Coherent control of strontium atoms trapped in an optical lattice and applications for quantum simulations

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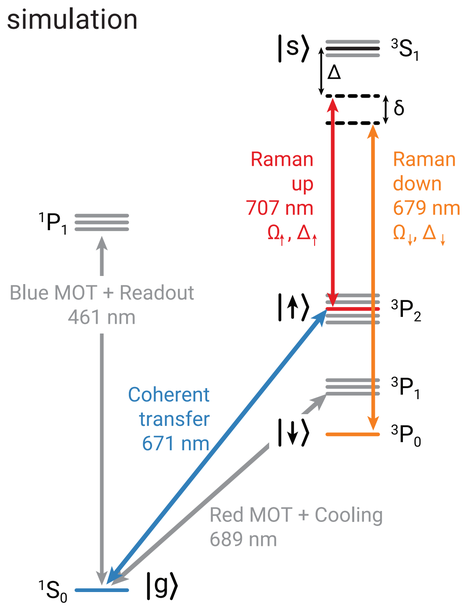
Introduction

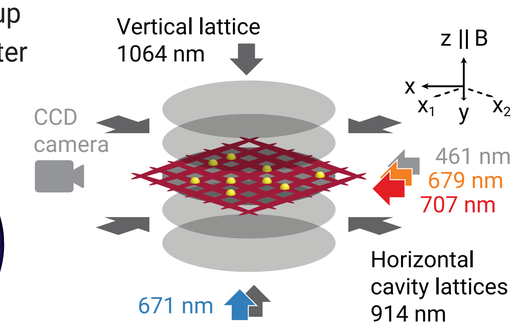
Strontium

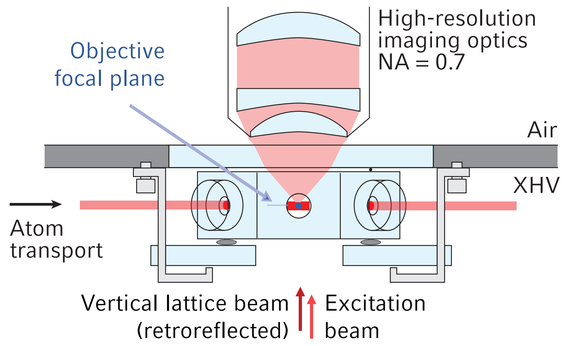
- Rich level structure
- Applications in atomic lattice clocks, quantum computing, and quantum simulation



Setup

- Crossed cavity setup
- Large mode diameter of ~1 mm

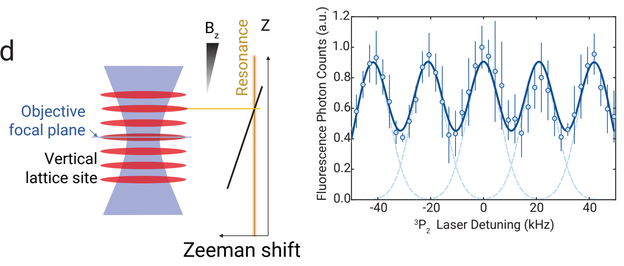




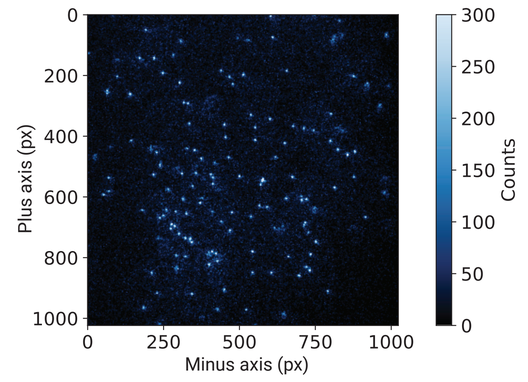
Imaging

Single-atom imaging

- Zeeman shift due to a magnetic field gradient
- Local addressing of individual layers using the $^1S_0$-$^3P_2$ (m=1) transition



