Confidential

QUANTUM DISCOVERY

PASQAL neutral atom arrays

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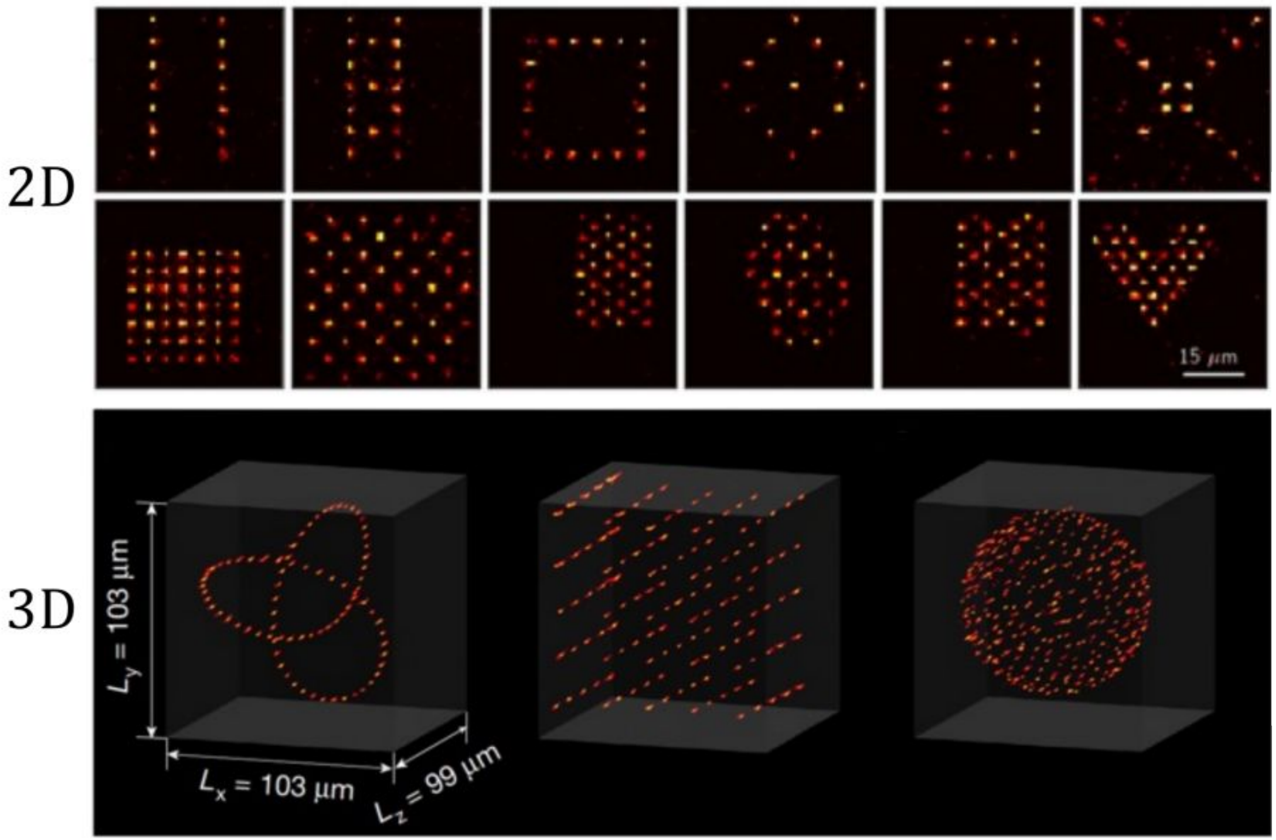
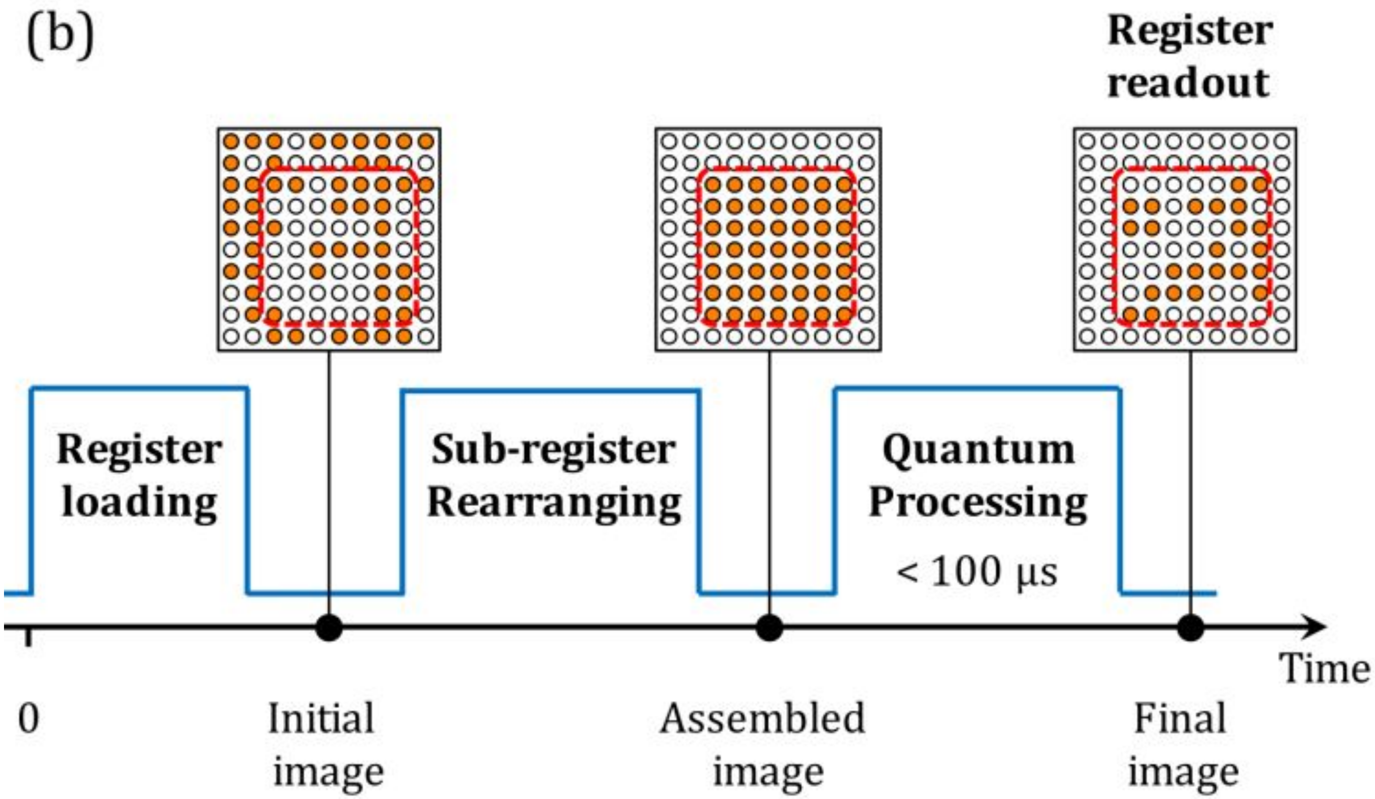
Neutral atom arrays

