Kako foton zna kud treba ići?

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MZOS projekti

Kvantno računanje: paralelizam i vizualizacija

(082-0982562-3160)

Voditelj: Mladen Pavičić, suradnici: Danko Bosanac i Krešimir Fresl

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Eksperimentalne tehnike kvantne komunikacije i kvantne informatike

(098-0352851-2873)

Voditelj: Mario Stipčević, suradnici: Branka Medved, Hrvoje Skenderović i Mladen Pavičić

Kvantni kompjutori: dostignuća i planovi

LA-UR-04-1778

A Quantum Information Science and Technology Roadmap

Part 1: Quantum Computation

**Report of the
Quantum Information Science and Technology
Experts Panel**

Implementacije

QC Approach	The DiVincenzo Criteria						
	Quantum Computation					QC Networkability	
	#1	#2	#3	#4	#5	#6	#7
NMR	🔴	🟠	🟠	🟢	🟠	🔴	🔴
Trapped Ion	🟠	🟢	🟠	🟢	🟢	🟠	🟠
Neutral Atom	🟠	🟢	🟠	🟠	🟠	🟠	🟠
Cavity QED	🟠	🟢	🟠	🟠	🟢	🟠	🟠
Optical	🟠	🟠	🟢	🟠	🟠	🟠	🟢
Solid State	🟠	🟠	🟠	🟠	🟠	🔴	🔴
Superconducting	🟠	🟢	🟠	🟠	🟠	🔴	🔴
Unique Qubits	This field is so diverse that it is not feasible to label the criteria with "Promise" symbols.						

Legend: 🟢 = a potentially viable approach has achieved sufficient proof of principle

🟠 = a potentially viable approach has been proposed, but there has not been sufficient proof of principle

🔴 = no viable approach is known

The column numbers correspond to the following QC criteria:

#1. A scalable physical system with well-characterized qubits.

#2. The ability to initialize the state of the qubits to a simple fiducial state.

#3. Long (relative) decoherence times, much longer than the gate-operation time.

#4. A universal set of quantum gates.

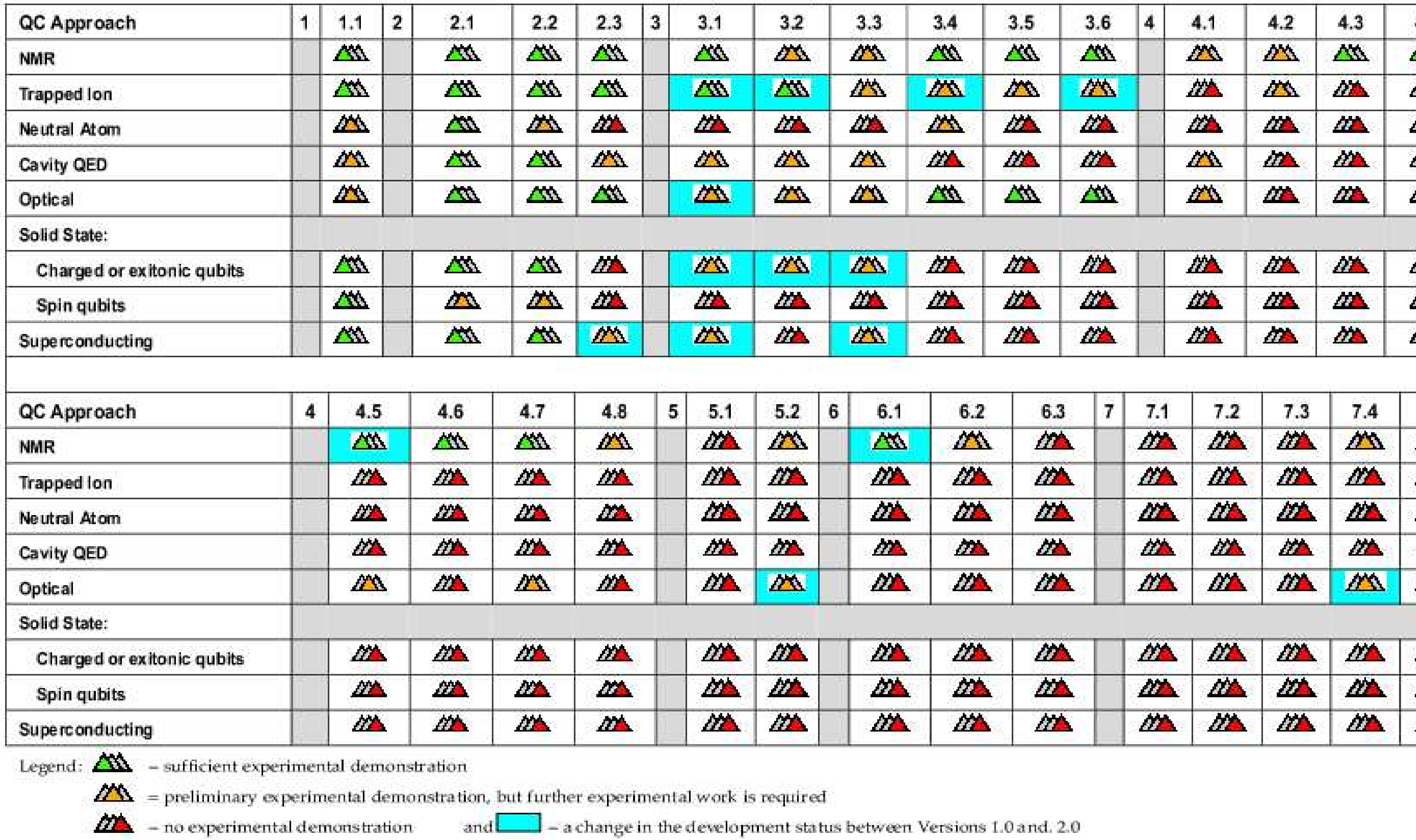
#5. A qubit-specific measurement capability.

