Superconducting Circuits for Quantum Information Processing

Master QLMN - Experimental quantum computing

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Errata

- Page 12, the number operator can then be mapped from $\hat{\boldsymbol{n}} - \frac{1}{2}\hat{\mathbb{I}}$ to $-\frac{1}{2}\hat{Z}$, which is represented as:

$$\frac{1}{2}\begin{pmatrix} -1 & 0 \\ 0 & 1 \end{pmatrix}.$$

- Page 12 also, I used $\boldsymbol{\sigma}_- = \begin{pmatrix} 0 & 1 \\ 0 & 0 \end{pmatrix}$ but sometimes it is referred to as $\boldsymbol{\sigma}_+$

Groups Working on Superconducting Circuits

Several major players and startups are actively advancing superconducting qubit technology as of 2026:

Qubit Technology	Groups / Institutes
JJ based qubits	ETH Zurich, IBM, Google, Rigetti, MIT, University of Maryland, IQM Quantum Computers, Fujitsu / RIKEN, Oxford Quantum Circuits
Transmons + cat code	AWS
Cat code	Alice&Bob, Yale, ENS Lyon / ENS Ulm
GKP code	Nord Quantique, ENS Ulm, MIT
Dual-Rail / Erasure Qubits	Quantum Circuits Inc, Yale

Introduction

Nobel Prize in Physics 2025

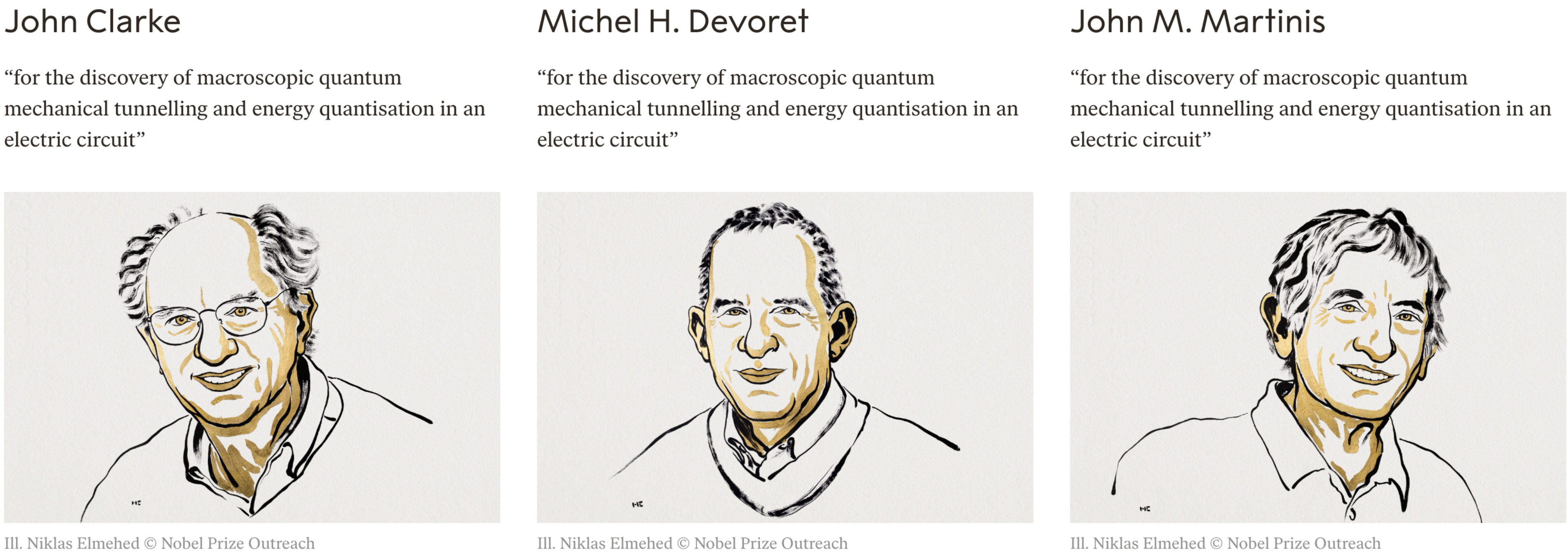

Figure 1: **Nobel Prize in Physics 2025**: Awarded to John Clarke, Michel H. Devoret, and John M. Martinis for the discovery of macroscopic quantum mechanical tunnelling and energy quantisation in an electric circuit.

Nobel Prize 2025

Quantum Harmonic Oscillator

Experimental Setup[1]

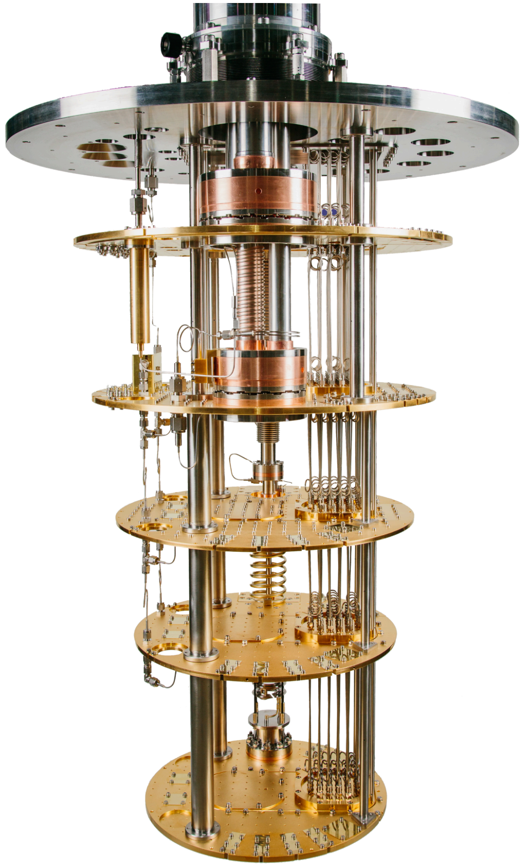

Figure 2: **Dilution Refrigerator**: Operating at $T \leq 20$ mK to ensure $k_B T \ll \hbar\omega_0$.

