Two-dimensional transport and transfer of a single atomic qubit in optical tweezers

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Nature Phys 3, 696–699 (2007).

Phys 596 Team VI

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17th December 2020

Introduction

Scalability is needed in the quest for a quantum computer.

A neutral-atom qubit can be transferred between 2 optical traps and moved to an interaction zone.

This experiment aims to provide a scalable setup needed for the implementation of a quantum computer.

Image from https://www.forbes.com/sites/ibm/2020/01/16/the-quantum-computing-era-is-here-why-it-mattersand-how-it-may-change-our-world/?sh=4506068d5c2b

Background Quantum Qubits

Preparing a qubit as a 2 state system.

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

Hyperfine splitting in Rb 87 atom.

While generally computing is done on a 0 or 1 basis, qubits allow for superposition of states.

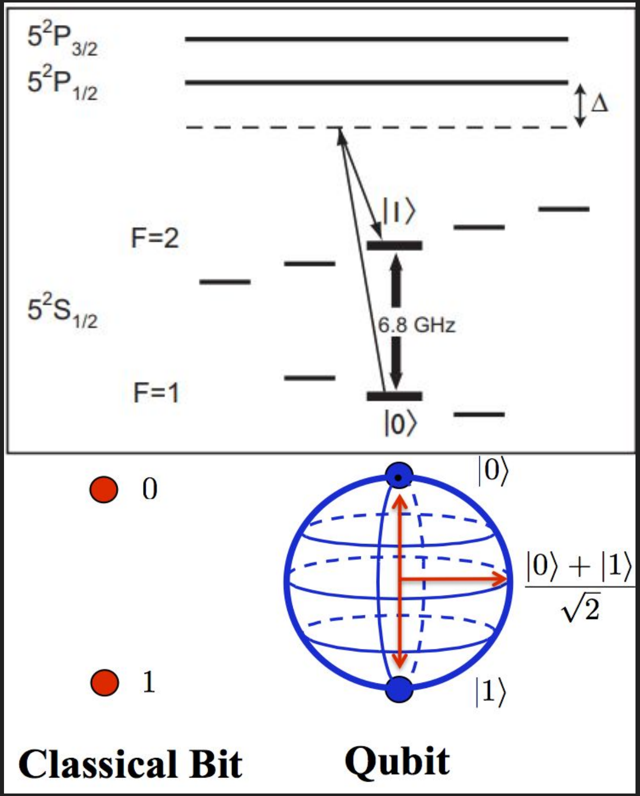


Image from https://www.autodesk.com/products/eagle/blog/future-computing-quantum-qubits/

Googles claim:(specific task)

Sycamore quantum processor: 200s ,Best Supercomputer expected: 10,000 years

Spin echoes

Method often used in NMR and MRI to study decoherence.

