Entangling gates in Neutral atoms via the Spin-flip blockade

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Motivation

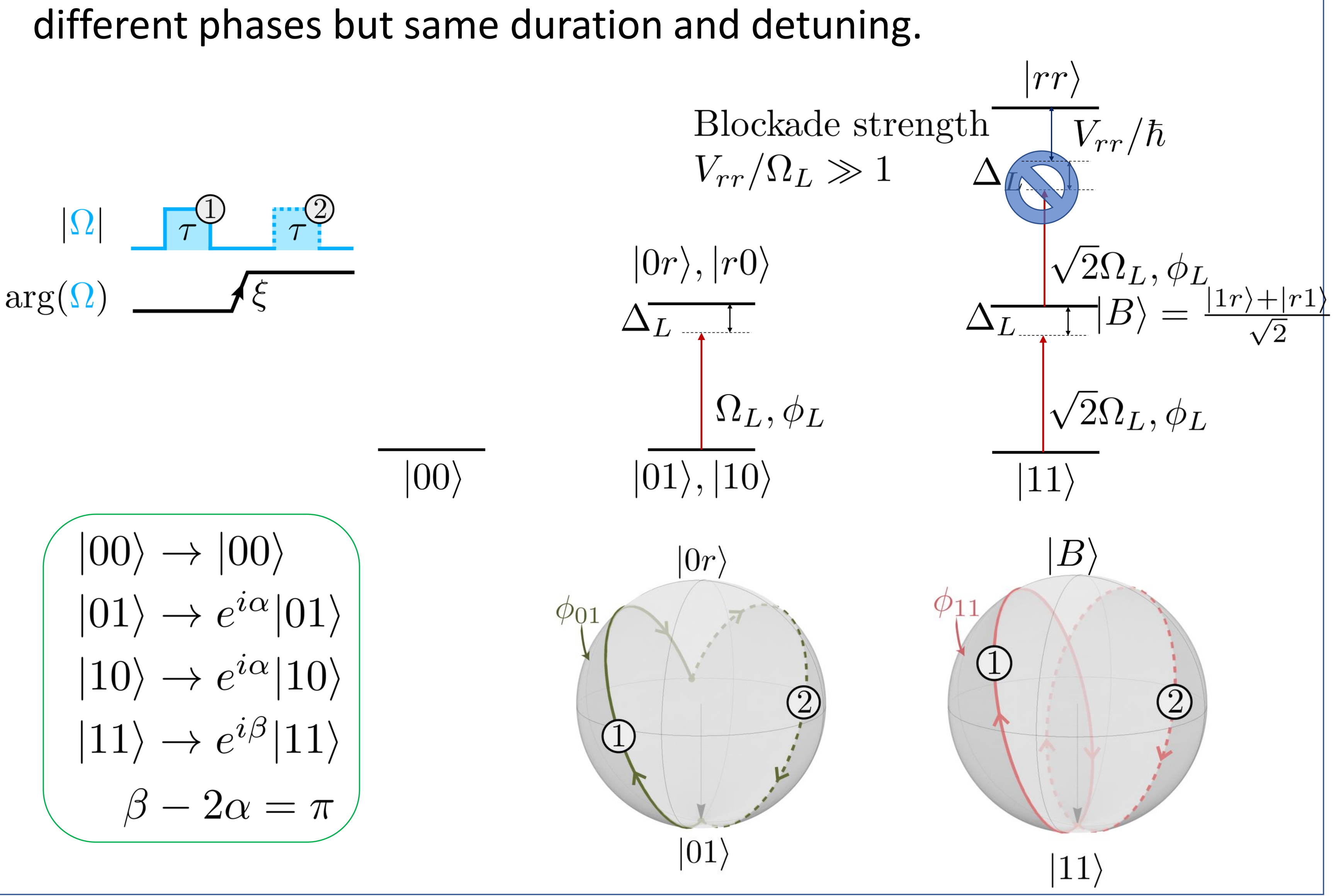
- Neutral atom quantum computation promises us a scalable way of implementing quantum circuits
- Entangling gates in Neutral atoms are implemented via the Rydberg states and their fidelities are limited by Rydberg decays.
- Improving these fidelities is an important step on our way to Fault-tolerant neutral atom quantum computers