1. Figure 2 is taken from Oxford instrument website.

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The Transmon Qubit

History of Superconducting Circuits

- **1985**: Discovery of macroscopic quantum mechanical tunnelling and energy quantisation in an electric circuit (Martinis, Devoret, and Clarke 1985).
- **1985**: Creation of the quantronics group at CEA Saclay.
- **1999**: First coherent control of a macroscopic quantum two-state system (Cooper Pair Box) (Nakamura, Pashkin, and Tsai 1999).
- **2007**: Invention of the Transmon qubit (Koch et al. 2007).

LC Circuit & Potential[1]

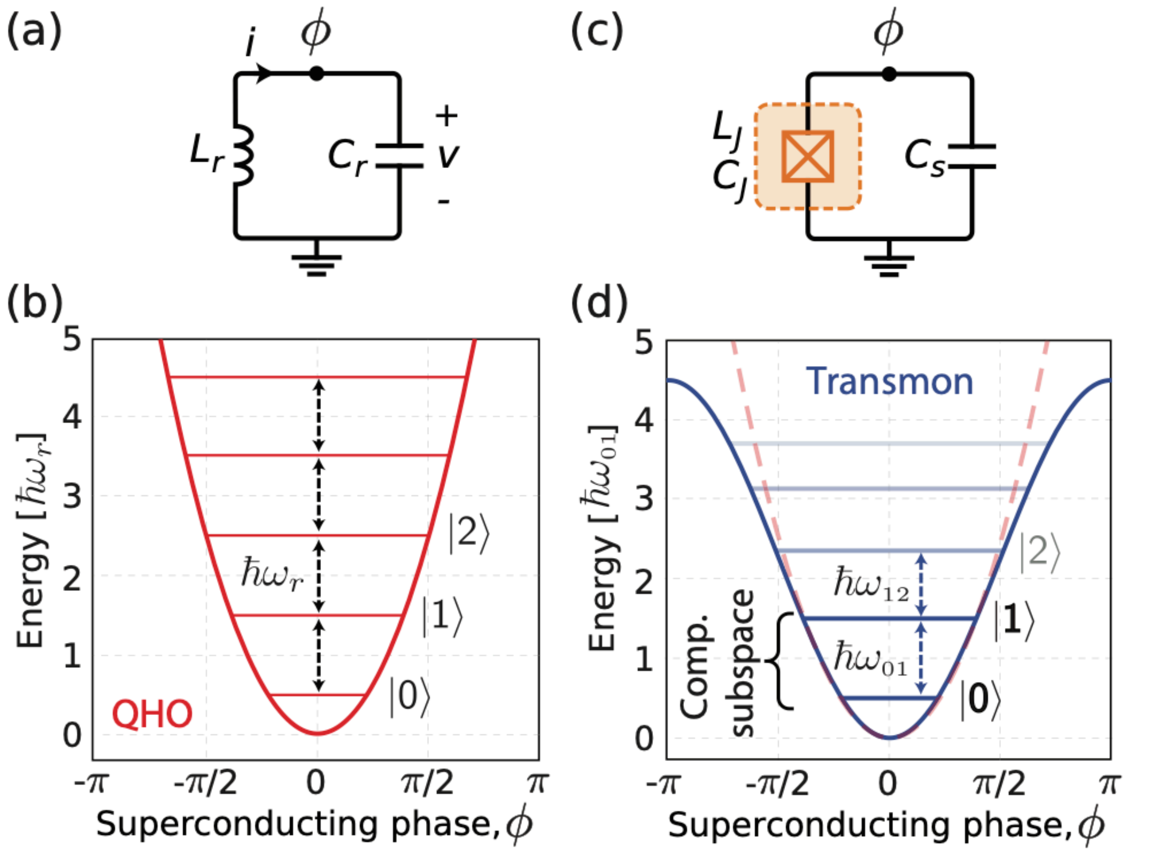

Figure 3: **a** Circuit for a parallel LC-oscillator. **b** Quadratic energy potential. **c** Josephson qubit circuit. **d** Cosine potential yielding anharmonicity.