This technique can also be applied to the Rb 87 qubit to study decoherence

A raman beam is used to induce the π and π/2 pulses

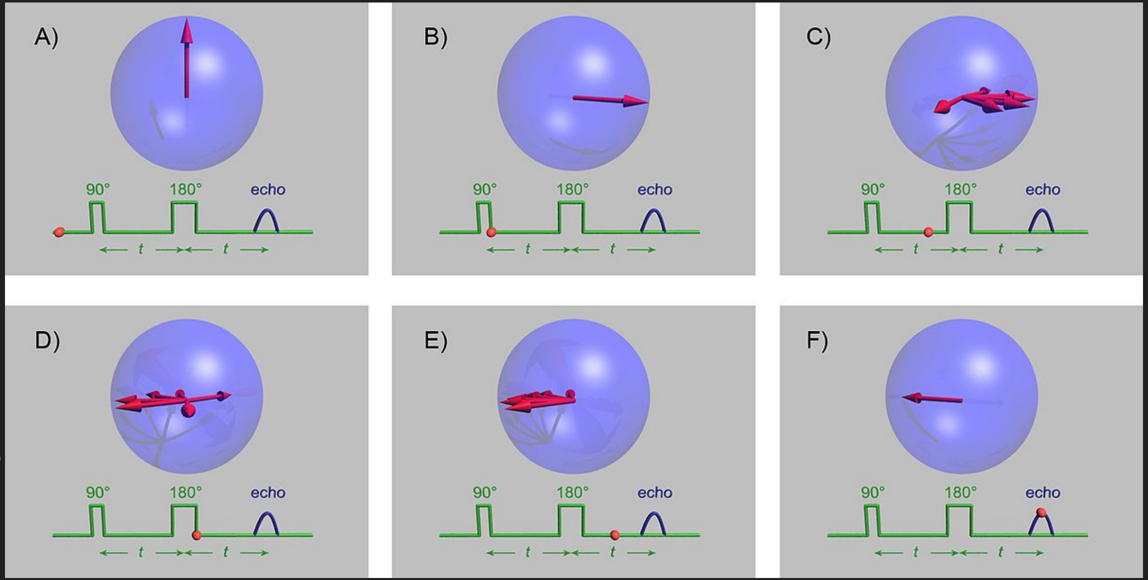


Image from https://en.wikipedia.org/wiki/Spin_echo

Temperature Measurement

Switch off and on the dipole trap for an adjustable time between 1 and 30 us.

Repeat 100 times to get probability of recapture of atom.

Compare the data to a 3D Monte Carlo simulation.

Methods

Trapping of a single rubidium-87 atom in an optical dipole trap created by a tightly focused laser beam.

Usage of raman laser beams.

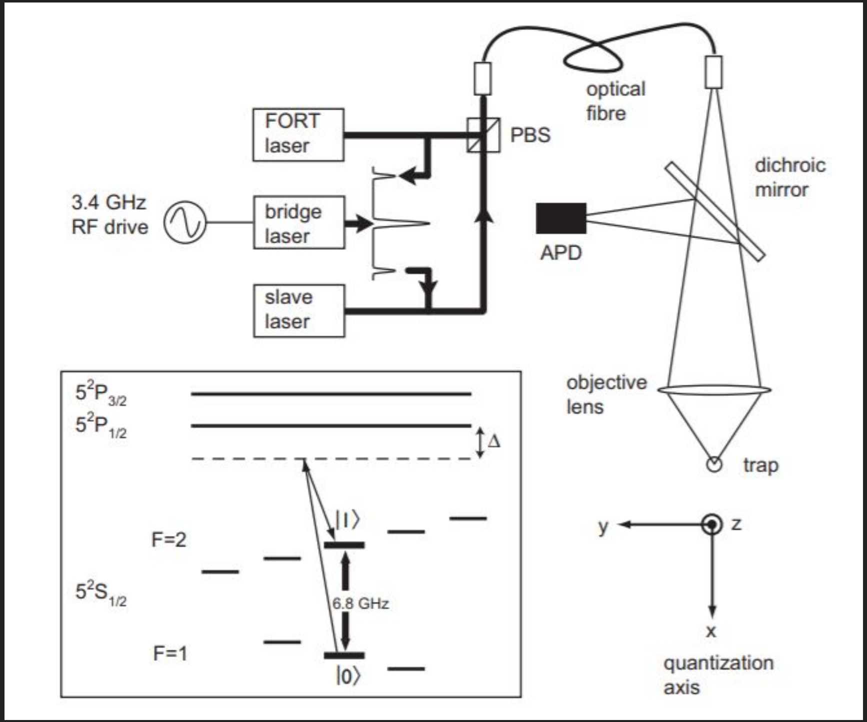
Coherence is measured through the spin echo technique.