Overview



Neutral atom arrays

Overview



Neutral atom arrays

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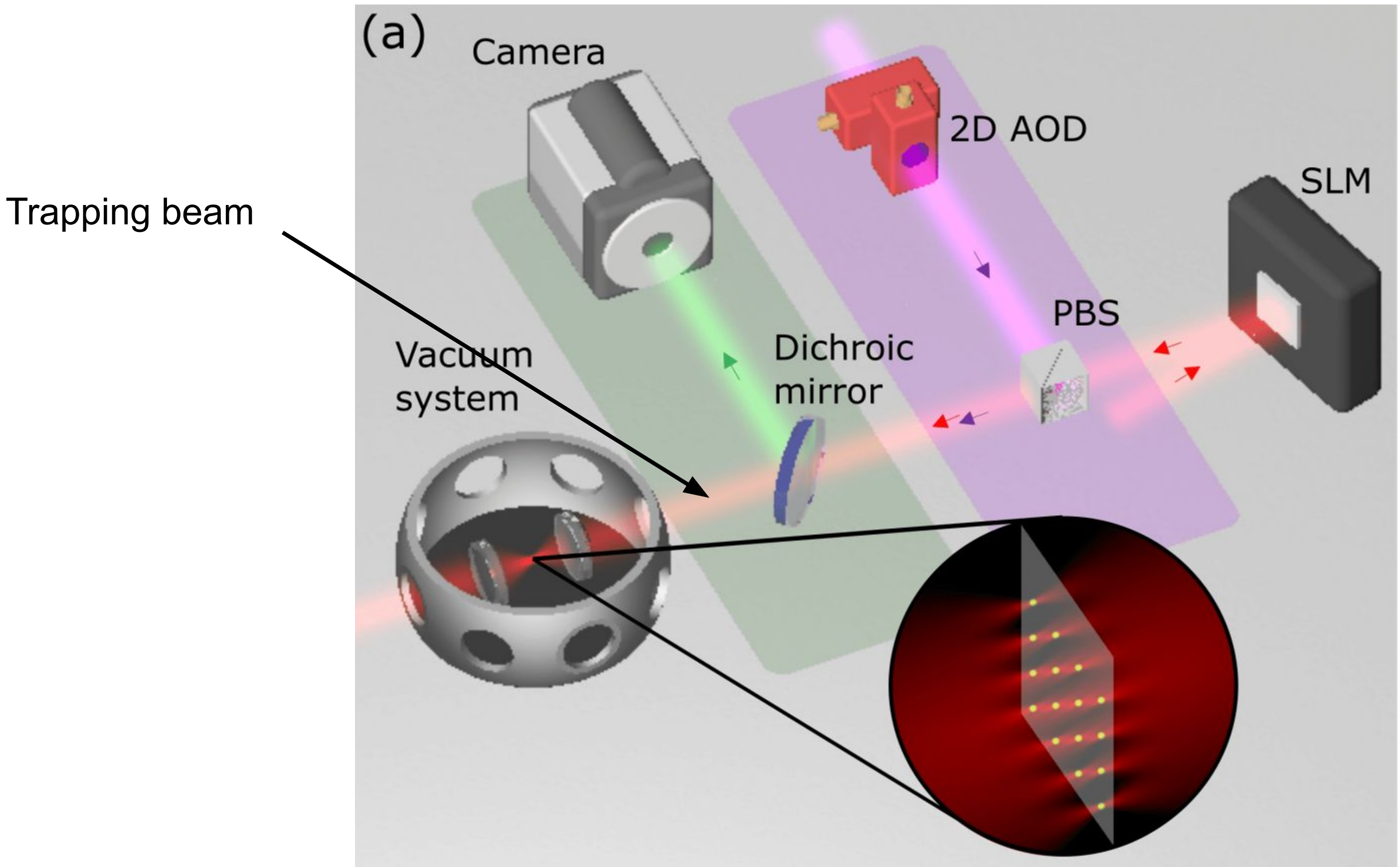
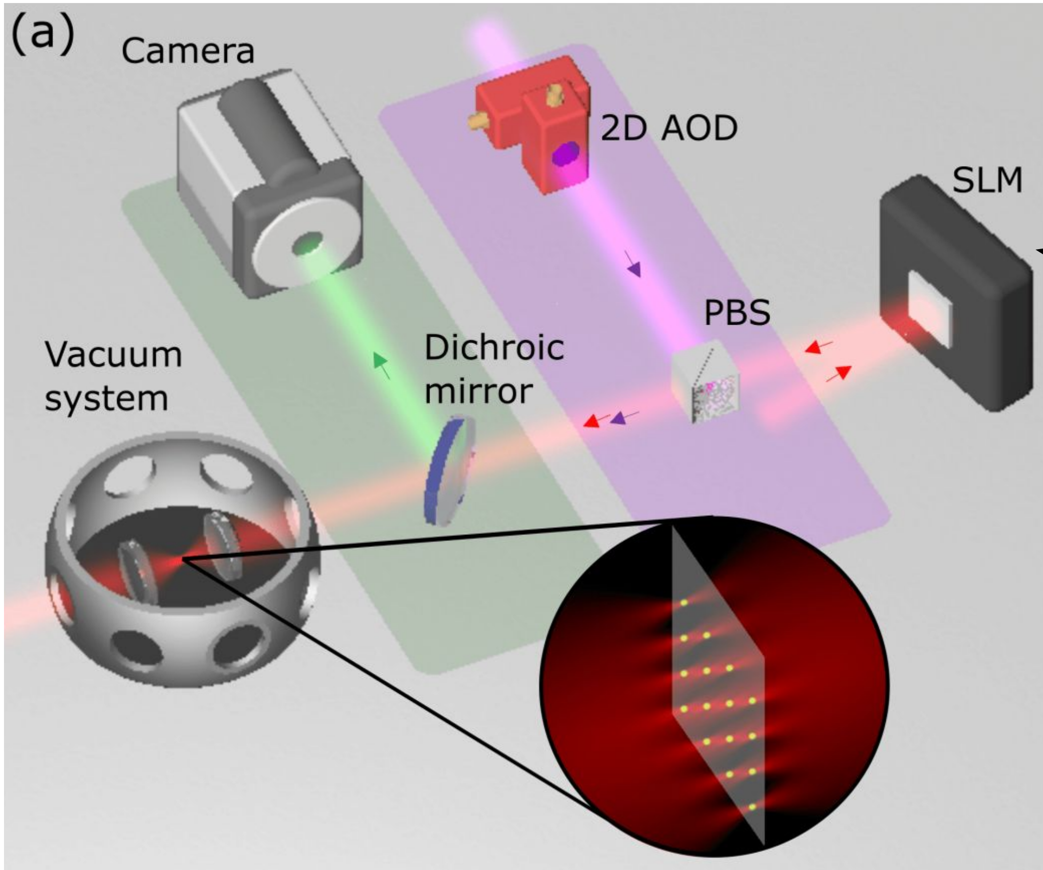


