling (XY16) sequence
- Long T_1 time of T_1 **= 119(1) s**, enabled by the far-detuned wavelength of the tweezer light
- Global **single-qubit gate fidelity of > 0.9998** (Randomized benchmarking)

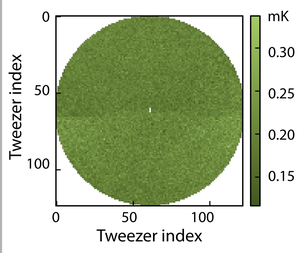




Loading single atoms

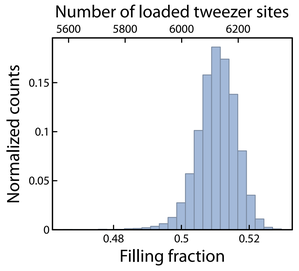
Trap depth

- Trap depth of **0.2 mK** on ave
- Std of 11% across the array



Filling fraction

- **6,100 atoms** load on ave
- Loading >50% on ave

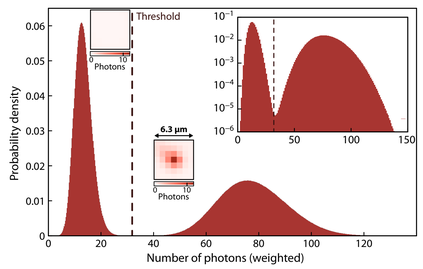


High-fidelity imaging

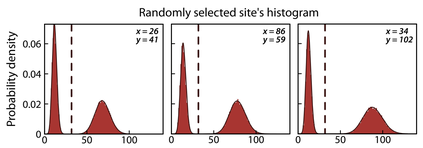
Imaging fidelity (> 0.9999)

- 80 ms imaging at 852 nm (D2-transition)
- High-fidelity distinction between 0 / 1 atom
- Uniform scattering rate (around 12 % std)
- Photon collection efficiency of 2.7% (x QE)

Site-averaged histogram

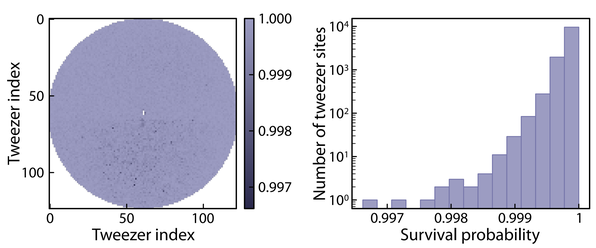


Single-site histogram

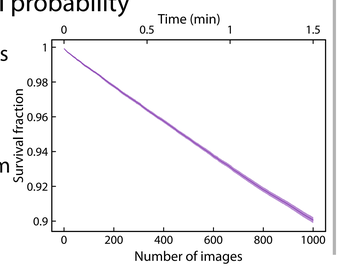


Imaging survival

Single-shot imaging survival probability
- **99.98%** survival probability on average
- High survival probability across the whole array



Repeated-imaging survival probability
- **90%** of initially-loaded atoms survives after **1000 images**
- Steady-state survival prob of **0.99989**
- Mostly limited by the vacuum lifetime



Outlook

Rearrangement

- Rearrange quadrant by quadrant
- Switching quadrants with Galvo mirror
- Estimated rearrangement time of 100ms*4

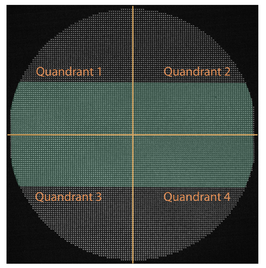
Raman single-qubit control

- Fast single-qubit control (2 MHz)
- Local single-qubit control

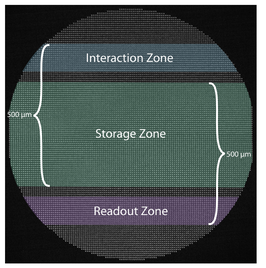
Rydberg interaction

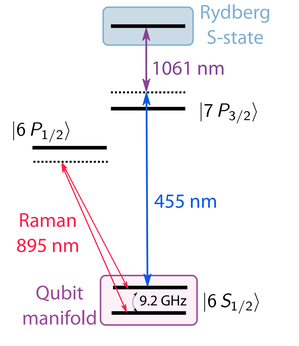
- High power fiber-amplifier (120 W) @ 1061 nm
- Effective Rabi frequency of around 5 MHz
- 58 $S_{1/2}$ with 2.5 μm spacing (Noise-free model)
  - CZ-gate fidelity of $1\text{-}10^{-5}$ (time-optimal gate)
  - Rydberg Bell state fidelity of $1\text{-}10^{-4}$

Rearrangement



Zone-scheme architecture





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