Background

- We exploit the Rydberg Electric dipole-dipole interaction energy to induce entanglement in Neutral atoms

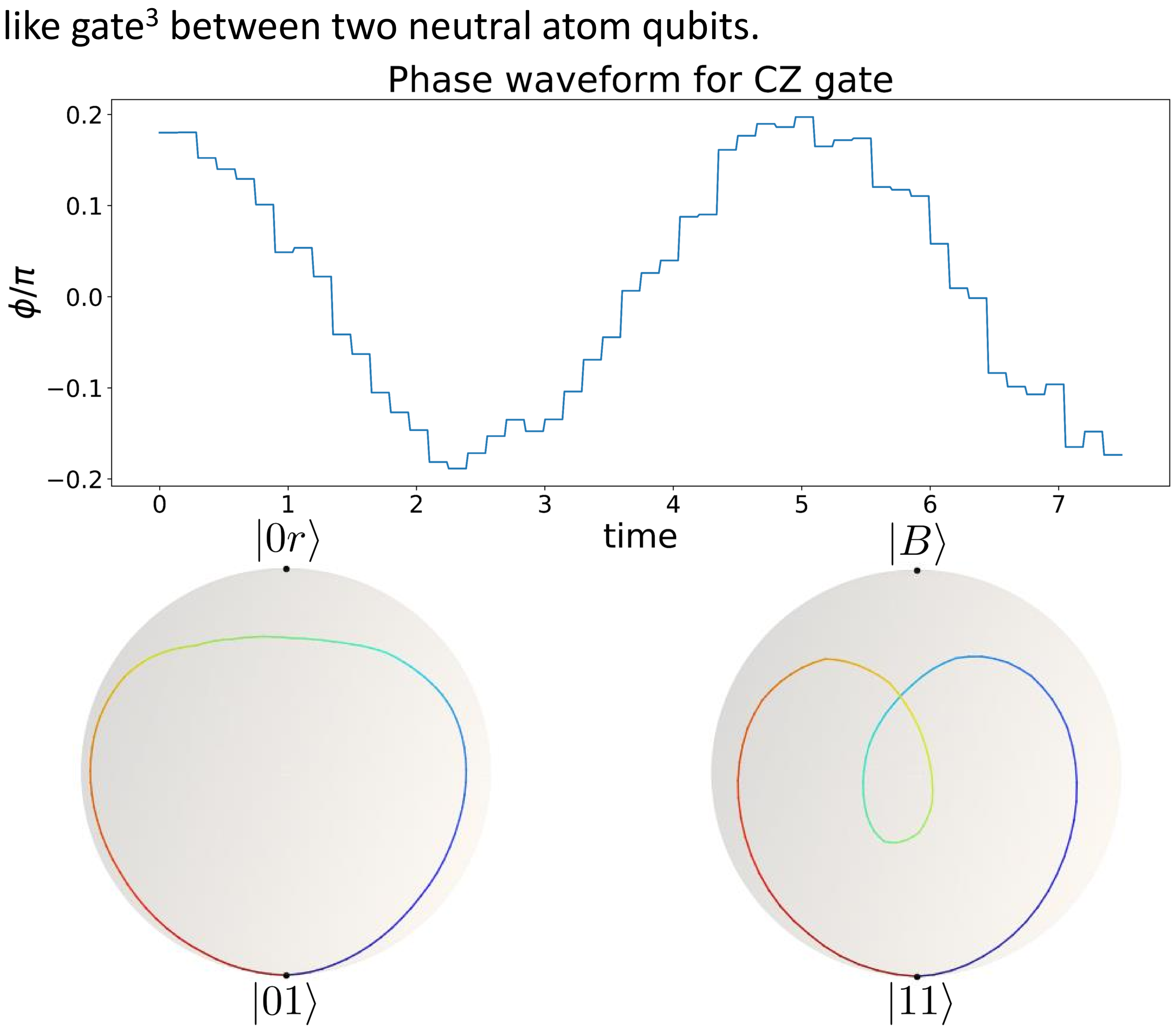
$$H_{int} = V_{rr}|rr\rangle\langle rr|$$

- In the previous protocols, the Rydberg Laser is modulated to induce entanglement between two qubits. The LP gate[2] uses two pulses of different phases but same duration and detuning.



