Stabilization and operation of Kerr-cat qubits

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April 26, 2022

Outline

- Quantum error correction with bosonic codes
    - Cat codes
- Kerr-cat qubits
- Coupled Kerr-cat qubits

Quantum error correction (QEC)

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  - Environmental noise is typically only locally correlated

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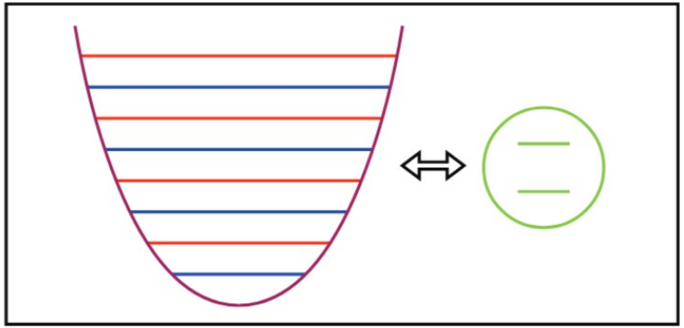

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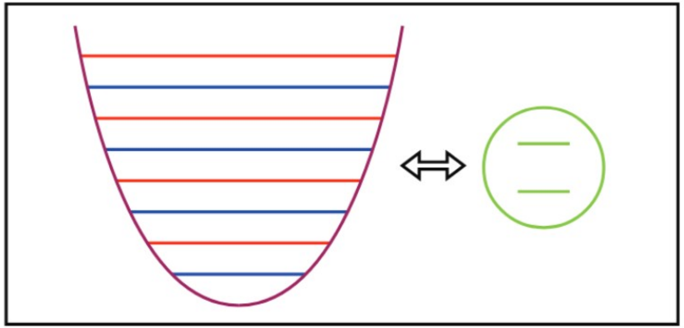

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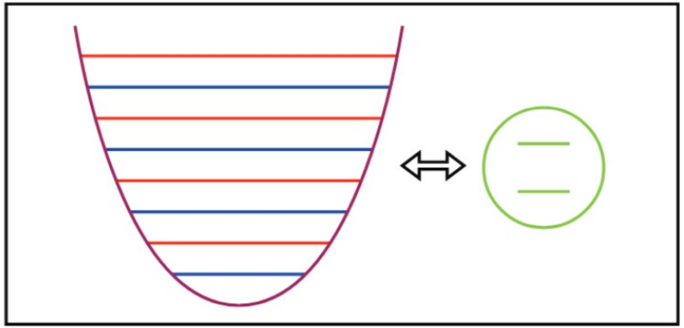

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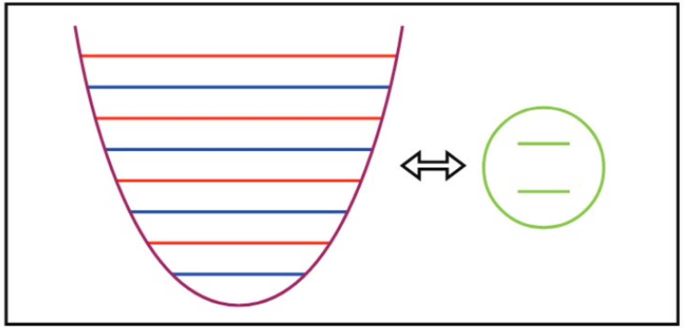

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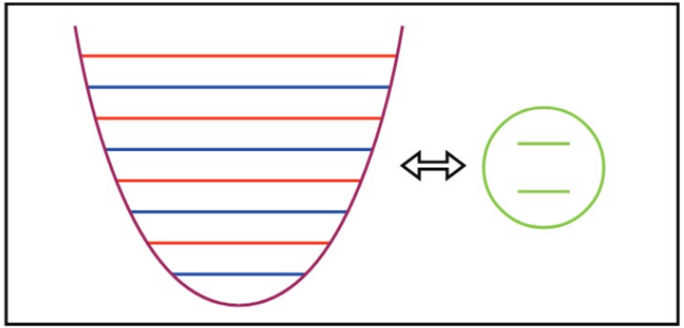