Neutral atom arrays

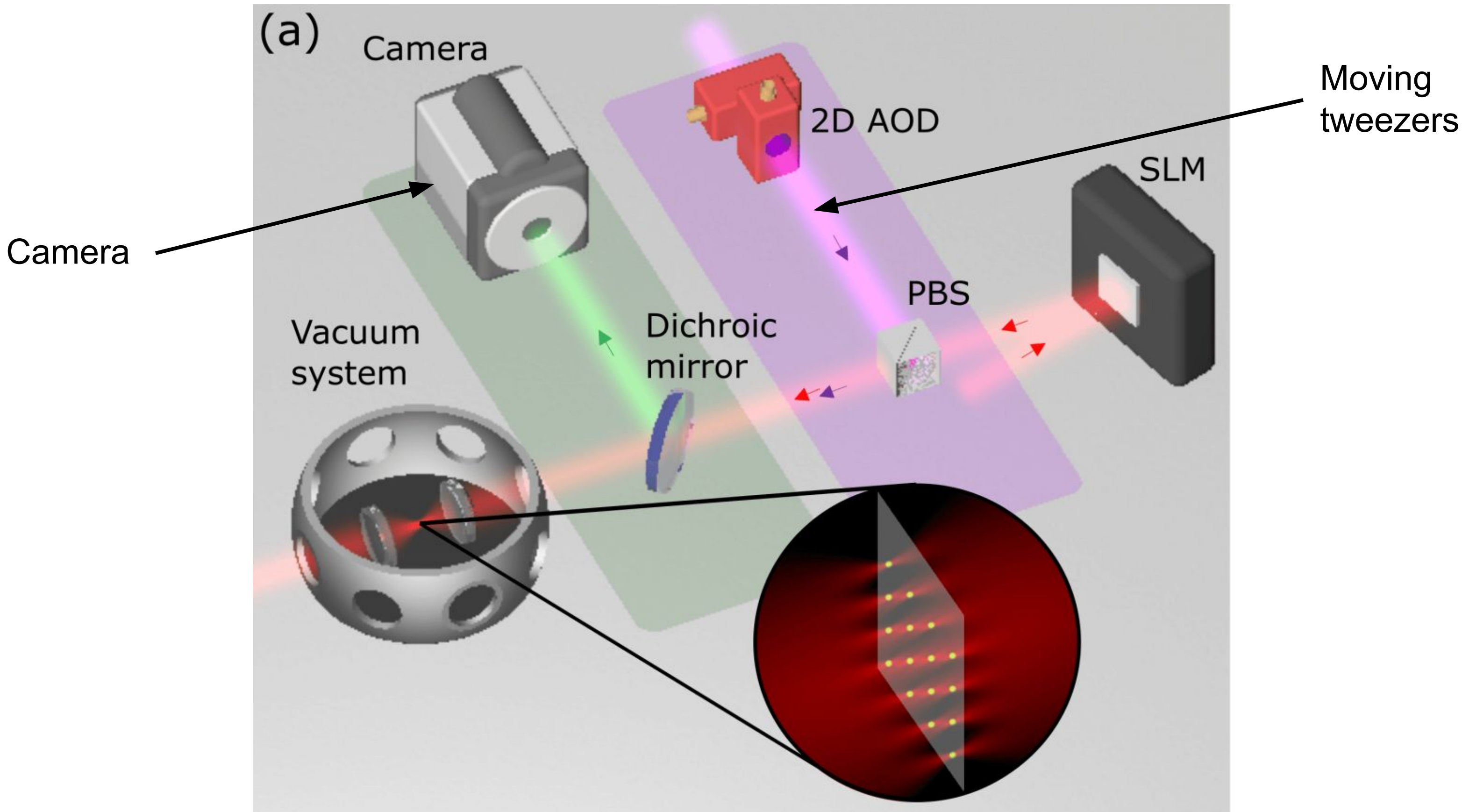
Overview



Spatial light modulator

Neutral atom arrays

Overview

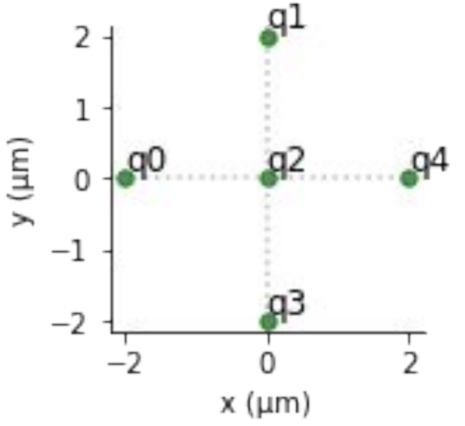


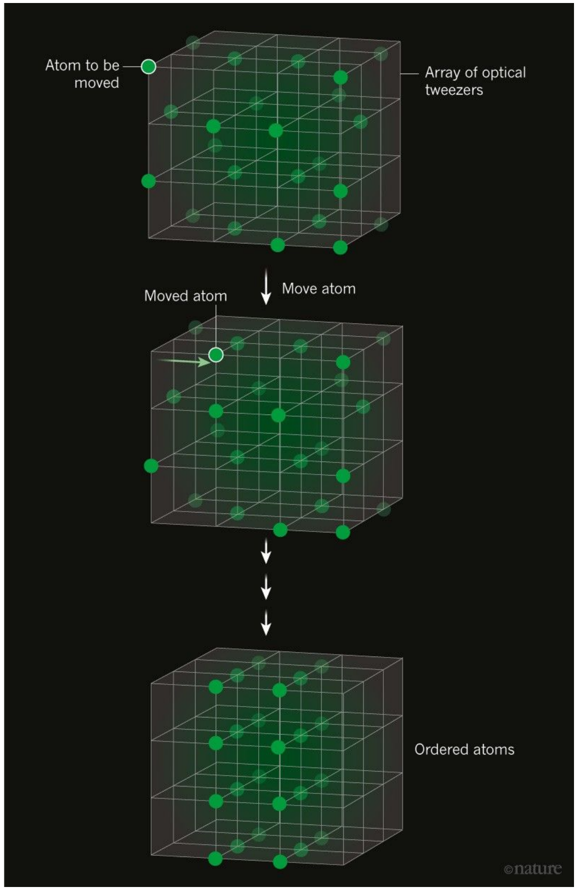
Neutral atom arrays

Building the register

Example (2D):