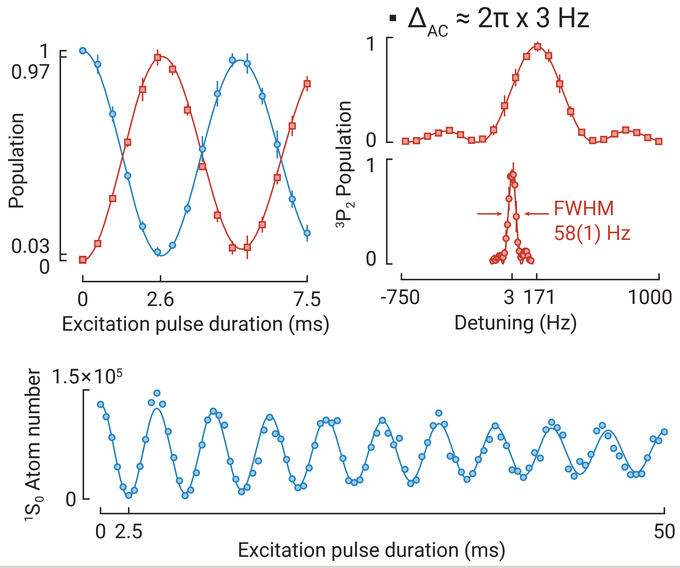
- Sideband cooling on $^1S_0$-$^3P_1$ transition
- Collection of blue photons



Spectroscopy

$^1S_0$-$^3P_2$ Transition

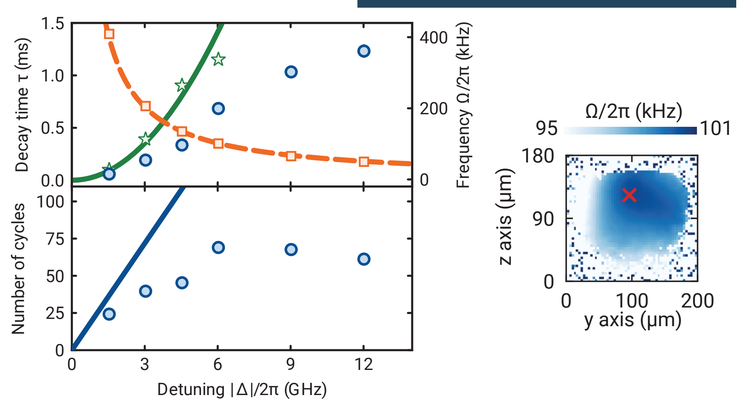
- Excitation fraction = 97(1) %
- Ω = 2π x 200(1) Hz
- 1/e damping time = 57(5) ms
- Laser linewidth: ~1.5 Hz
- π-pulse duration = 2.6 ms:
  - FWHM = 370(2) Hz
  - Δ_{AC} ≈ 2π x 171 Hz
- π-pulse duration = 15 ms:
  - FWHM = 58(1) Hz
  - Δ_{AC} ≈ 2π x 3 Hz

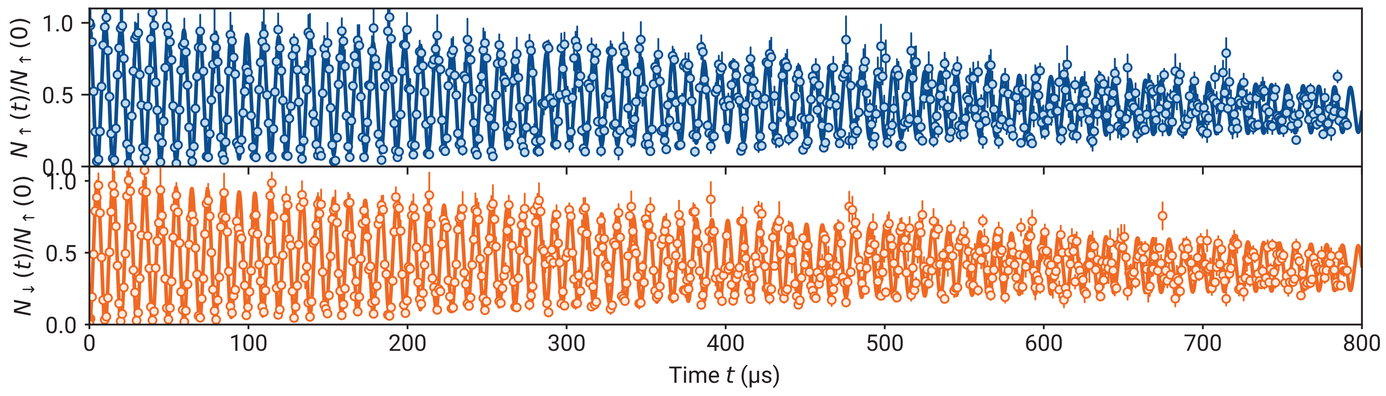


Quantum Computing

Fine-structure Qubit

- around 70 cycles
- Rabi Frequency of Ω= 2π x 100.92(4) kHz
- 1/e decay time τ = 0.68(1) ms
- π-pulse duration on the µs scale
- π-pulse excitation fraction of 98(1) %
- detection of $^3P_2$ and $^3P_0$ state