Optical Tweezer

Experiments are carried out by using Raman spectroscopy

- Trapping
- Preparation
- Qubit operation
- Readout

In a superposition of $\alpha|0\rangle + \beta|1\rangle$



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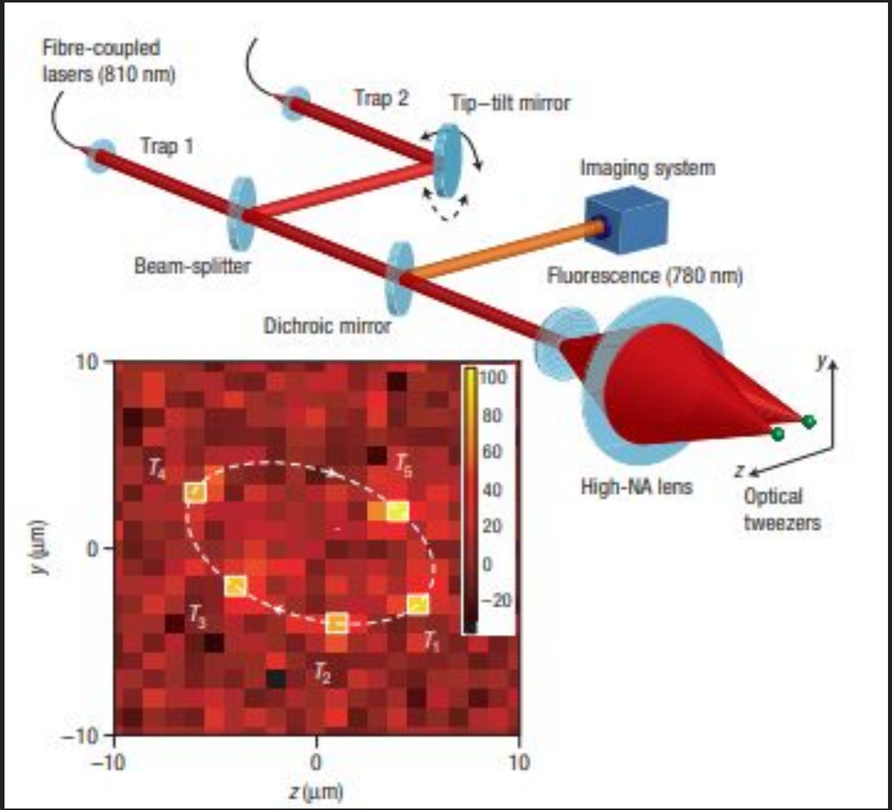
Experimental Setup

- Moving-qubit experiment
- Transfer of the qubit between the two tweezers

The coherence and motional heating of the qubit are measured using this setup



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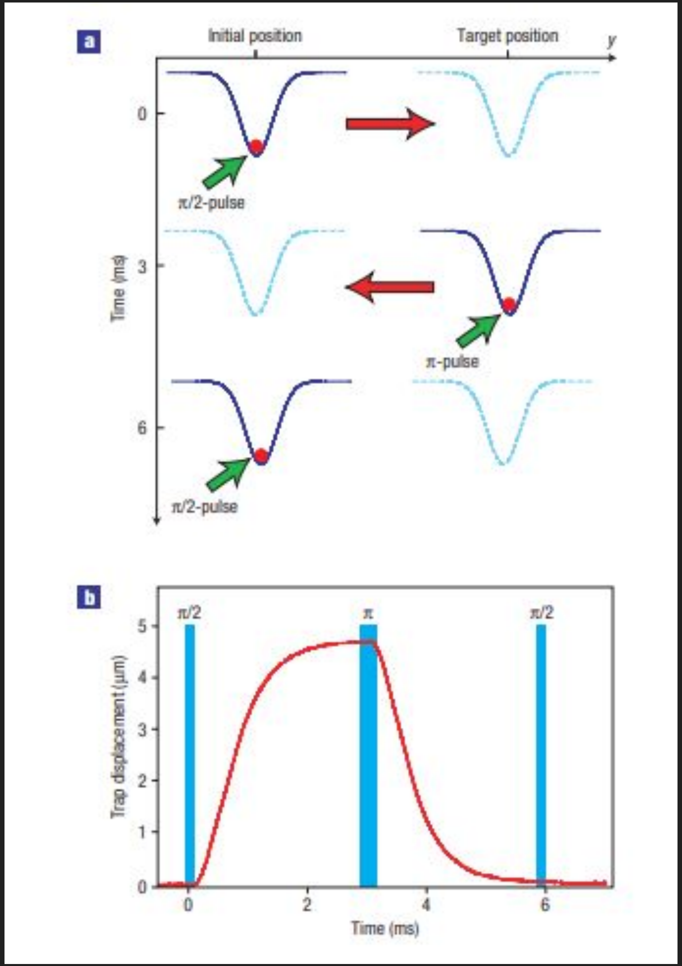
Moving qubit experiment