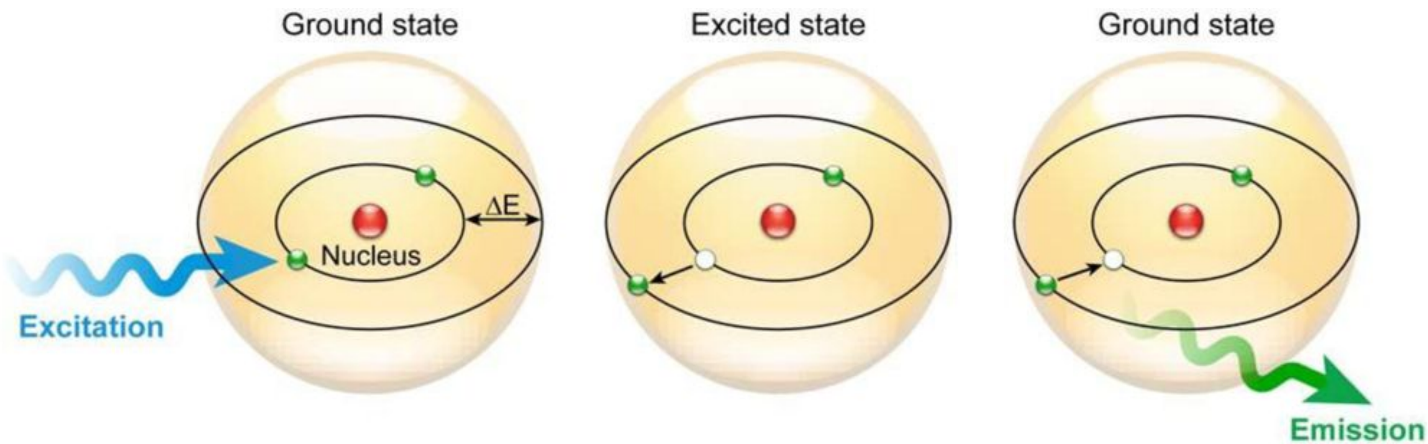
```
!pip install pulser
from pulser import Register

# Coordinates in micrometers
qubits = {'q0': (-2, 0), 'q1': (0, 2),
'q2': (0, 0), 'q3': (0, -2), 'q4': (2, 0)}
reg = Register(qubits)
reg.draw()
```

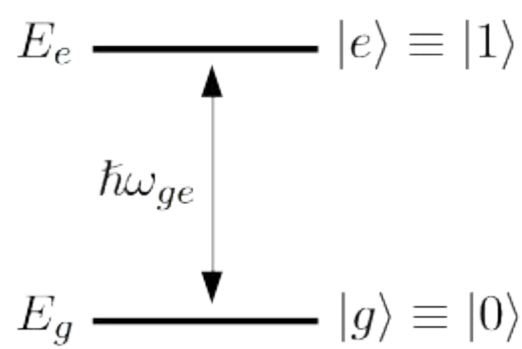




Driving two-level transitions

Two-level transitions

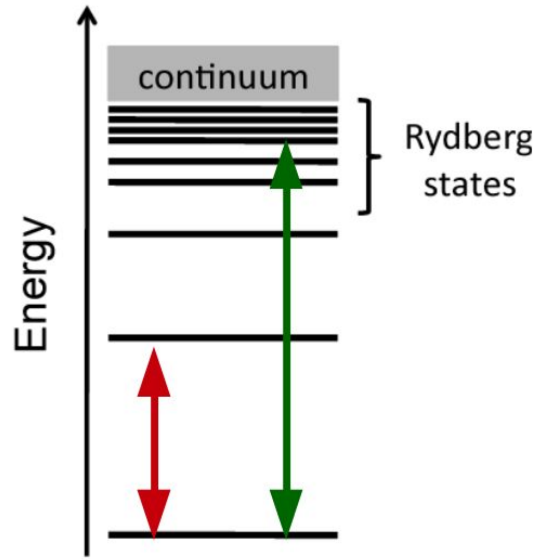




Driving two-level transitions

Available channels

Available channels	Raman transition	Rydberg transition
Addressing 1 atom	'raman_local'	'rydberg_local'
Addressing all the atoms	'raman_global'	'rydberg_global'

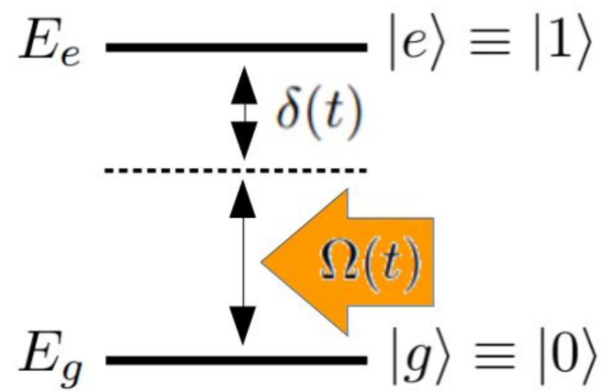


Driving two-level transitions

Pulse parameters

A pulse is defined as the modulation of a signal's amplitude, detuning and phase over a finite duration:

- $\Omega(t)$: Rabi frequency (i.e. amplitude) at instant *t*
- $\delta(t) = \omega(t) - \omega_{ge}$: detuning at instant *t*
- ϕ : phase
- τ : pulse duration



Driving two-level transitions

Drive Hamiltonian

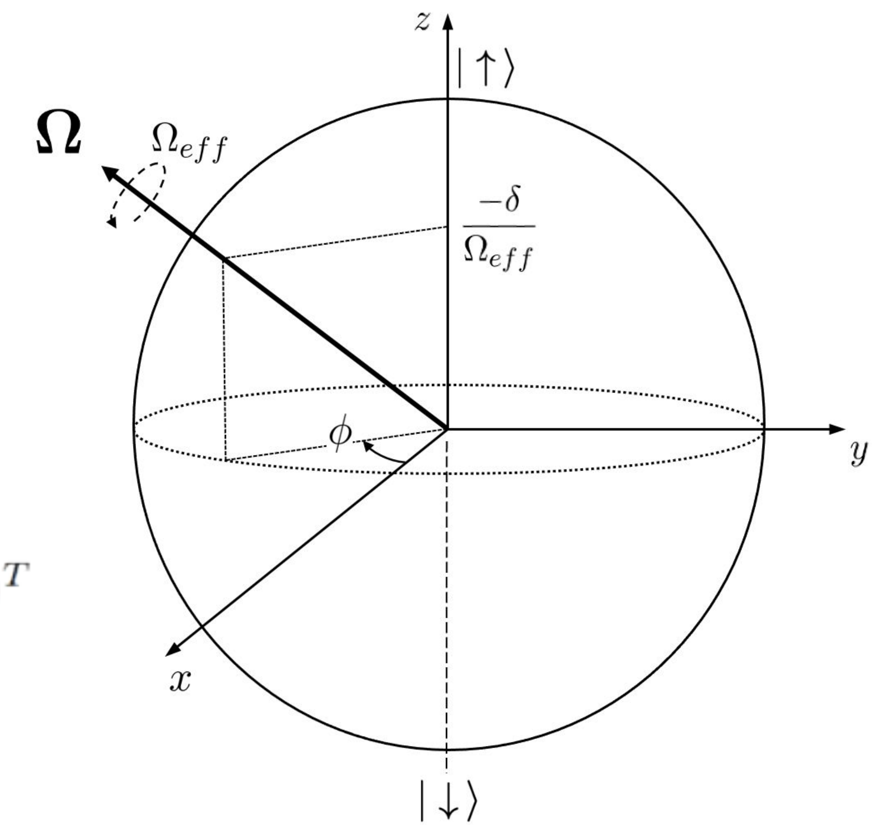
At a single-qubit level, an atomic transition is described by the drive Hamiltonian:

$$H^D(t) = \frac{\hbar}{2}\mathbf{\Omega} \cdot \sigma$$

- Pauli vector: $\sigma = (X, Y, Z)^T$
- Rotation vector:

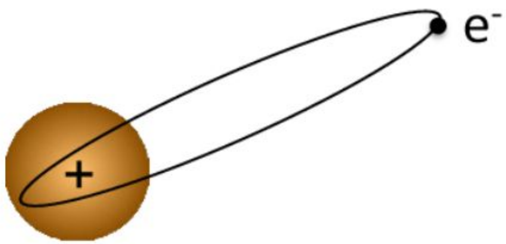
$$\mathbf{\Omega}(t) = (\Omega(t)\cos(\phi), -\Omega(t)\sin(\phi), -\delta(t))^T$$

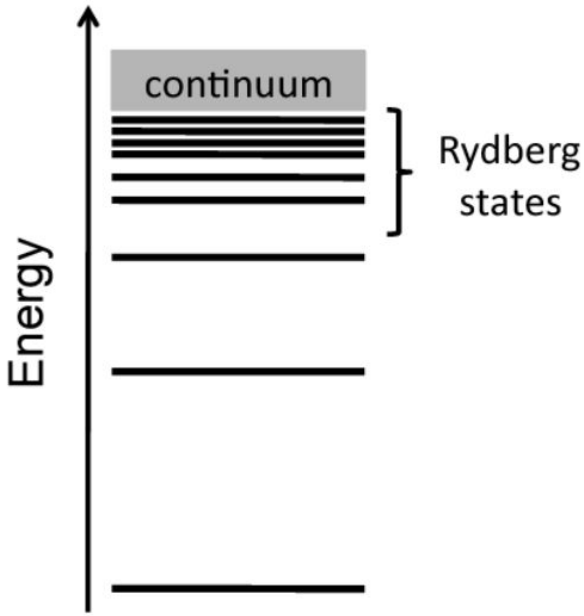
- Angular velocity: $\Omega_{eff} = |\mathbf{\Omega}| = \sqrt{\Omega^2 + \delta^2}$