1. Krantz et al. (2019)

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Real Device

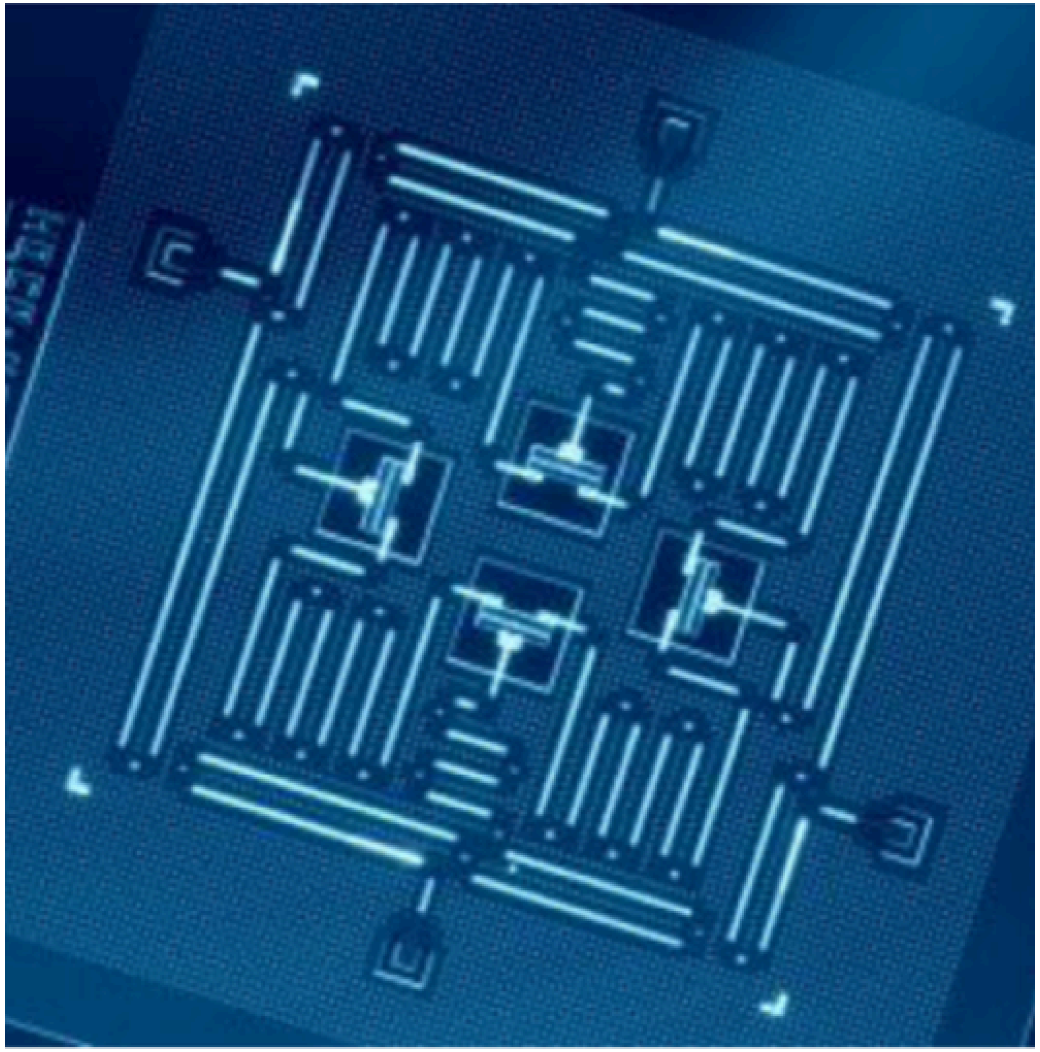

Figure 4: Multi-qubit transmon processor.

Phase Space

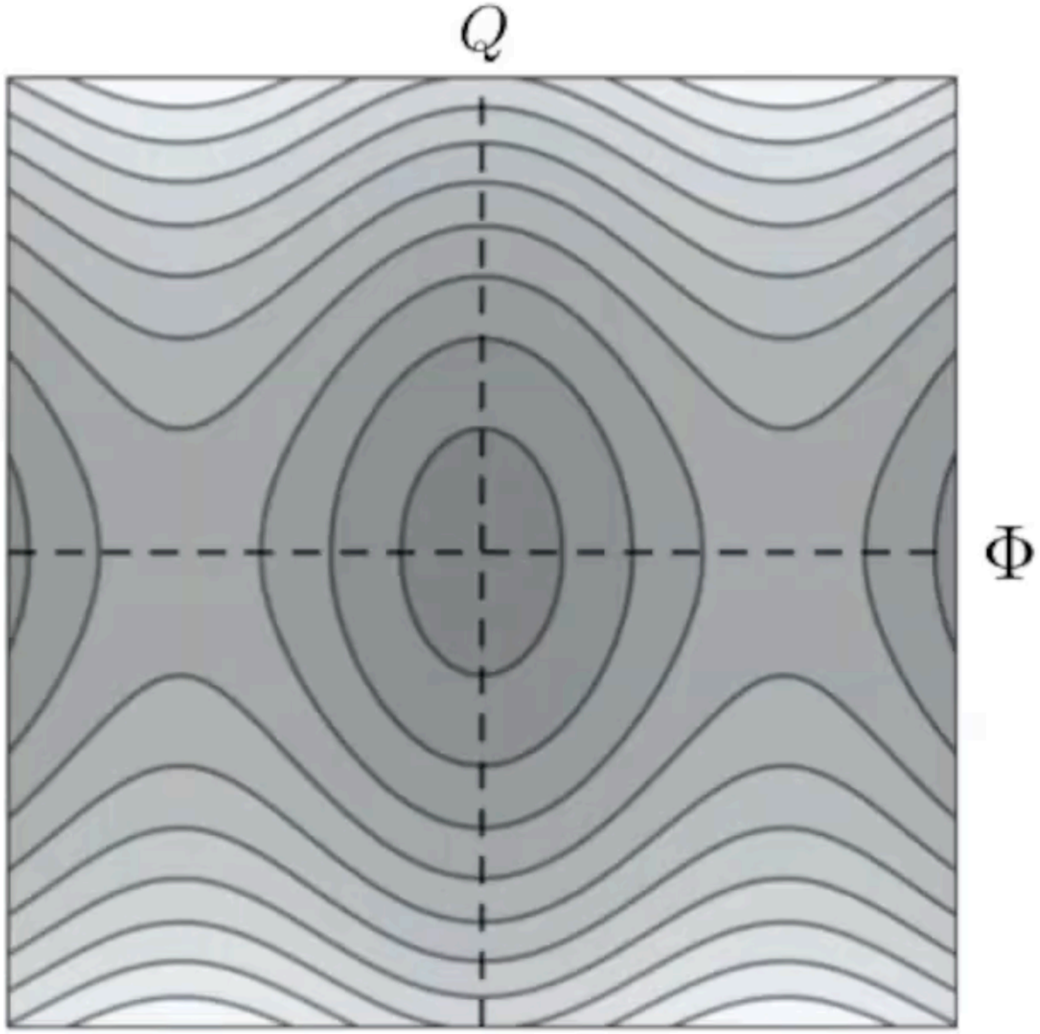

Figure 5: Eigenenergies of the Transmon Hamiltonian in phase space (Q vs Φ).