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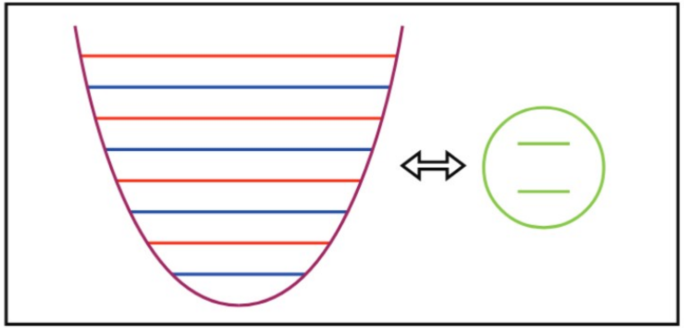

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- Encode logical qubit basis states as Schrödinger cat states:

$$|C_\alpha^\pm\rangle = \mathcal{N}_\alpha^\pm(|\alpha\rangle \pm |-\alpha\rangle), \quad \mathcal{N}_\alpha^\pm = \frac{1}{\sqrt{2\left(1 \pm e^{-2|\alpha|^2}\right)}}$$

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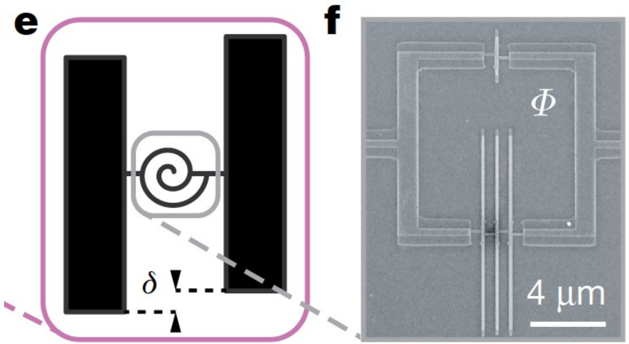
- Note that $\hat{a}\,|C_\alpha^\pm\rangle = \alpha\,|C_\alpha^\mp\rangle$
    - Photon loss → bit flip error
    - Detect through non-destructive photon number parity measurement

Creating cat states with a Kerr nonlinearity

Grimm et al. Stabilization and operation of a Kerr-cat qubit, Nature (2020)



- Nonlinear superconducting resonator inside a 3D cavity
- Two-photon squeezing drive (through three-wave mixing)
- Hamiltonian:

$$\hat{H}_s/\hbar = -K\hat{a}^{\dagger 2}\hat{a}^2 + \epsilon_2\hat{a}^{\dagger 2} + \epsilon_2^*\hat{a}^2$$

- Degenerate eigenstates at $|\pm\alpha\rangle = |\pm\sqrt{\epsilon_2/K}\rangle$

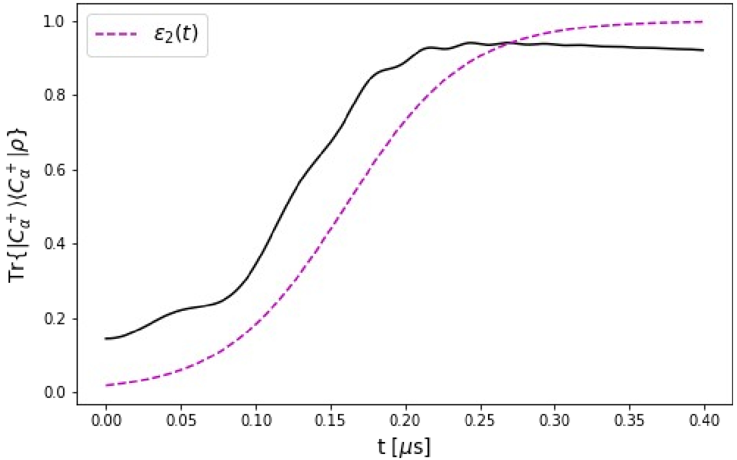
Creating cat states with a Kerr nonlinearity