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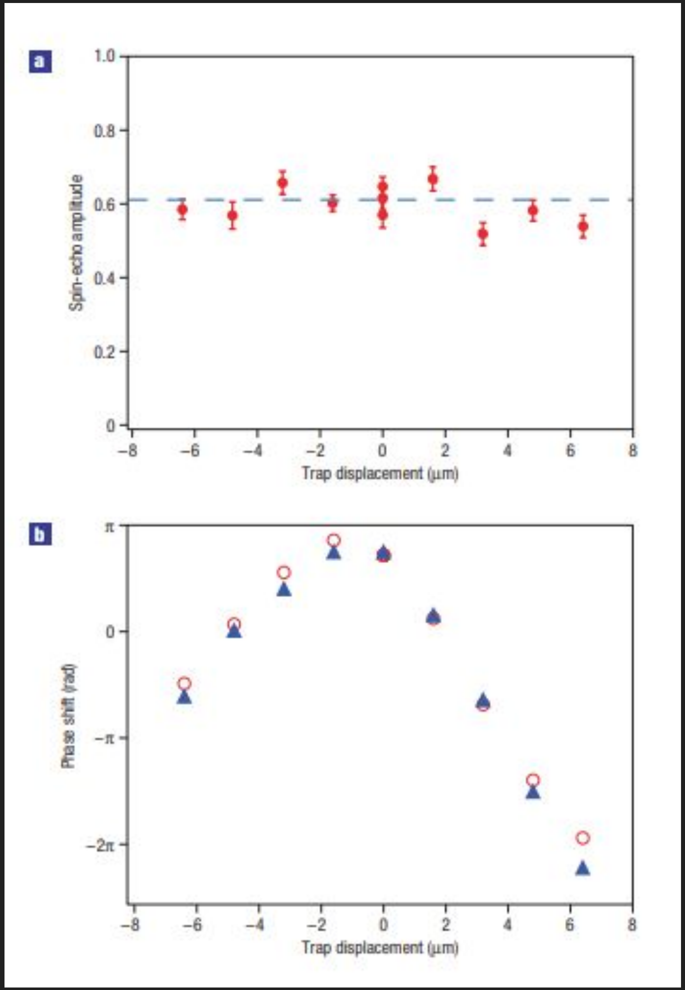
Moving qubit results

T before 56.0±1.4 μK
T after 54.8±1.6 μK.