Superconducting Qubit Zoo

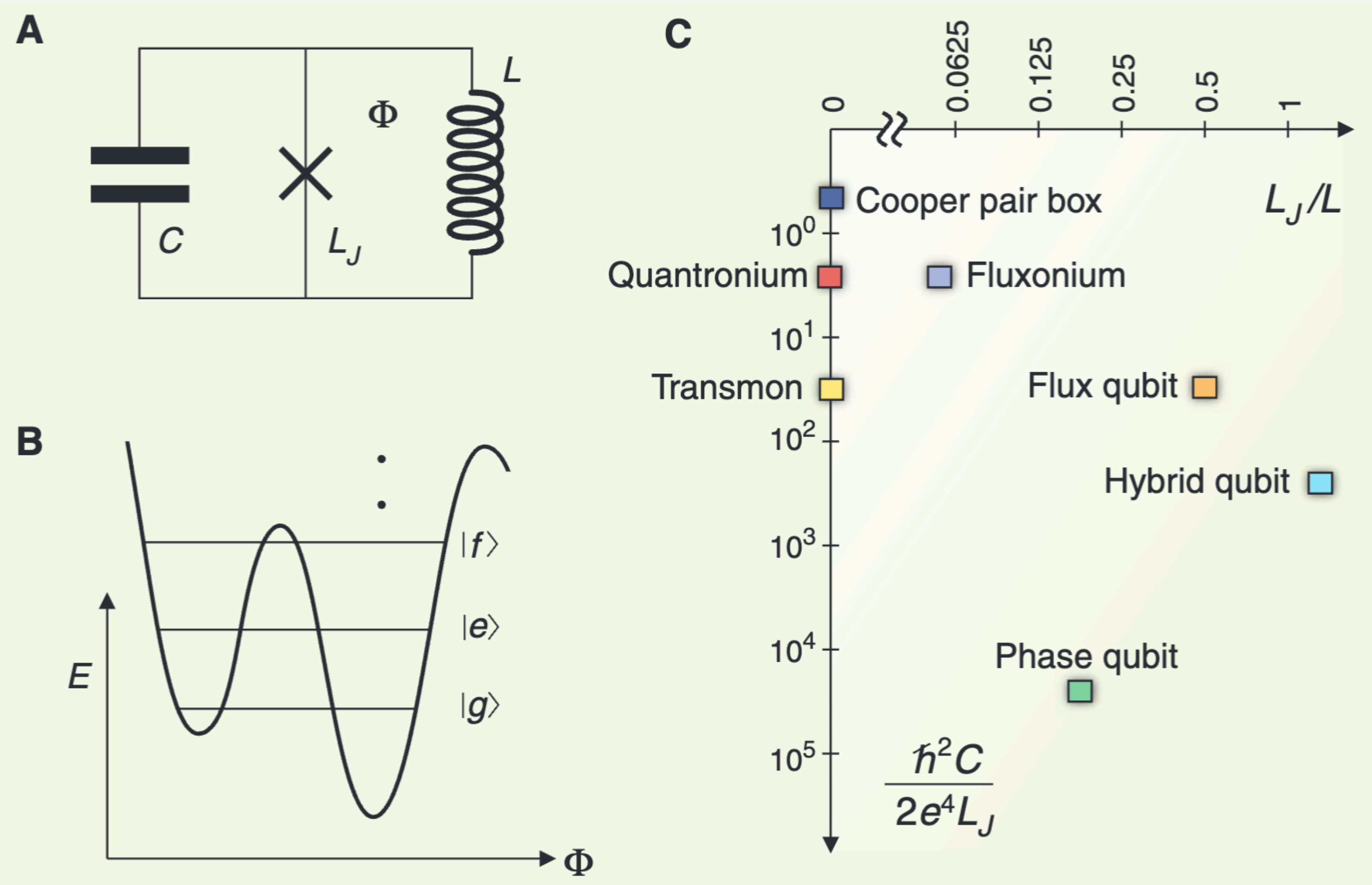

Figure 6: The landscape of superconducting qubits defined by E_J, E_C, and E_L.

Coherence Times

Figure 7: Evolution of T_1 and T_2 times over two decades. See Awesome Quantum Computing Experiments.

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Bosonic Encoding

Damped cavity

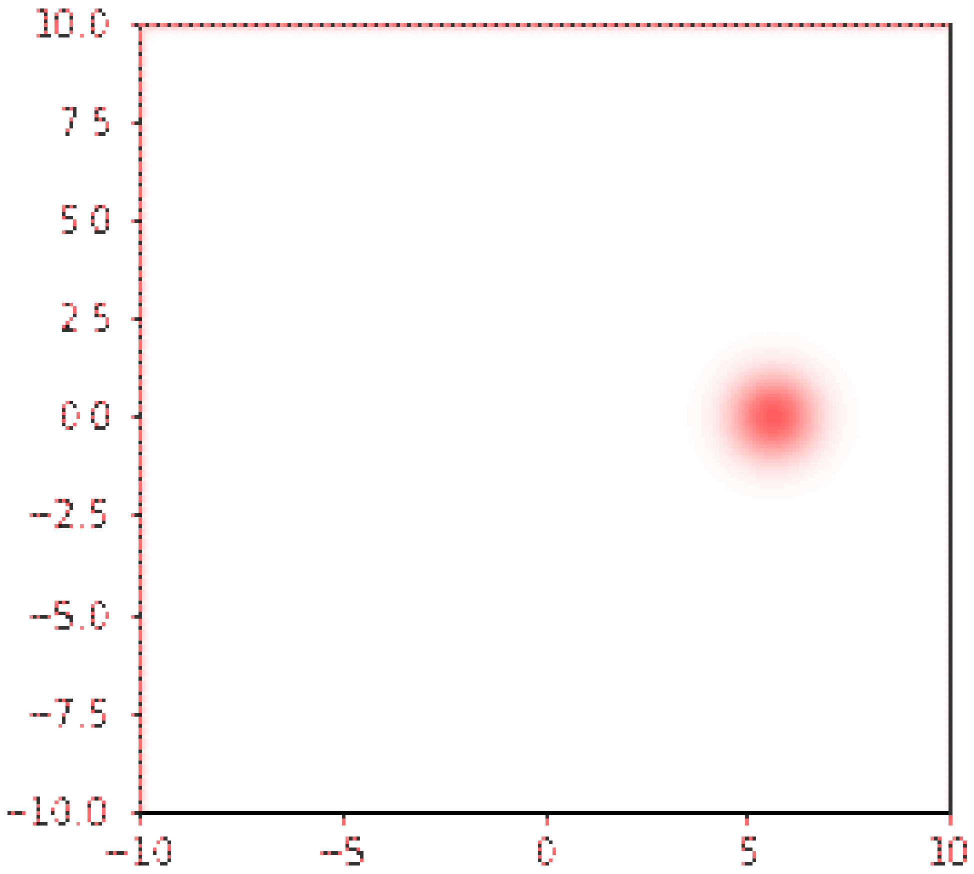

Figure 8: Evolution of a damped cavity with an initial coherent state.

