Adiabatic Quantum Operations with UltraStrongly Coupled Artificial Atoms

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quantum control of quantum system

quantum technologies

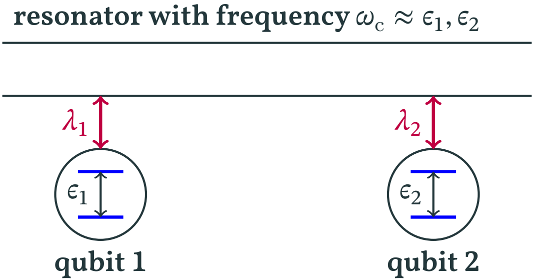
transformations need to be

- high fidelity $\gtrsim 1 - 10^{-4} \longrightarrow$ QEC
- fast
- robust

outline

- system: 2 qubits coupled to a resonator mode
- coupling regimes: Strong Coupling (SC) and Ultra SC (USC)
- adiabatic protocol for state transfer in USC
- numerical results
- conclusion and outlook

system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λ_1
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ϵ_1
ϵ_2
qubit 1
qubit 2

system

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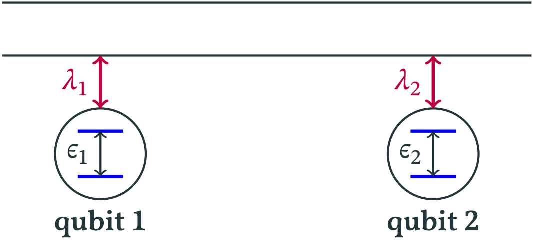

resonator as quantum bus [1] → scalable

[1] F. Plastina and G. Falci. Phys. Rev. B 67, 224514 (2003), I. J. Cirac and P. Zoller. Phys. Rev. Lett. 74, 4091–4094 (1995)

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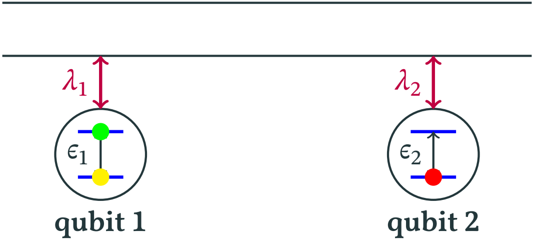

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example of quantum operation: state transfer

$$|0\rangle_c \otimes |g\rangle_2 \otimes \left[a|g\rangle + b|e\rangle \right]_1 \rightarrow |0\rangle_c \otimes \left[a|g\rangle + b|e\rangle \right]_2 \otimes |g\rangle_1$$

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Strong Coupling (SC): $\kappa, \gamma \ll \lambda \ll \omega_c, \epsilon_i$

Hamiltonian

$$H_{\mathrm{RW}} = \omega_c a^\dagger a - \frac{1}{2}\sum_{i=1}^{2} \epsilon_i(t)\sigma_i^z + \sum_{i=1}^{2} \lambda_i(t)\left(a^\dagger \sigma_i^- + a\sigma_i^+\right)$$

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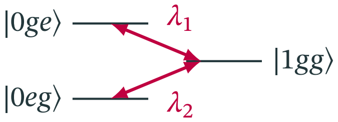

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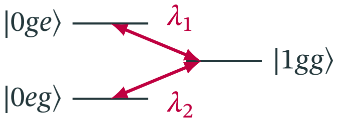

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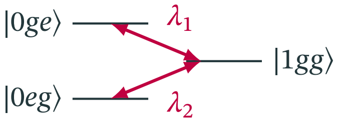

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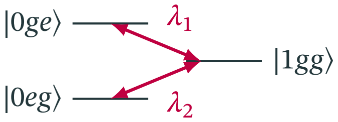

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Ultra Strong Coupling (USC) is a natural candidate for implementation of faster quantum operations

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problems

- the resonator may provide many (virtual) photons
- Dynamical Casimir Effect (DCE) limits the fidelity [2]

[2] G. Benenti, A. D'Arrigo, S. Siccardi, and G. Strini, Phys. Rev. A 90, 052313 (2014)

proposed solution

resonator as a **virtual quantum bus** [3] → **adiabatic protocol similar to STIRAP** [4]