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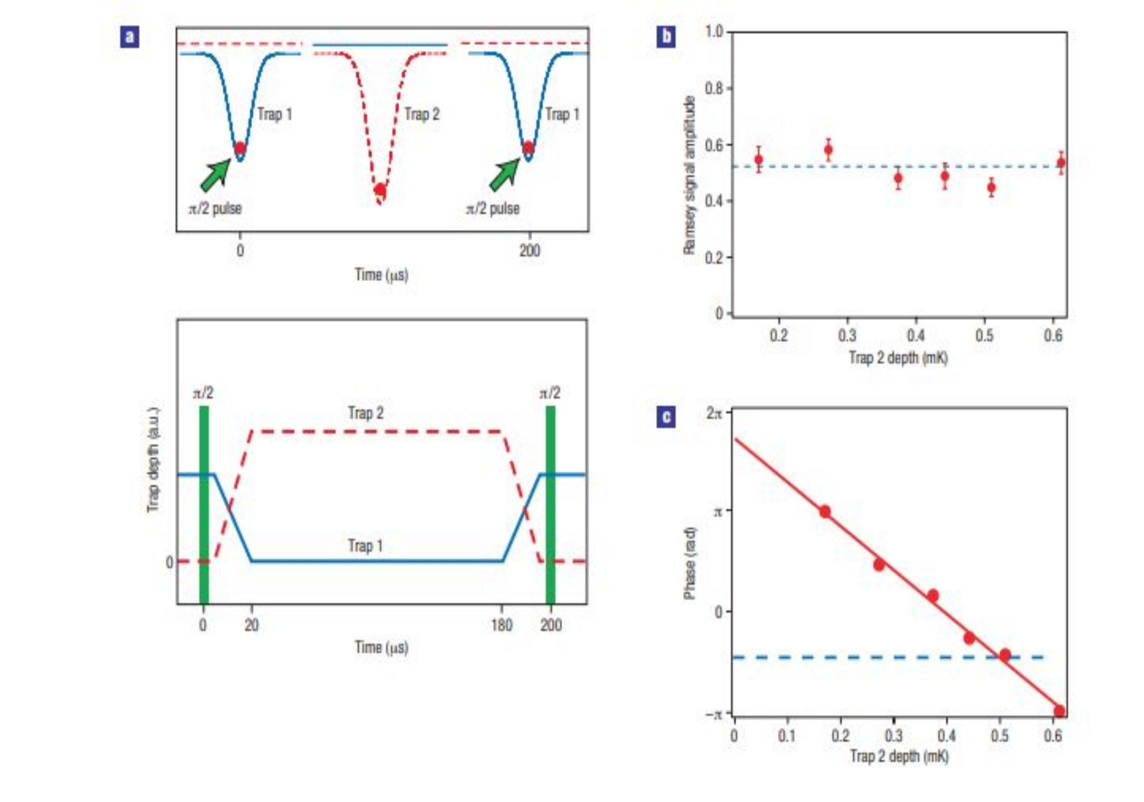
Transfer of qubit between 2 optical traps

T before 53.4± 1.4 μK
T after 56.3±1.8 μK,



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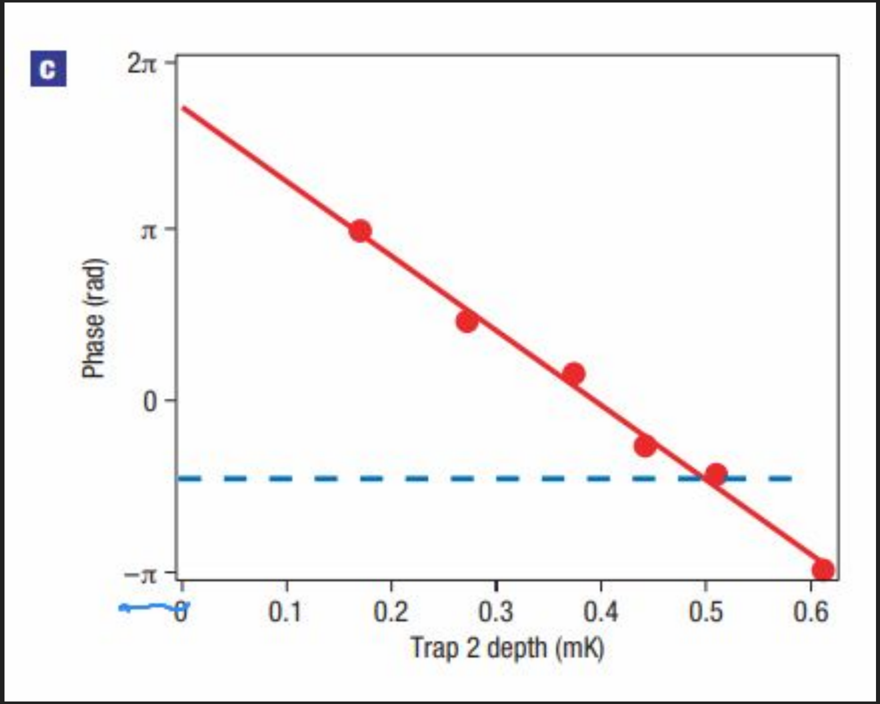
Phase change with increase in trap depth