#6. The ability to interconvert stationary and flying qubits.

#7. The ability to faithfully transmit flying qubits between specified locations.

Uspjesi

The Mid-Level QC Roadmap—Development Status Metrics



Uspjesi - legenda

1. Creation of a qubit
   1.1 Demonstrate preparation and readout of both qubit states.
2. Single-qubit operations
   2.1 Demonstrate Rabi flops of a qubit.
   2.2 Demonstrate decoherence times much longer than the Rabi oscillation period.
   2.3 Demonstrate control of both degrees of freedom on the Bloch sphere.
3. Two-qubit operations
   3.1 Implement coherent two-qubit quantum logic operations.
   3.2 Produce and characterize the Bell entangled states.
   3.3 Demonstrate decoherence times much longer than two-qubit gate times.
   3.4 Demonstrate quantum state and process tomography for two qubits.
   3.5 Demonstrate a two-qubit decoherence-free subspace (DFS).
   3.6 Demonstrate a two-qubit quantum algorithm.
4. Operations on 3–10 physical qubits
   4.1 Produce a Greenberger, Horne, and Zeilinger (GHZ) entangled state of three physical qubits.
   4.2 Produce maximally-entangled states of four or more physical qubits.
   4.3 Quantum state and process tomography.
   4.4 Demonstrate DFSs.
   4.5 Demonstrate the transfer of quantum information (e.g., teleportation, entanglement swapping, multip SWAP operations etc.) between physical qubits.
   4.6 Demonstrate quantum error-correcting codes.
   4.7 Demonstrate simple quantum algorithms (e.g., Deu Josza).
   4.8 Demonstrate quantum logic operations with fault-tolerant precision.
5. Operations on one logical qubit
   5.1 Create a single logical qubit and "keep it alive" usir repetitive error correction.
   5.2 Demonstrate fault-tolerant quantum control of a sin logical qubit.
6. Operations on two logical qubits
   6.1 Implement two-logical-qubit operations.
   6.2 Produce two-logical-qubit Bell states.
   6.3 Demonstrate fault-tolerant two-logical-qubit operat
7. Operations on 3–10 logical qubits
   7.1 Produce a GHZ-state of three logical qubits.
   7.2 Produce maximally-entangled states of four or more logical qubits.
   7.3 Demonstrate the transfer of quantum information between logical qubits.
   7.4 Demonstrate simple quantum algorithms (e.g., Deu Josza) with logical qubits.
   7.5 Demonstrate fault-tolerant implementation of simp quantum algorithms with logical qubits.

Bit i qubit

Jedan klasični tranzistor ima dva stanja:

$$0 \quad \text{i} \quad 1$$

Stanje klasičnog tranzistora (0 ili 1) nazivamo bitom.

Jedan kvantni tranzistor (foton, elektron, atom, molekual) ima takodjer dva osnovna stanja

$$|0\rangle \quad \text{i} \quad |1\rangle$$

koja nazivamo qubit-om (kvantni bit).