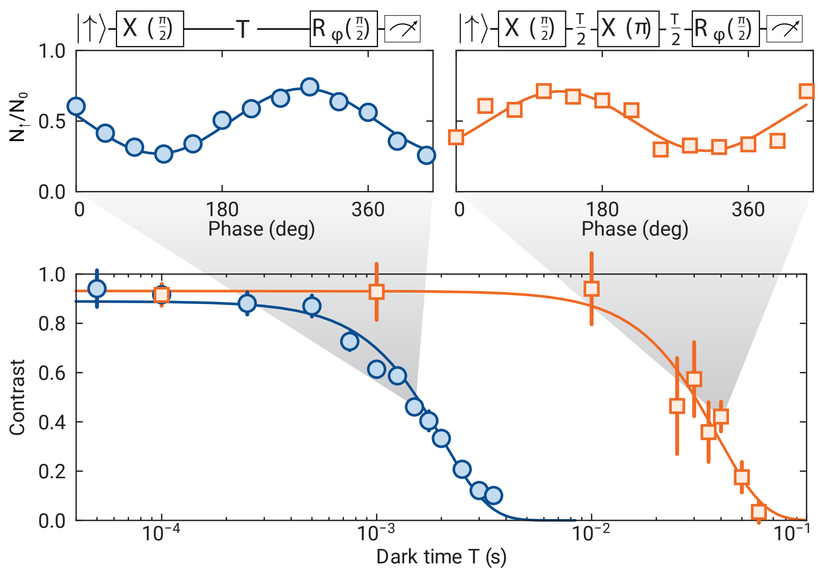




Coherence

Coherence measurements

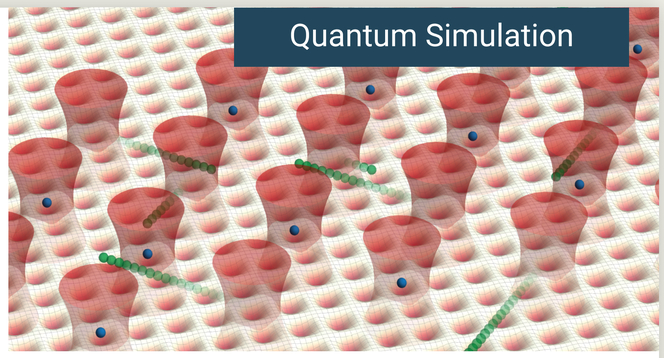
	Fine-structure Qubit	$^1S_0$-$^3P_2$ transition
Ramsey	• $T_2^* = 2.03(7)$ ms	• $T_2^* = 14(1)$ ms
Spin Echo	• $T_2' = 38(3)$ ms	• $T_2' = 266(36)$ ms



Quantum Simulation

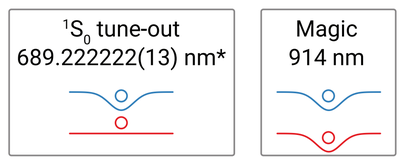
Quantum emitters coupled to bath

- Idea:
  - Simulation of quantum emitters coupled to a bath with cold atoms



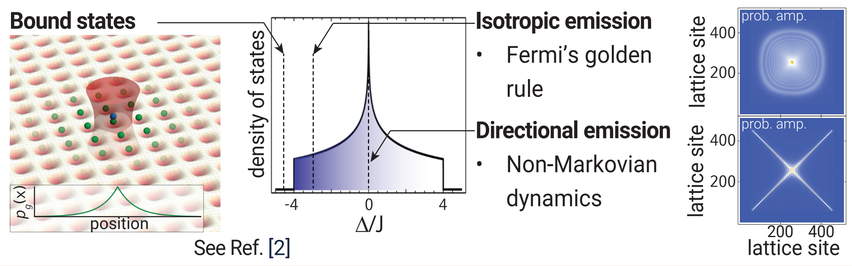
Tune-out and magic lattice

- Magic and tune-out lattice realizable



Single emitter dynamics

- Bound states
- Directional emission



See Ref. [2]

References

- **$^1S_0$-$^3P_2$Transition: V. Klüsener et al., arXiv:2401.03934**
- **Fine-structure Qubit: S. Pucher et al., PhysRevLett.132.150605**

[1] L. Krinner et al., Nature **559**, 589–592 (2018)
[2] A. González-Tudela et al., Phys. Rev. Lett. **119**, 143602 (2017)

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