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Conclusions

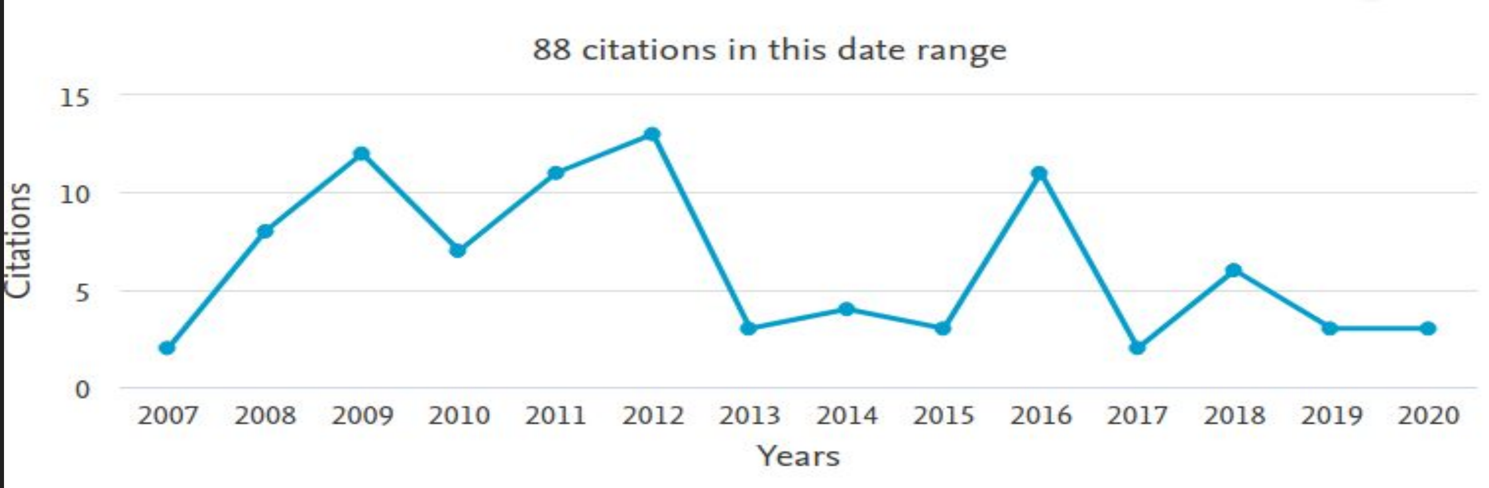
- Movement of qubits within optical traps without heating and decoherence.

- Movement of qubits between optical traps without heating and decoherence.

- Claim of a first step towards a scalable quantum computer architecture.

Citations

- Published in October 2007
- Total citations: 88
- Field-Weighted Citation Impact: 3.47 (94th percentile)



Citing Papers and Follow Up Work

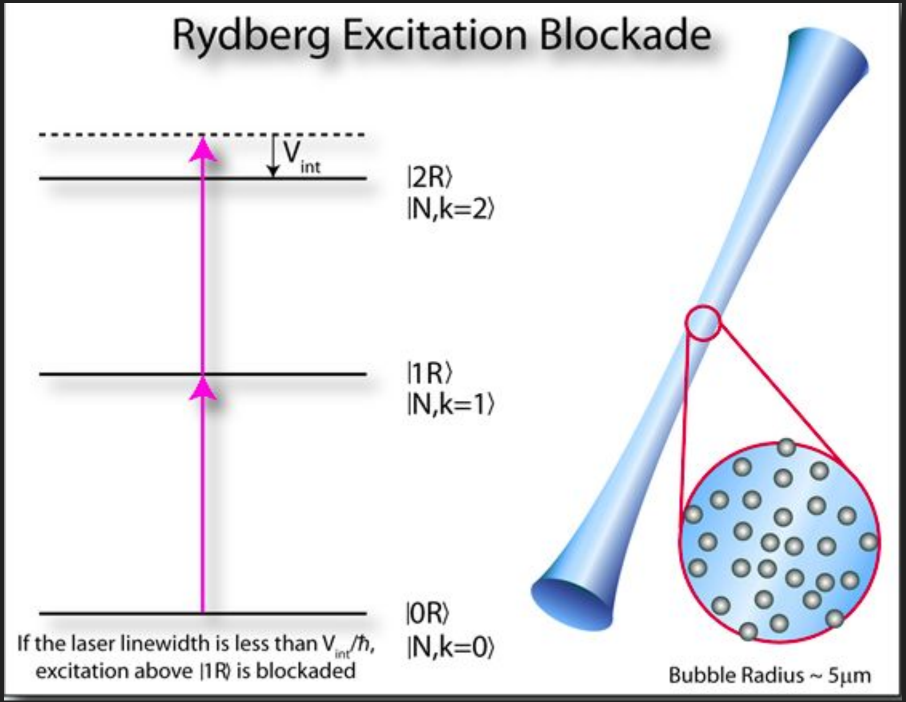
- Apart from review articles, the article which cites this paper with most citations is,
  - Observation of collective excitation of two individual atoms in the Rydberg blockade regime - 526 Citations