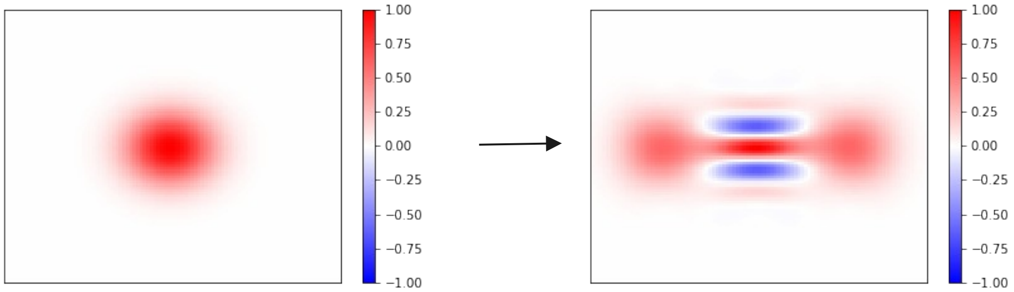
Procedure for initializing a cat state:

1. Begin in the ground state of the resonator (the n=0 Fock state) with the two-photon drive turned off
2. Slowly ramp up the amplitude of the two-photon drive $\epsilon_2 \hat{a}^{\dagger 2} + \epsilon_2^* \hat{a}^2$
3. Because the squeezing Hamiltonian preserves photon number parity, this process adiabatically maps the resonator ground state onto $|0_L\rangle = |C_\alpha^+\rangle$!

Generation of cat states

Simulation of the master equation describing this system with single-photon loss using realistic parameters





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Apply a single-photon drive

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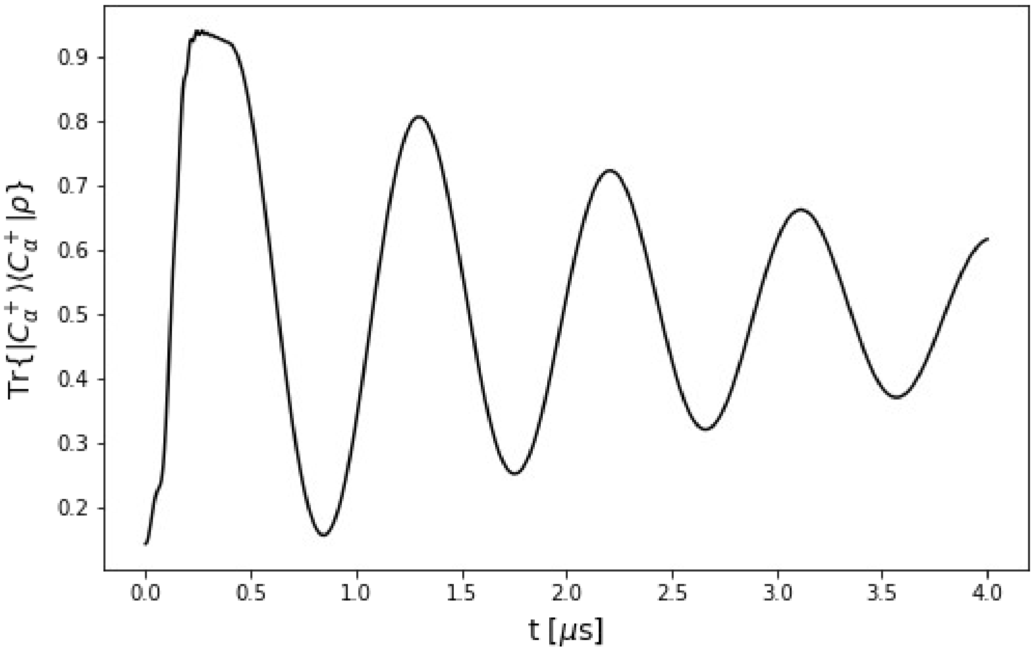


Two cat qubits

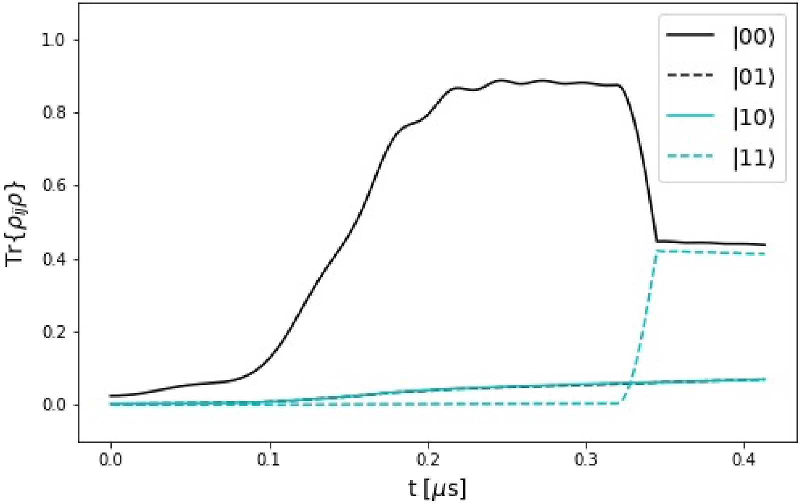
As a simple model for two coupled cat qubits, consider a coupling Hamiltonian:

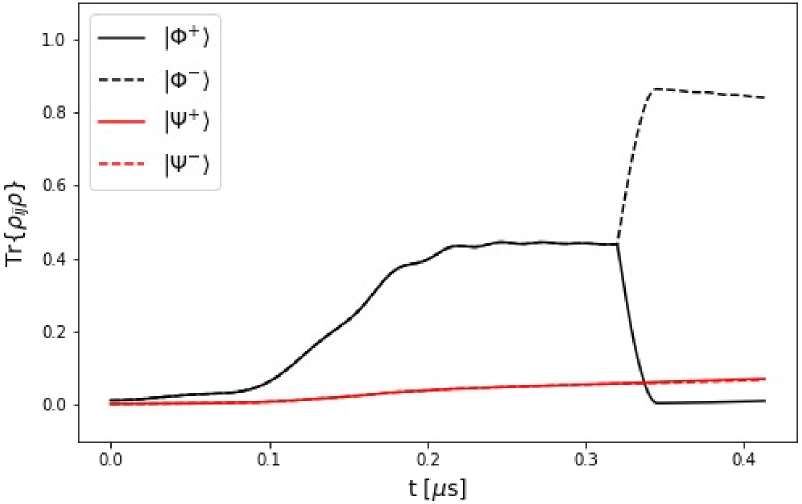
$$\hat{H}_c/\hbar = g(t)(\hat{a}_1^\dagger \otimes \hat{a}_2 + \hat{a}_1 \otimes \hat{a}_2^\dagger)$$

It turns out that if we project this onto the subspace spanned by the logical (cat) qubits, it is proportional to $\sigma_x \otimes \sigma_x$, which we can use as an entangling gate!

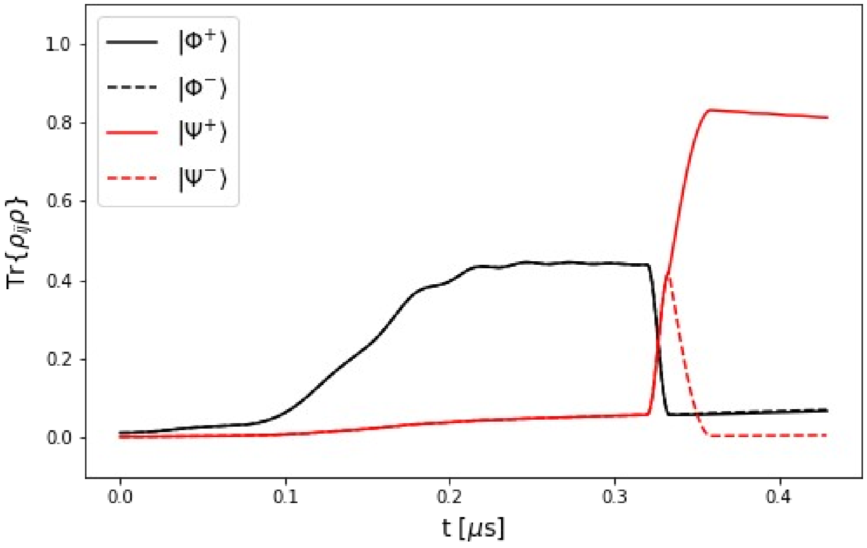
Note: for simplicity I'm assuming the interaction can be turned on and off with g(t)

Two-qubit entangling gate





… or create other Bell states



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- Do a more careful calculation of gate fidelities
- Do a comparison to simply encoding the qubit in the first two Fock states (decay times, gate fidelities, etc.)

the end. enjoy these additional cat states :)