Cat Qubit

Bloch Sphere

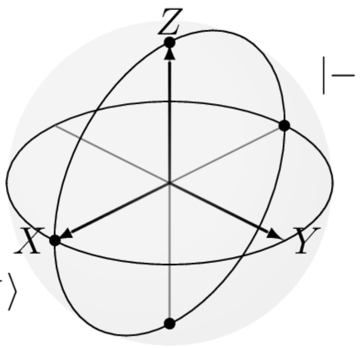

Figure 9: Bloch sphere representation of the cat qubit.

Basis States

Figure 10: $|0\rangle_L = |\alpha\rangle$

Figure 11: $|1\rangle_L = | - \alpha\rangle$

Coherent superposition

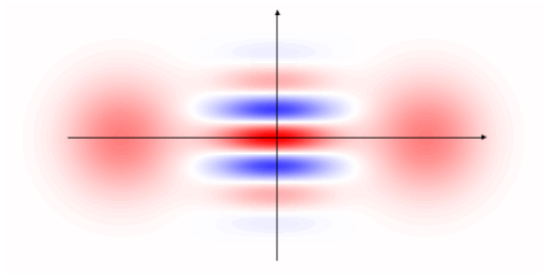

Figure 12:
$|+\rangle_L \propto |\alpha\rangle + | - \alpha\rangle$

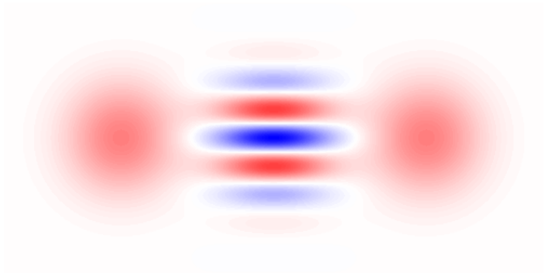

Figure 13:
$|-\rangle_L \propto |\alpha\rangle - | - \alpha\rangle$

Error Suppression[1]

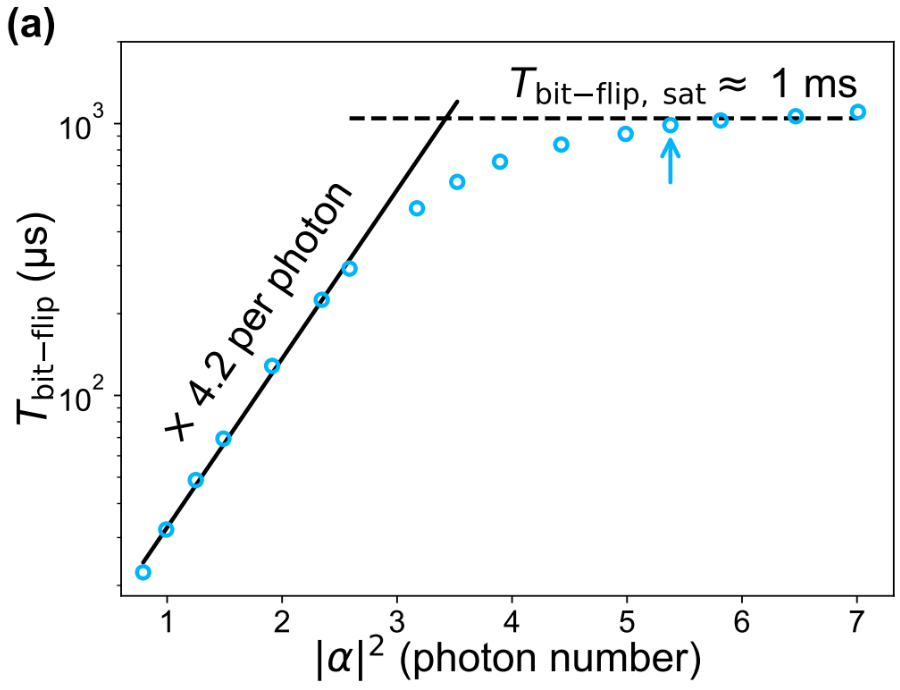

Figure 14: Bit-flip time T_X increases exponentially with cat size $|\alpha|^2$.

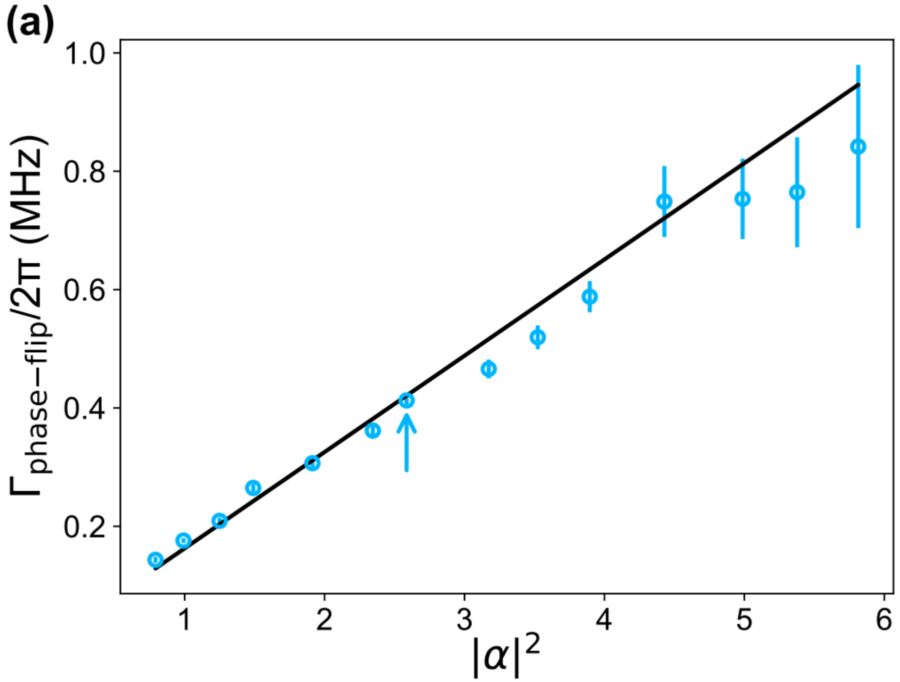

Figure 15: Phase-flip rate Γ_Z increases linearly with cat size $|\alpha|^2$.