- Using Rydberg Blockade to entangle two qubit systems.

When two quantum systems interact strongly with each other, their simultaneous excitation by the same driving pulse may be forbidden. The phenomenon is known as blockade of excitation. Recently, extensive studies have been devoted to the so-called Rydberg blockade between neutral atoms, which appears when the atoms are in highly excited electronic states, owing to the interaction induced by the accompanying large dipole moments. Rydberg blockade has been proposed as a basic tool in quantum-information processing with neutral atoms, and can be used to deterministically generate entanglement of several atoms. Here, we demonstrate Rydberg blockade between two atoms individually trapped in optical tweezers at a distance of 4μm. Moreover, we show experimentally that collective two-atom behaviour, associated with the excitation of an entangled state between the ground and Rydberg levels, enhances the allowed single-atom excitation. These observations should be a crucial step towards the deterministic manipulation of entanglement of two or more atoms, with possible implications for quantum-information science, as well as for quantum metrology, the study of strongly correlated systems in many-body physics, and fundamental studies in quantum physics.

Rydberg Blockade

- Occurs when there are highly excited neutral atoms and with strong-dipolar forces
- Helps in creating quantum gates and preserving collective excitation.
- The paper uses this method to entangle 2 qubits.



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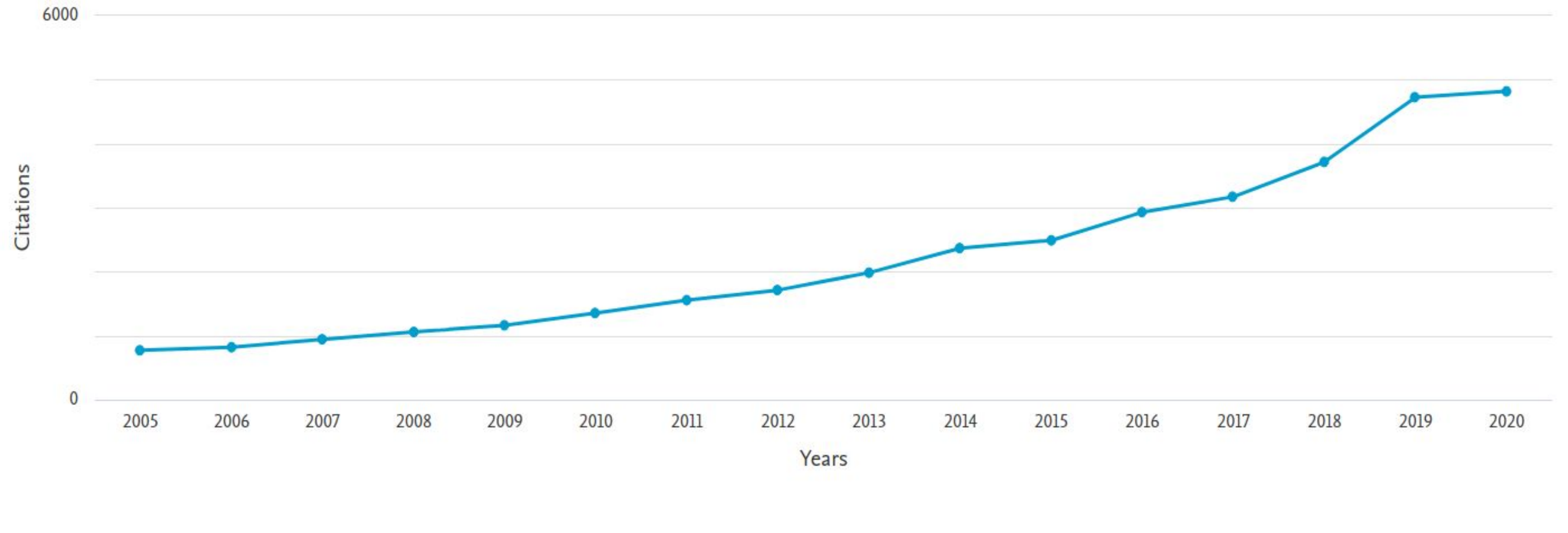
Follow Up Work