Interacting qubits

Rydberg states





Interacting qubits

Ising Hamiltonian

Taking into account the dipole-dipole interaction, the Hamiltonian of the atomic register writes:

sum over all the atoms

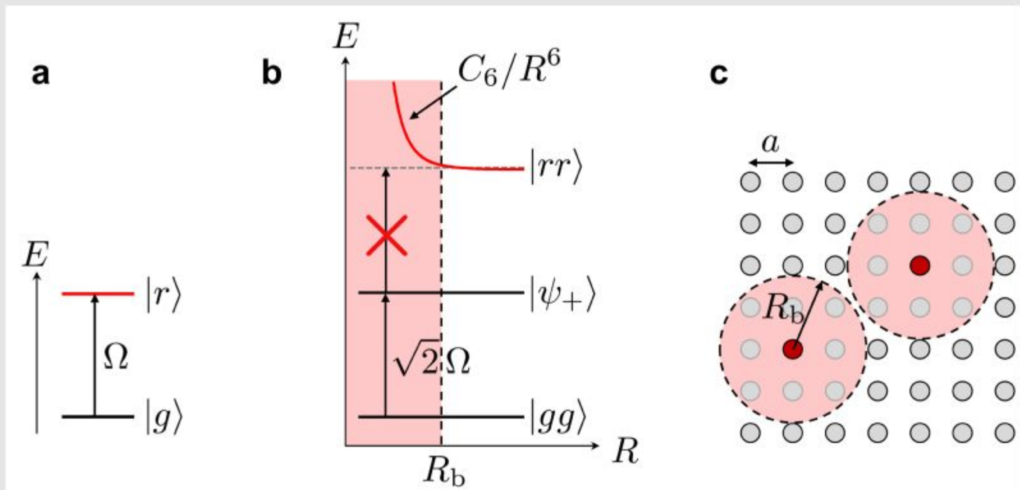
$$\mathcal{H}^{gr}(t) = \sum_{i} \left(H_i^D(t) + \boxed{\sum_{j<i} \frac{C_6}{(R_{ij})^6} \hat{n}_i \hat{n}_j} \right)$$

dipole-dipole interaction

- $\hat{n}_i$: projector onto the Rydberg state for the *i*-th atom
- R_{ij} : interatomic distance in between atoms *i* and *j*
- C_6 : a constant depending on the specific Rydberg level

Interacting qubits

Blockade effect



$$R_b = \left(\frac{C_6}{\hbar\Omega}\right)^{1/6}$$

Figure B1 | The Rydberg blockade. a: The ground and Rydberg states $|g\rangle$ and $|r\rangle$ are coupled by a resonant laser with Rabi frequency Ω. **b:** For two atoms separated by a distance $R < R_\mathrm{b}$, the collective ground state $|gg\rangle$ is coupled only to $|\psi_+\rangle = (|gr\rangle + |rg\rangle)/\sqrt{2}$, but not to $|rr\rangle$, which is shifted out of resonance by the van der Waals interaction. **c:** In a large ensemble of atoms, e.g. a regular array with spacing a, an atom excited in $|r\rangle$ (red dot) prevents the excitation of all the atoms contained in a sphere of radius R_b.

Conclusion

- ➔ Neutral atoms trapped in optical tweezers have emerged as a powerful platform for quantum information processing
- ➔ Registers of neutral atoms are reconfigurable from one run of the experiment to another
- ➔ One can play with the amplitude, the detuning and the phase of pulses sent to the atoms to implement quantum information processing tasks with selected energy levels
- ➔ In Raman and Rydberg transitions, the ground state is taken as the zero state, and the excited state as the one state
- ➔ The blockade effect prevents exciting two atoms in a Rydberg state when those atoms are close to each other
- ➔ Atoms in a register can be controlled either locally (sequentially) or globally (simultaneously)