1. Lescanne et al. (2020)

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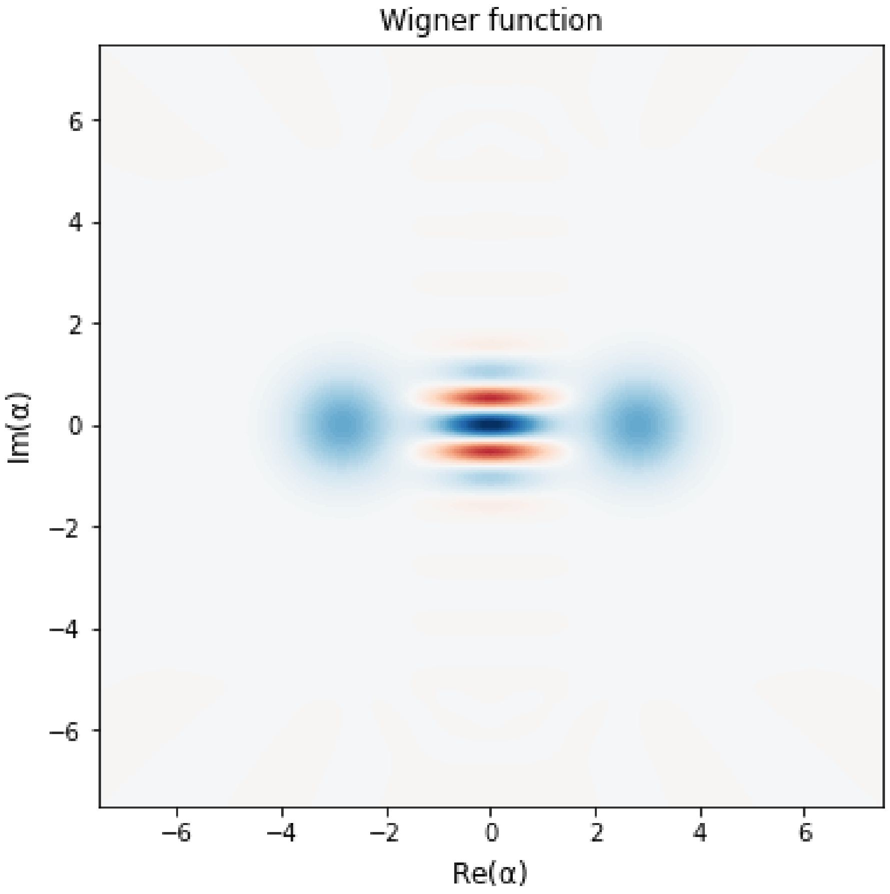
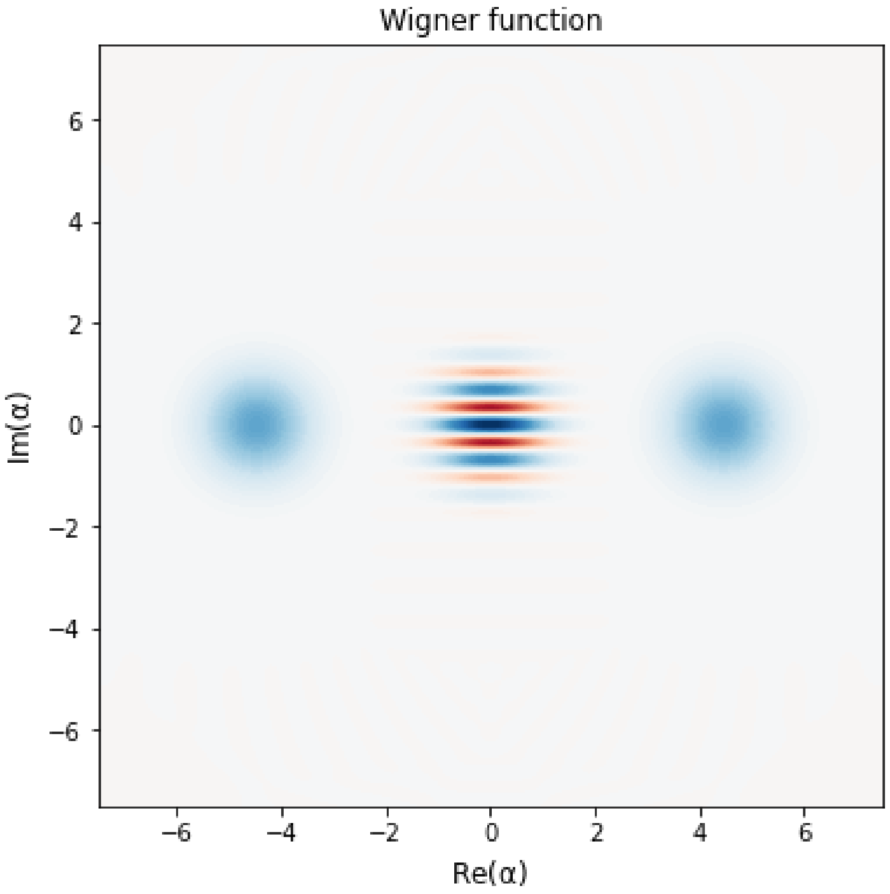
Cat States for different α

Increasing α increases exponentially the bit-flip time (hills more separated) but increases linearly the phase-flip rate (smaller fringes)





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Other Bosonic Codes[1]