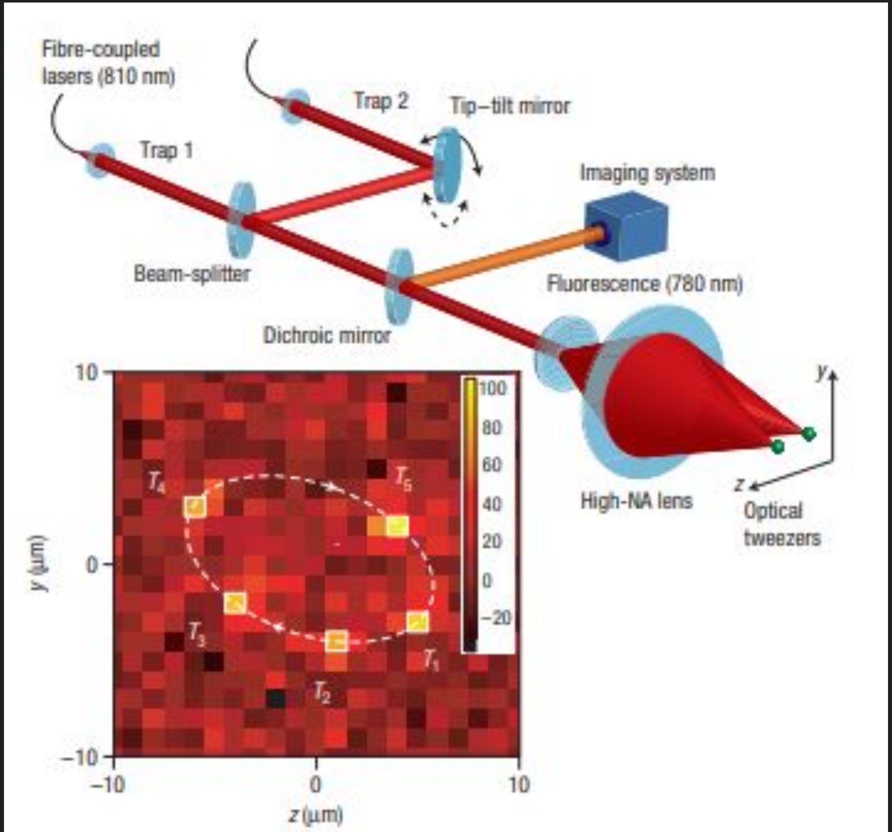
- There has been steady progress towards a scalable quantum computer.



Recent Reviews

- For recent reviews, see
  - Hybrid quantum circuits: Superconducting circuits interacting with other quantum systems- Xiang Z,L et.at
  - Natural and artificial atoms for quantum computation- Buluta et.al

Questions?



Fibre-coupled lasers (810 nm)
Trap 2
Tip–tilt mirror
Trap 1
Imaging system
Beam-splitter
Fluorescence (780 nm)
Dichroic mirror
High-NA lens
Optical tweezers
y
z
10
0
−10
y (μm)
−10
0
10
z (μm)
100
80
60
40
20
0
−20
T_1
T_2
T_3
T_4
T_5