Quantum optimal control

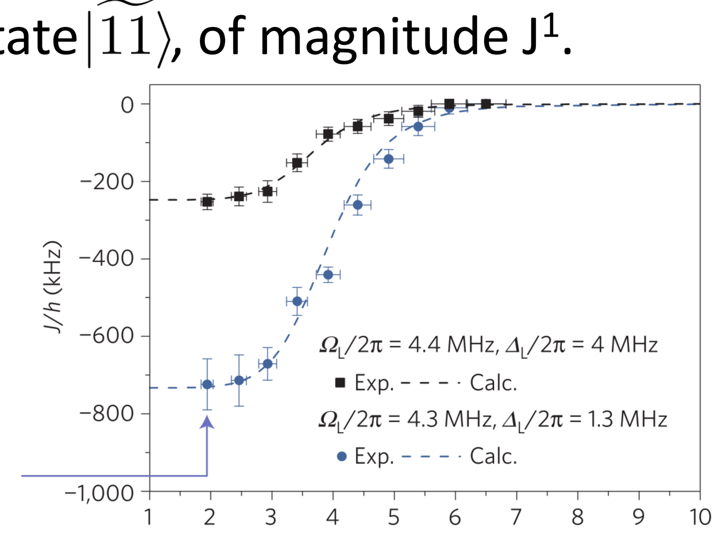
- We use Quantum Optimal control algorithms to optimize for phase gates in Rydberg atoms. Using Gradient Ascent Pulse Engineering (GRAPE) algorithm, we find the phase waveform that implements a CZ-like gate[3] between two neutral atom qubits.

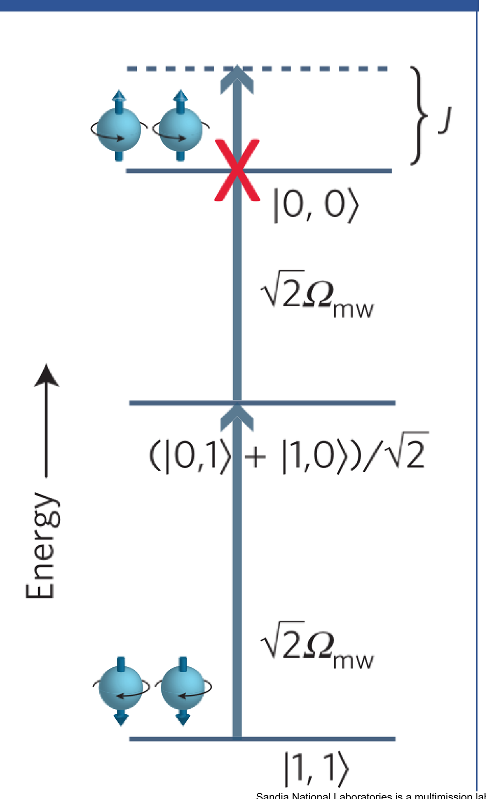


Spin-flip blockade

If a state, say $|1\rangle$, is dressed with the Rydberg laser, it acquires partial Rydberg character. This in turn adds a non-linear light-shift to the two atom dressed state $|\widetilde{11}\rangle$, of magnitude J[1].