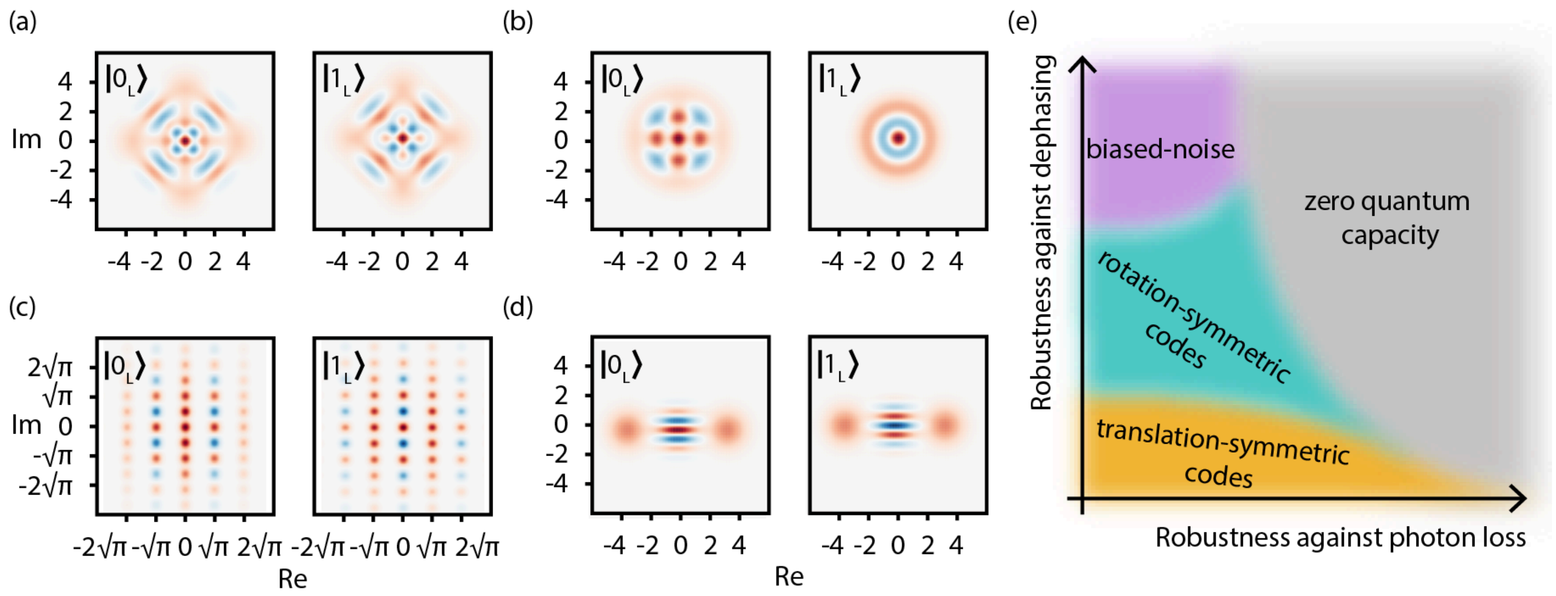

Figure 16: Wigner functions of various bosonic codes: 4-cat, binomial, GKP, 2-cat.

1. Joshi, Noh, and Gao (2021)

Four-Component Cat Code[1]

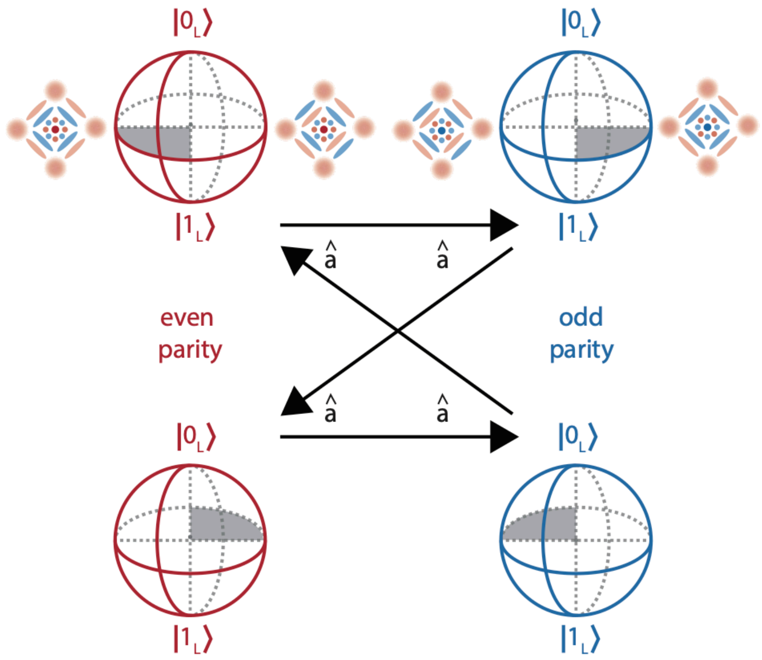

Figure 17: **Four-component cat code under photon loss**. Every photon loss event $\hat{a}$ changes not only the parity of the basis states, but also changes the phase relationship between them. The encoded state cycles between the even logical and odd error parity subspaces, while also rotating about the Z-axis by $\pi/2$. The decoding sequence must take both these effects into account to correctly recover the logical information.