Paralelizam

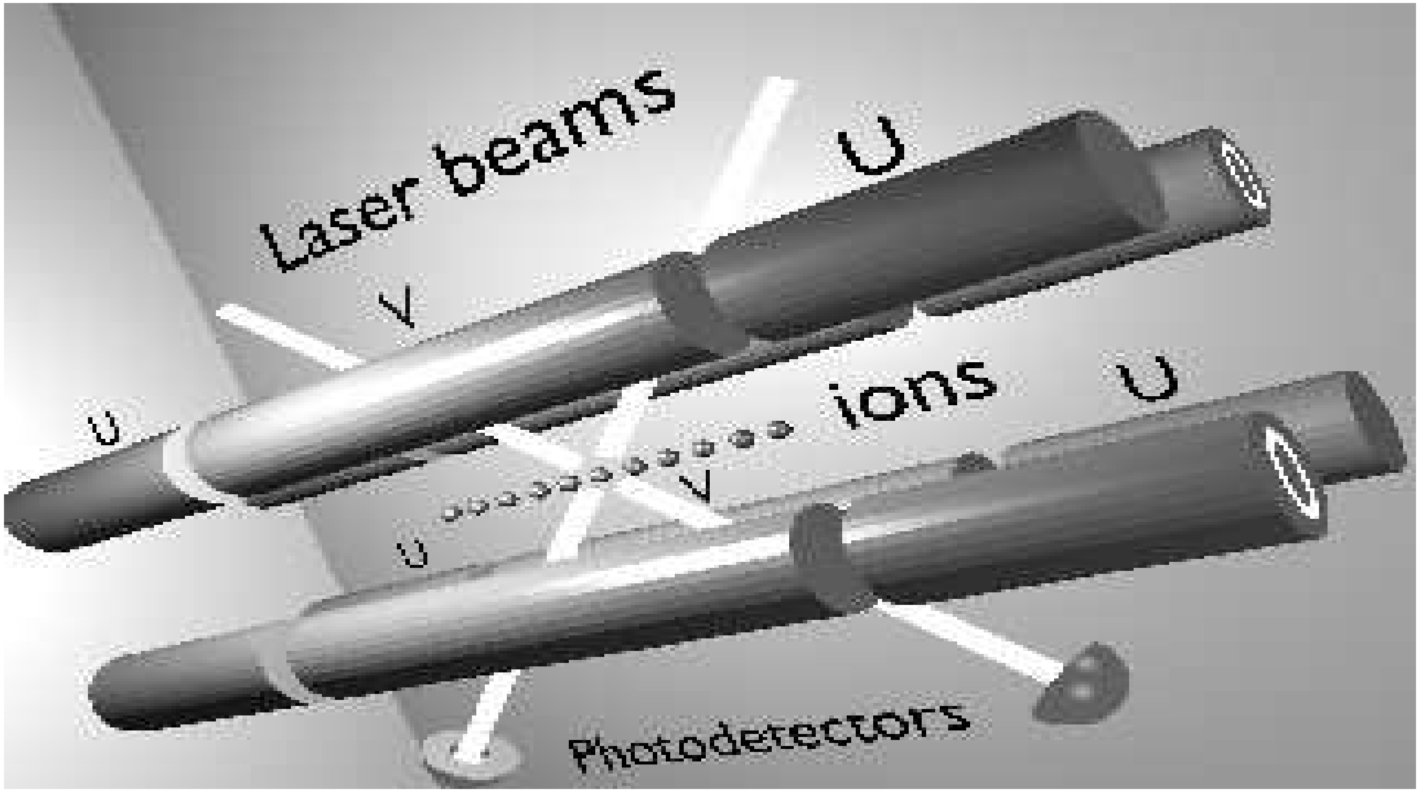
Medjutim, dok klasični tranzistor mora biti ili u jednom ili u drugom svom osnovnom stanju, kvantni transistor je općenito u superpoziciji svoja dva osnovna stanja ($|0\rangle$ i $|1\rangle$):

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

a broj tih superpozicija je beskonačan.

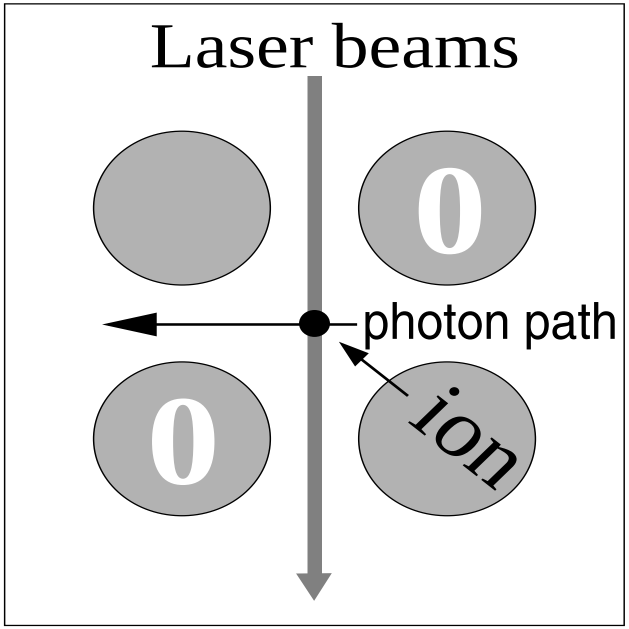
Idealno bi samo 50 atoma odgovaralo računalnoj moći jednog miliona miliardi klasičnih tranzistora, tj. nekoliko miliona klasiņih kompjutera spojenih u cluster. Realistične procjene za takvu moć predvidjaju oko 1000 qubita (atoma).

Atom-photon



Mladen Pavičić, Quantum Computation and Quantum Communication: Theory and Experiments, *Springer Verlag*, New York (2005)