$$J = E_{LS}^2 - 2E_{LS}^1$$

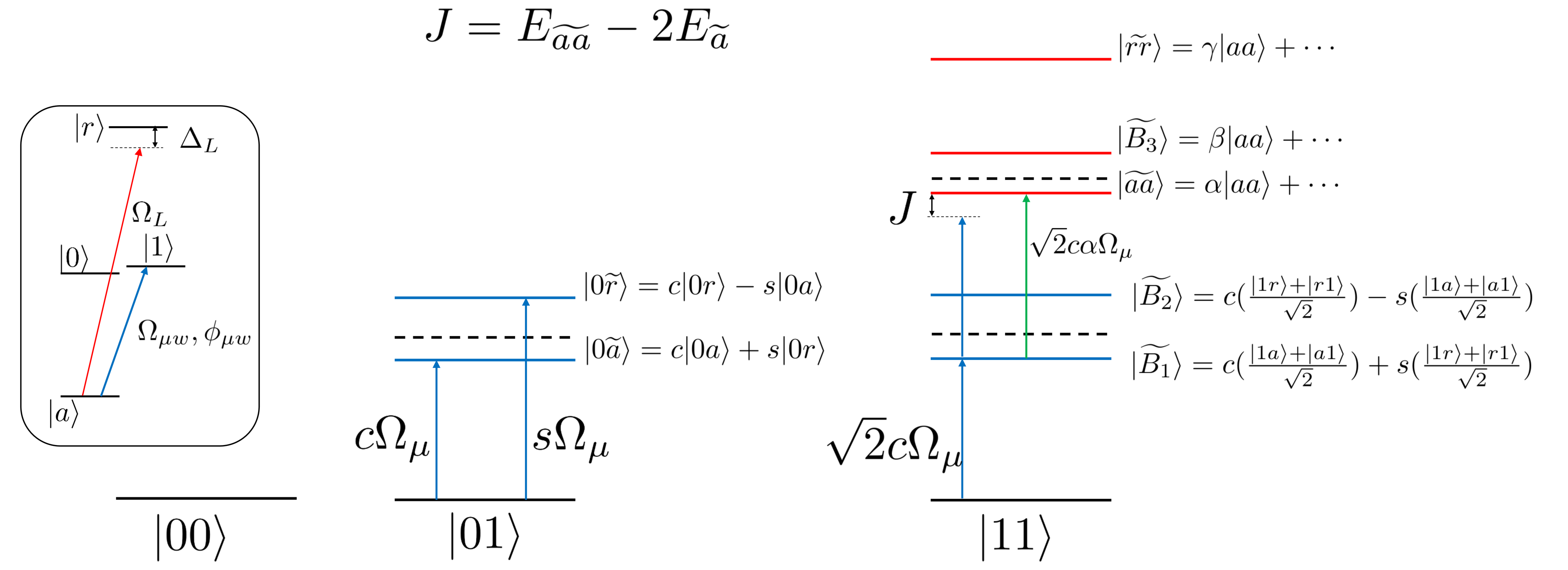




Microwave controlled gates

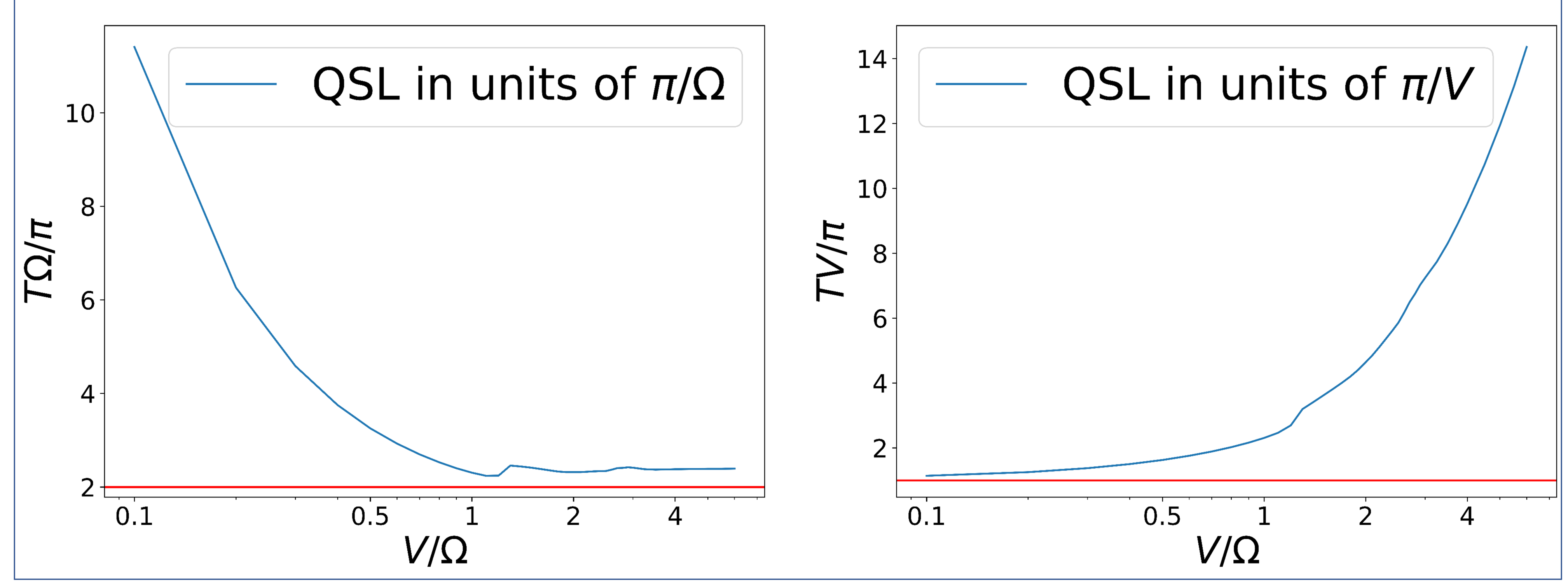
- We utilize Spin-flip blockade to create an entangling interaction within the Hyperfine ground space of a Cesium atom. We dress an auxiliary state $|a\rangle$ to impart it with partial Rydberg character and use it as the stand-in for the Rydberg state within the ground manifold.