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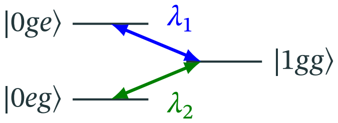
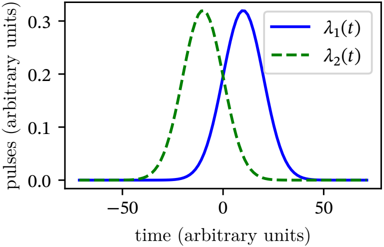
evolution in $N = 1$ subspace





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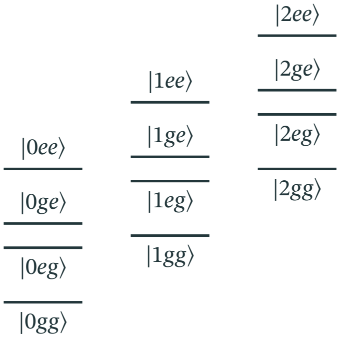

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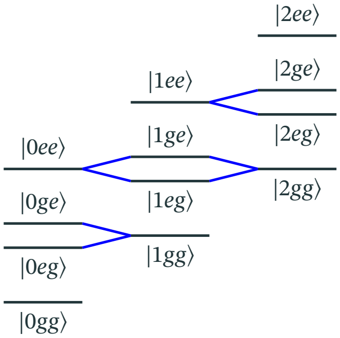

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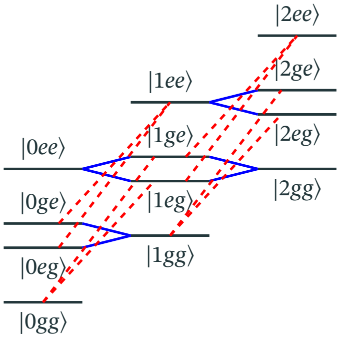

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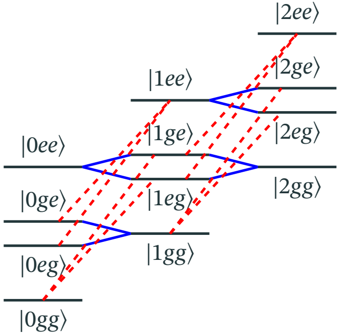
low energy Hamiltonian ↓

$$\tilde{H} = (P_0 + P_1)H_{\mathrm{Rabi}}(P_0 + P_1) + \delta H$$



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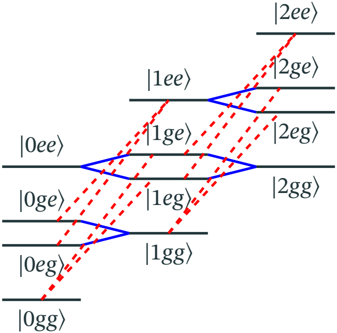

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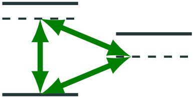

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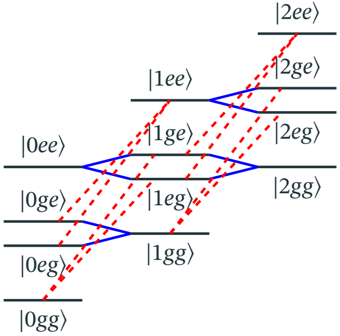

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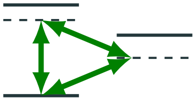

new solution for dark-state

detuning modulated [5]

$$\epsilon_2(t) - \epsilon_1(t) = \frac{\lambda_1(t)^2 - \lambda_2(t)^2}{\omega_c}$$

$$\epsilon_1(t) = \omega_c - \frac{2\lambda_1(t)^2 + \lambda_2(t)^2}{2\omega_c}$$

[5] T.J. Pope, *et al.*, Jour. Stat. Mech. (2019)

results

Theorem

conservation of parity $\Rightarrow$ fid. of pop. trans. = fid. of state trans.,
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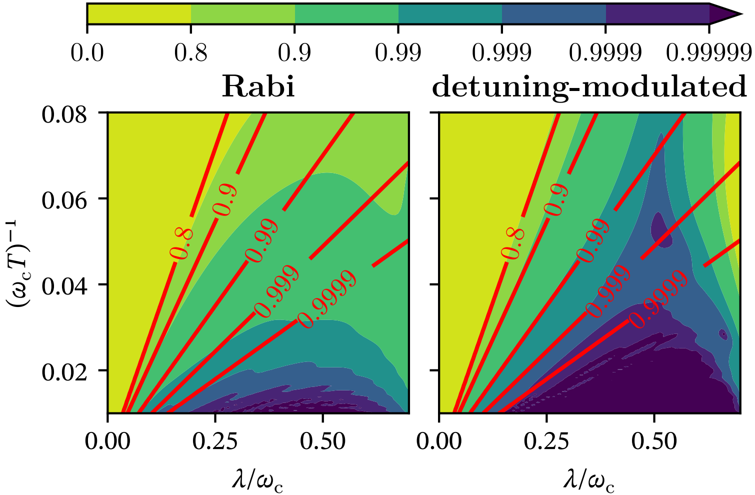