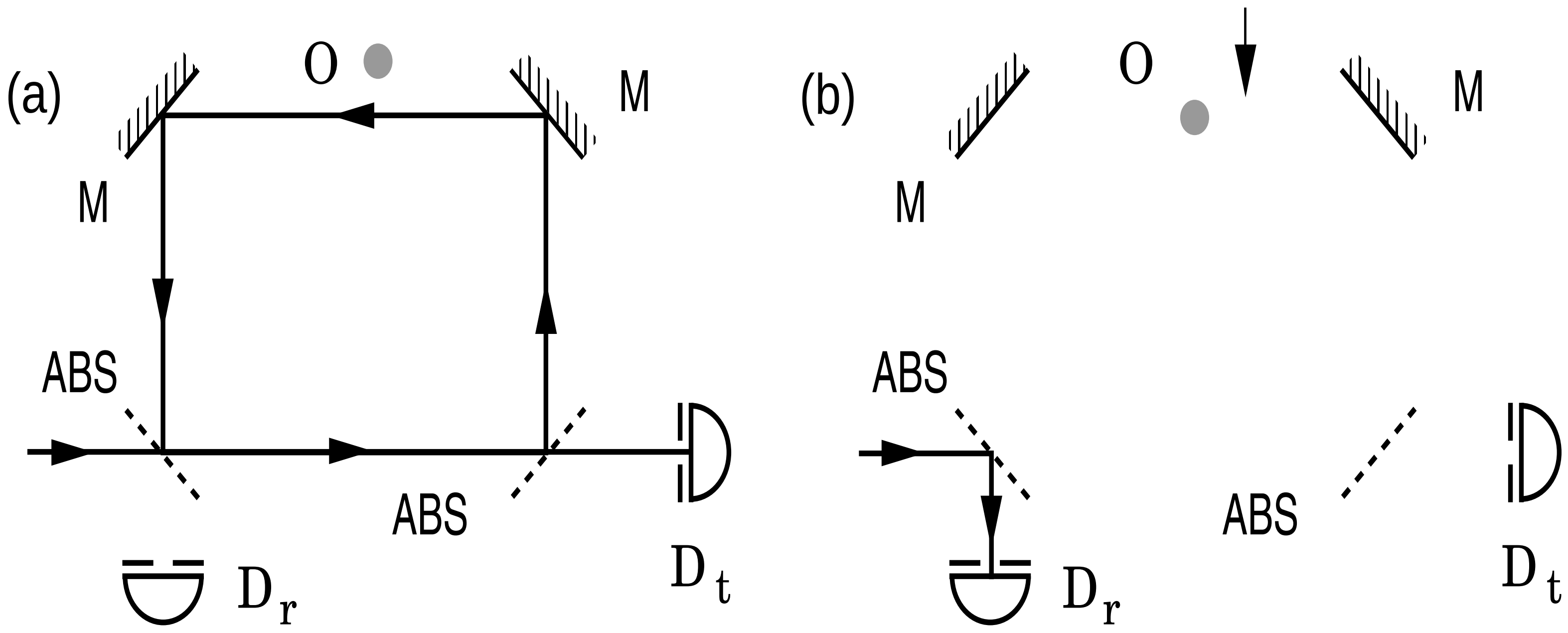
Atom-photon path



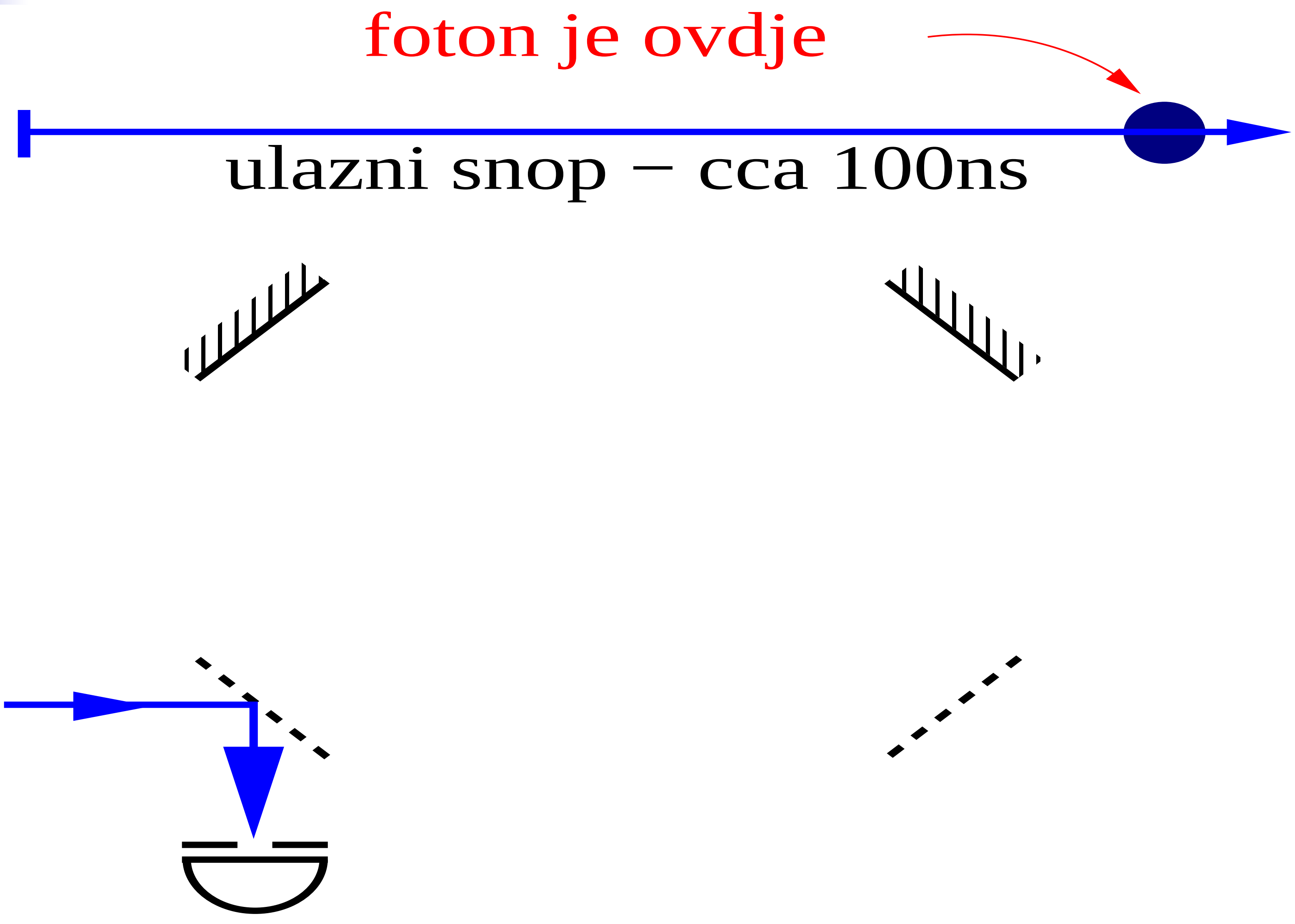
Mladen Pavičić, Nondestructive interaction-free atom-photon controlled-NOT gate, *Physical Review A*, **75**, 032342-1-8 (2007)