$$J = E_{\widetilde{aa}} - 2E_{\tilde{a}}$$



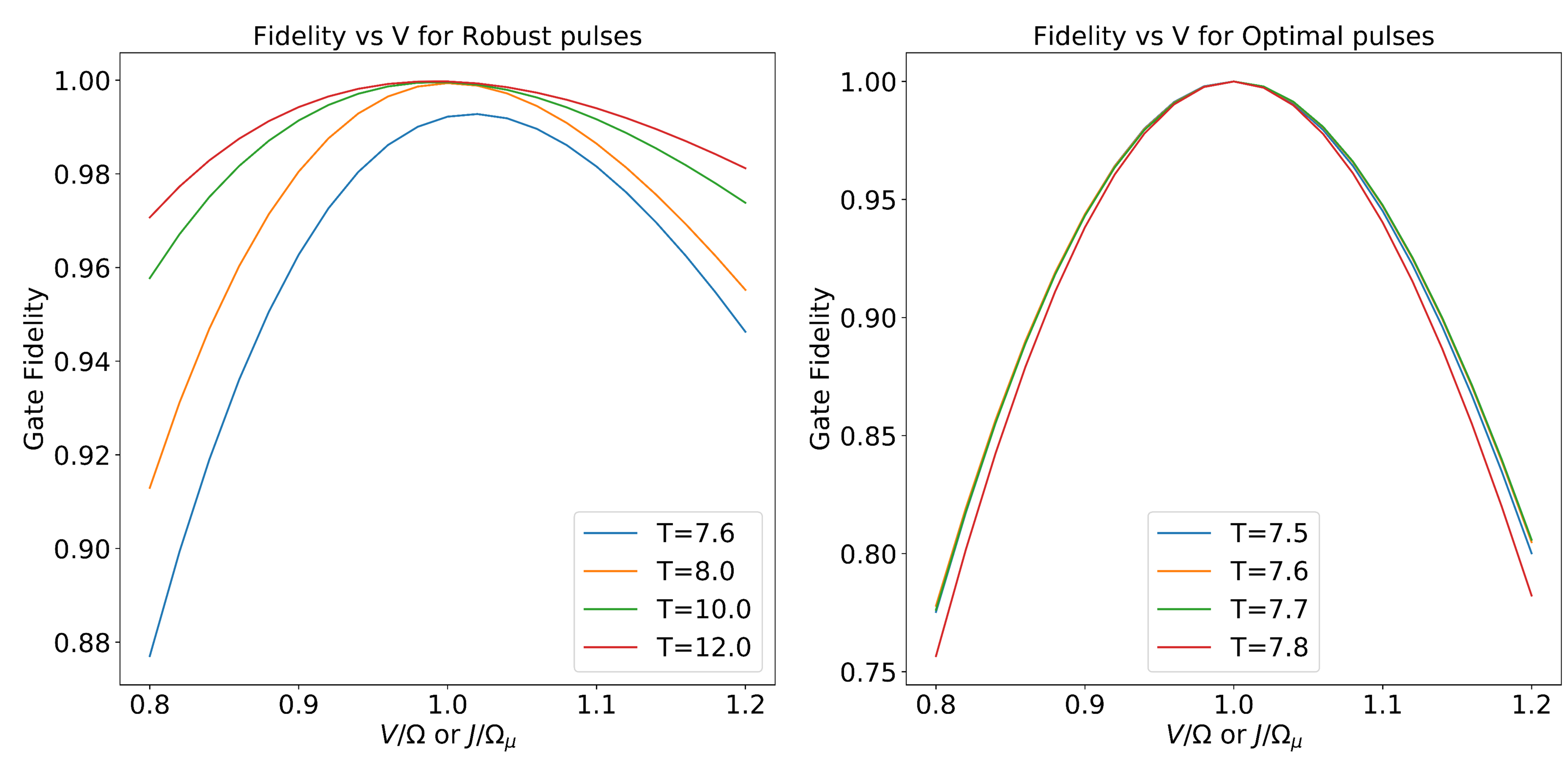
Quantum speed limit

- We find that the Minimum time needed to implement a CZ gate in the units of Ω_μ actually gets faster for smaller blockade strength and saturates to the theoretical minimum for very weak blockade[4].



Quantum robust control

- We use Quantum robust control methods, similar to Optimal control methods, to make our gates robust against variations in a particular parameter



Conclusions

- Using dressed states and Spin-flip Blockade, we can implement entangling gates within the hyperfine regime using a microwave control field. It helps against Doppler noise, and also gives an extra layer of control via the dressing.
- Using Quantum control techniques, we can implement gates at imperfect and weak blockade, which makes our gates faster and more efficient against T_1 decay.
- We can also make our gates Robust against variations in certain parameters which will be important if we use imperfectly blockaded systems.

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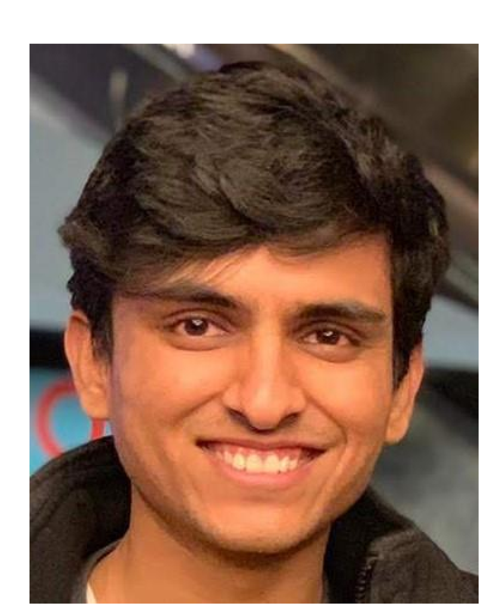

References

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- [2]H. Levine et al, Phys. Rev. Lett. 123, 170503 (2019)
- [3]S. Jandura et al, Quantum 6, 712 (2022)
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