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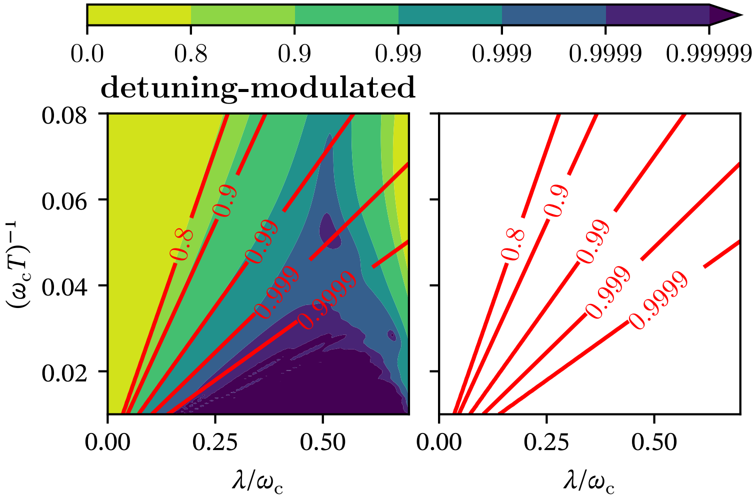

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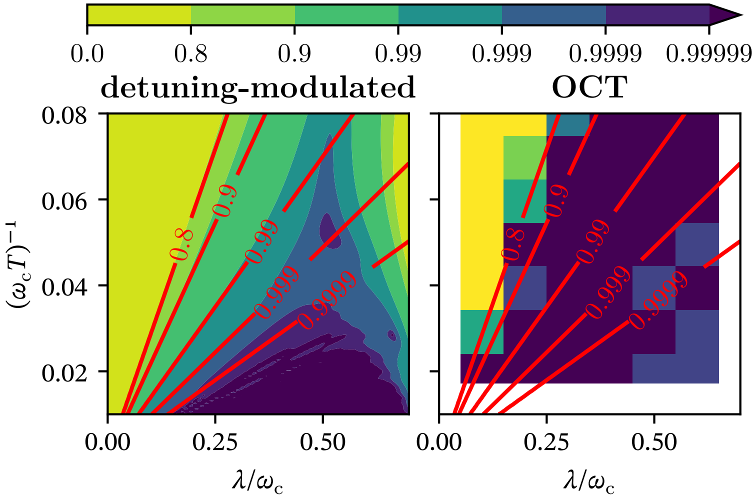
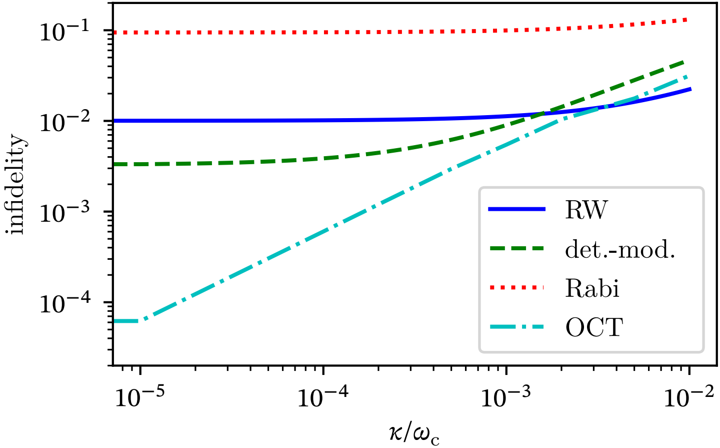


infidelity vs decay rate of the cavity



simulations with Lindblad master equation

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outlook

- Theorem: state transfer = final rotation $\circ$ population transfer
- entanglement generation in multiqubit systems
- two-qubits gate?

thank you