Prstenasti rezonator

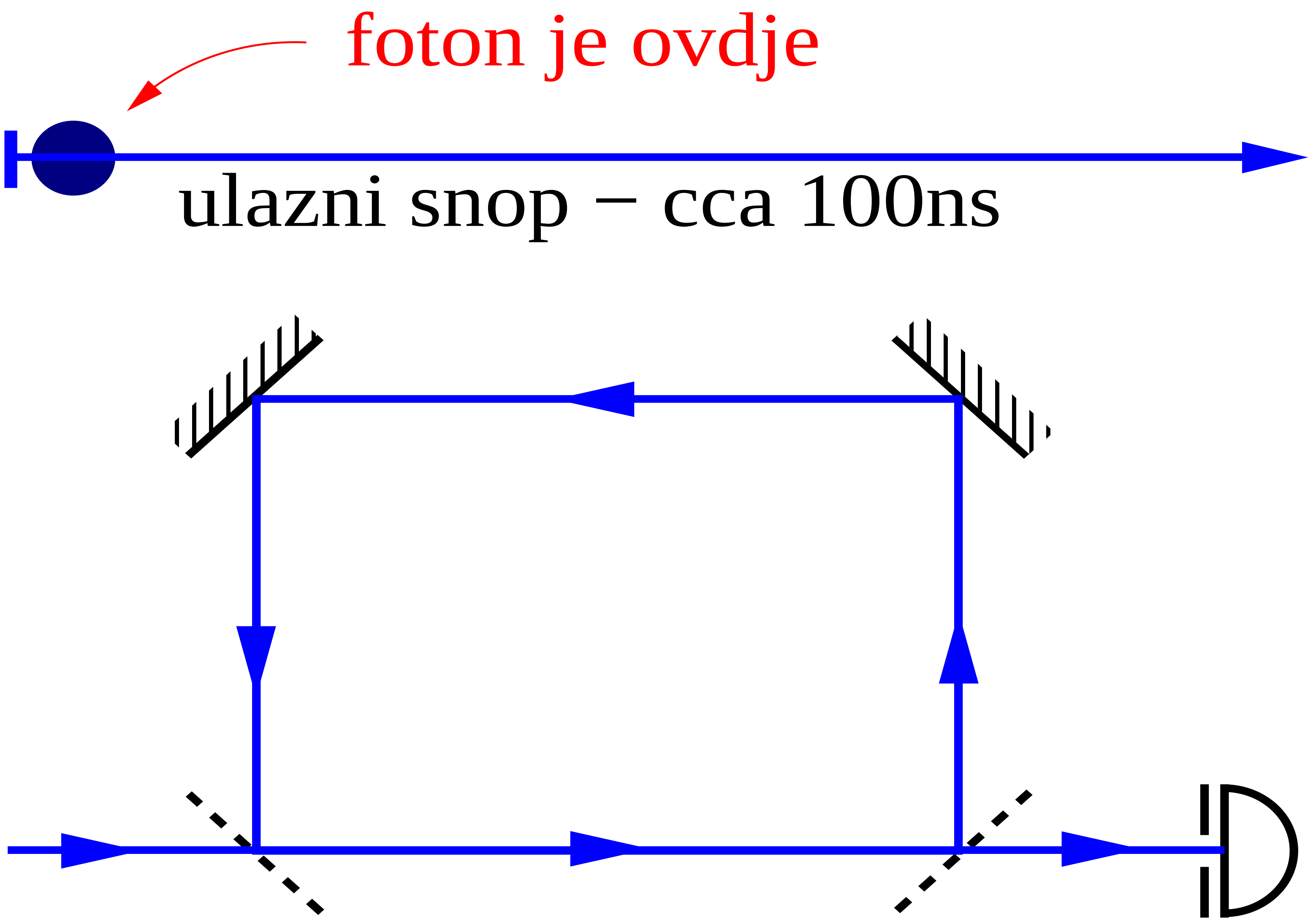
Mladen Pavičić, Resonance Energy-Exchange-Free Detection and ‘Welcher Weg’ Experiment, *Physics Letters A*, **223**, 241-245 (1996):