1. Joshi, Noh, and Gao (2021)

State Preparation

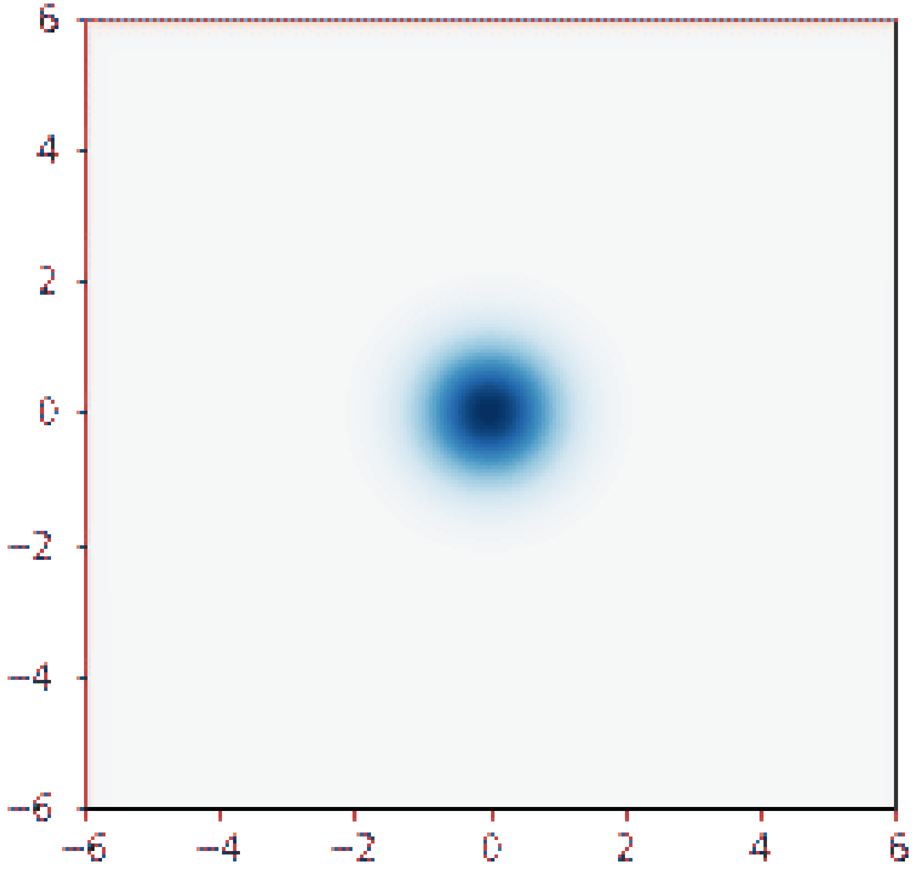

Figure 18: Preparation of $|+\rangle_L$ from $|0\rangle_L$.

Gates

Z Gate

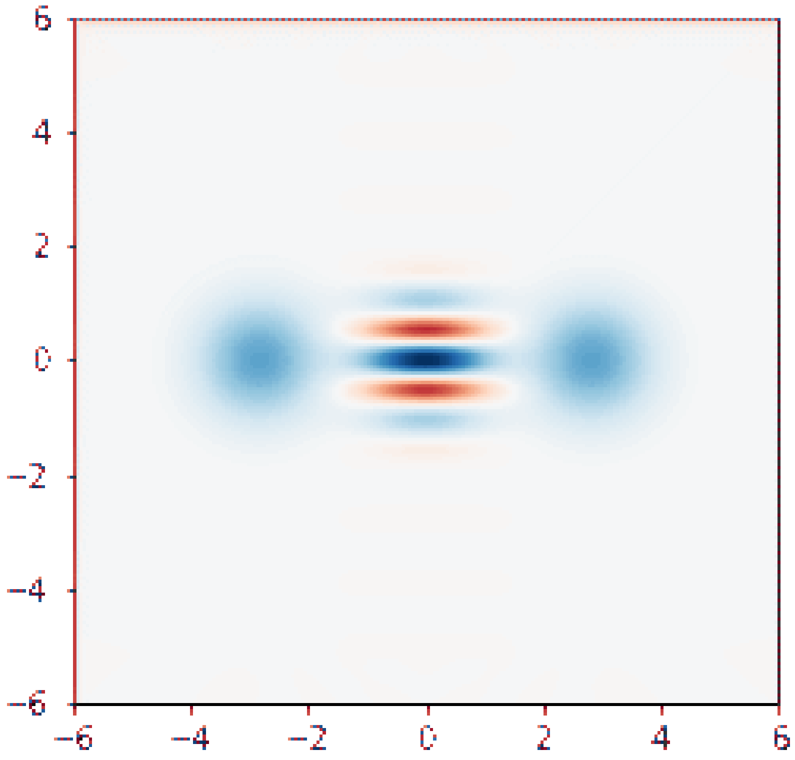

Figure 19: Logical Z rotation.

X Gate

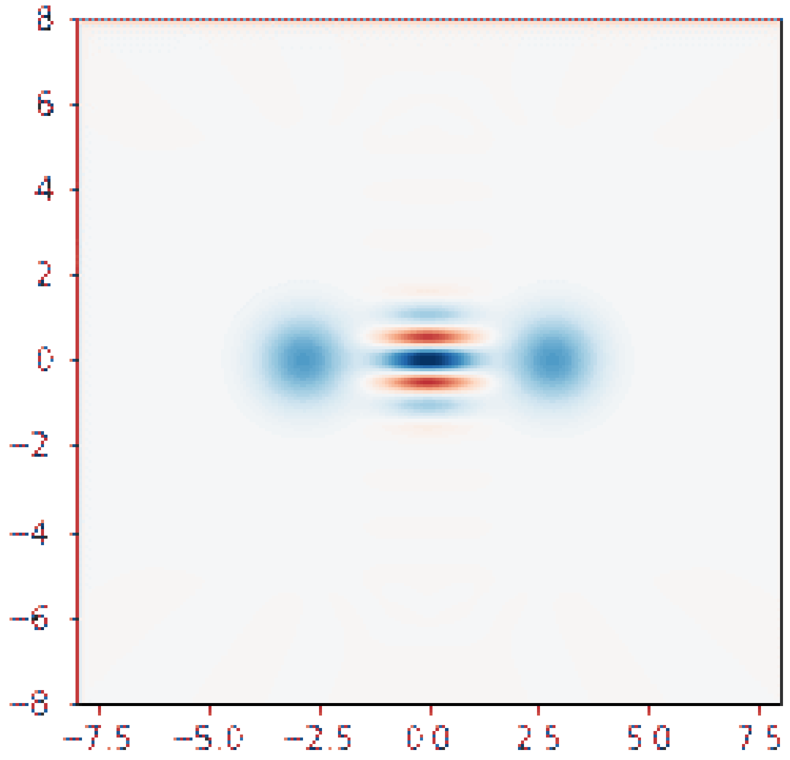

Figure 20: Logical X gate (rotation by π).

Thank you for your attention!

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