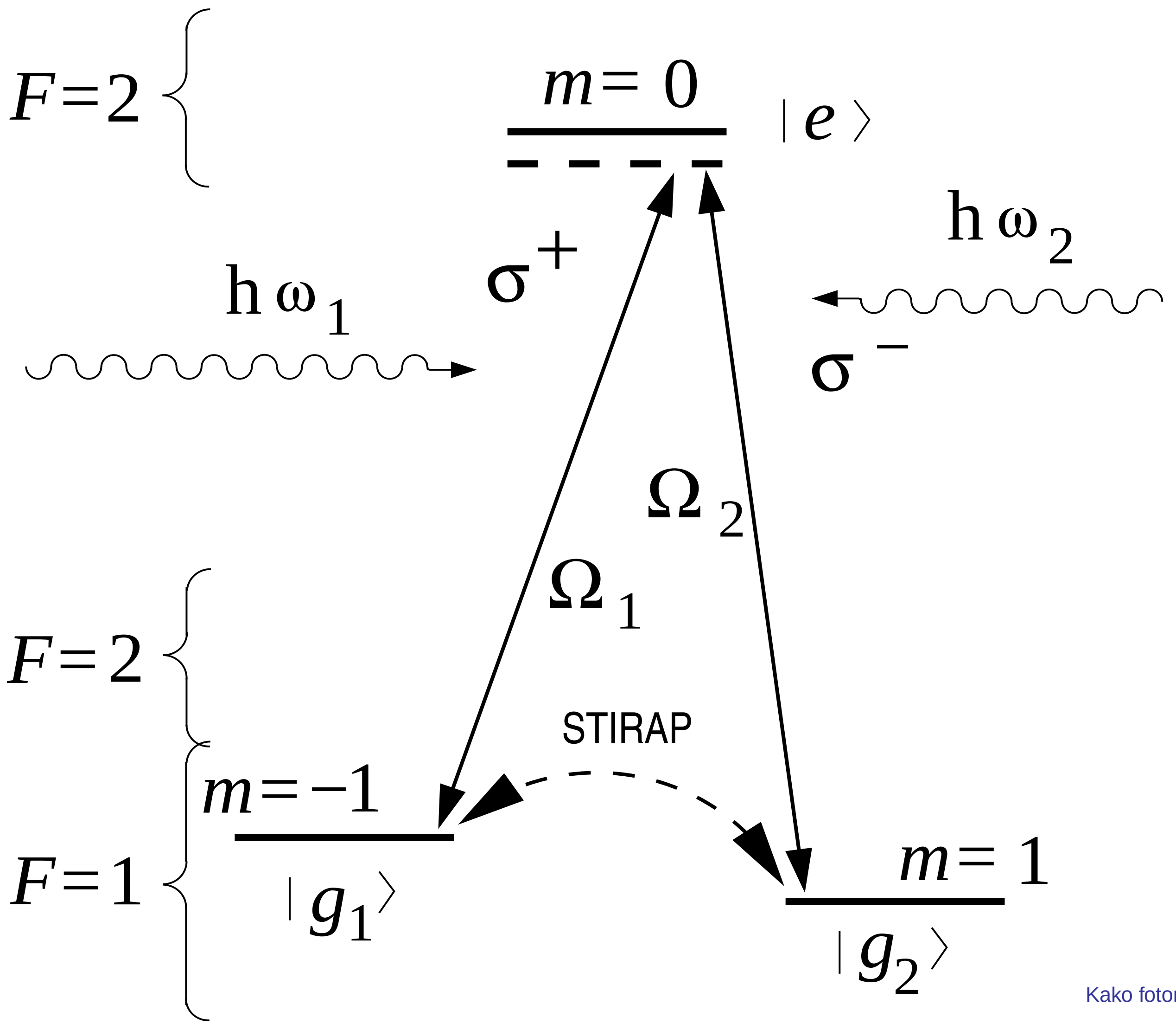
Naš eksperiment



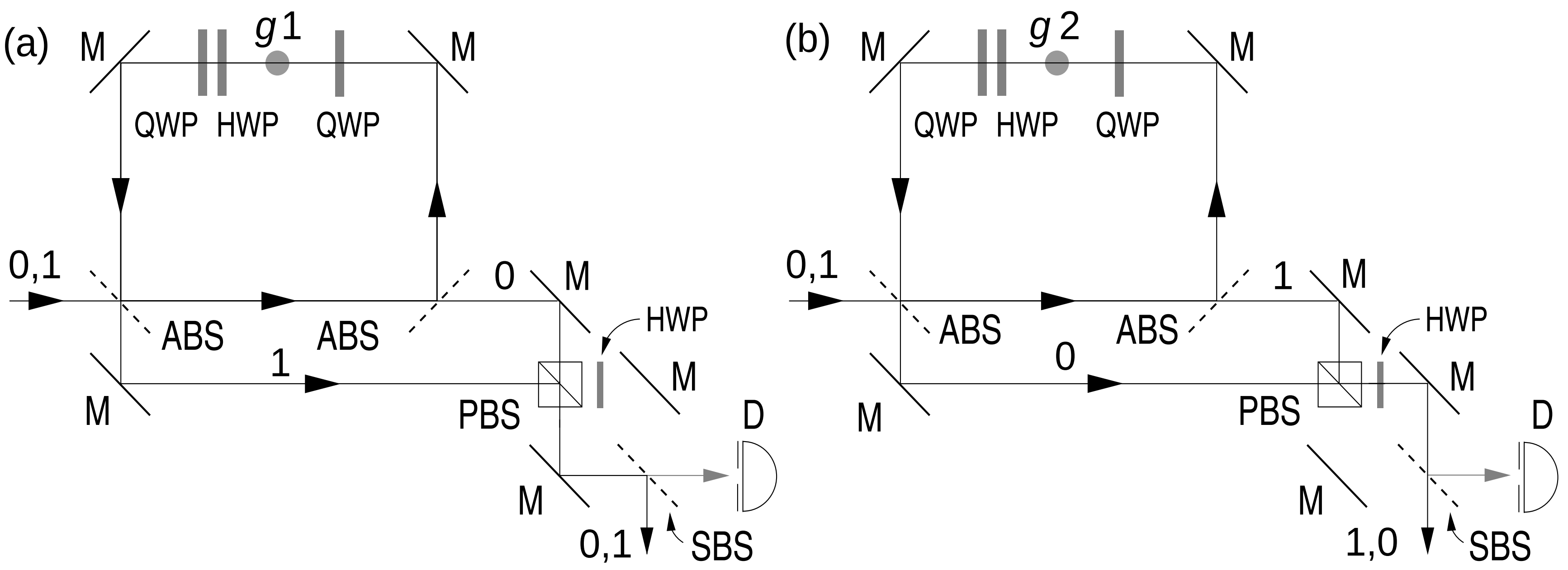
Naš eksperiment



STIRAP $|g_1\rangle \leftrightarrow |g_2\rangle$



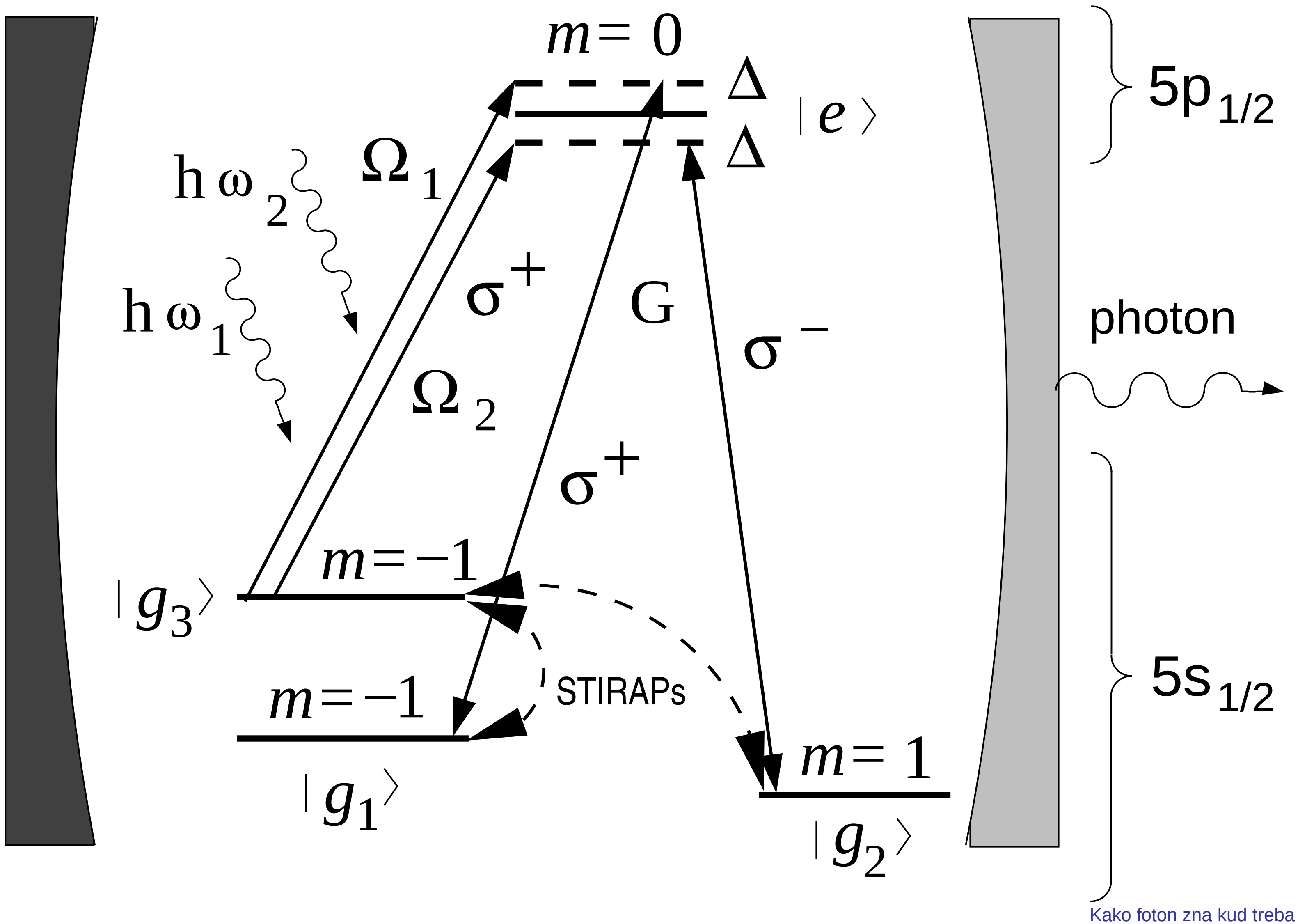
Interaction-free CNOT gate



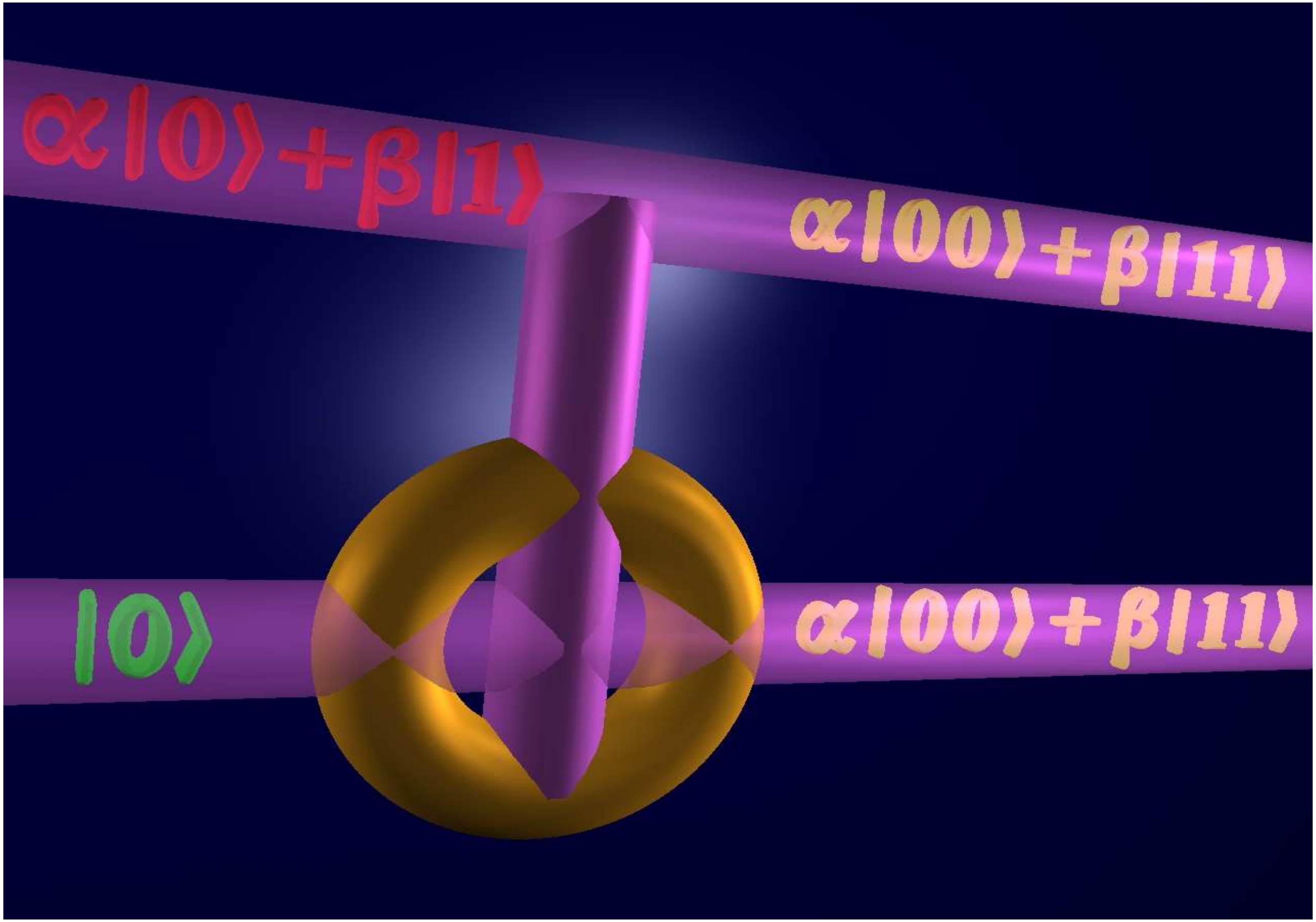
(a) atom je u stanju $|g_1\rangle$ i može absorbirati $|1\rangle$;
(b) atom je u stanju $|g_2\rangle$ i može absorbirati $|0\rangle$;

$$|00\rangle \to |00\rangle,\ |01\rangle \to |01\rangle,\ |10\rangle \to |11\rangle,\ |11\rangle \to |10\rangle$$

Atom u superpoziji stanja



Spregnuta atom-foton stanja



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Potpisan ugovor po pozivu za

Mladen Pavičić, Companion to Quantum Compution and Communication, John Wiley & Sons & VCH (2009).