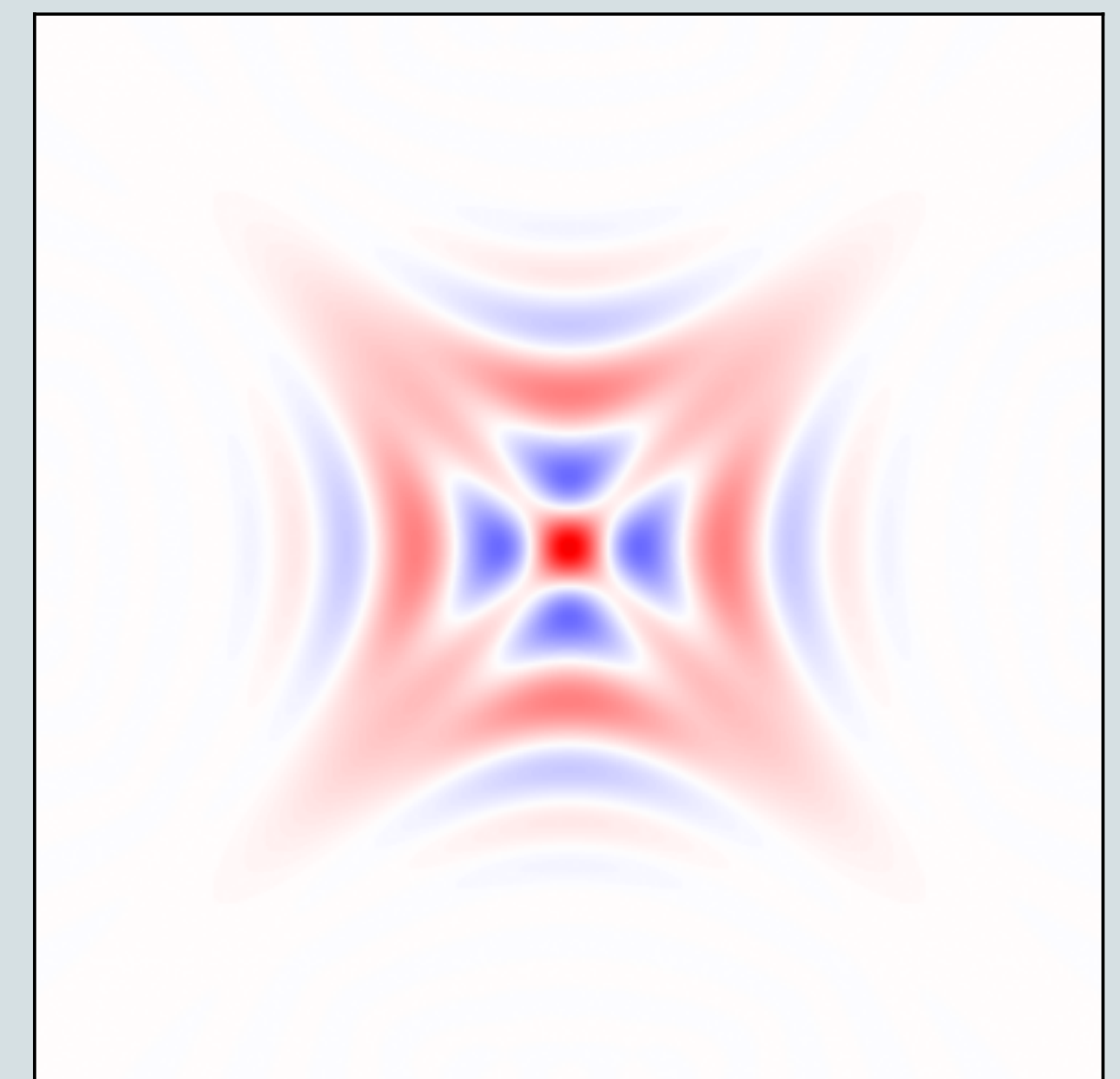
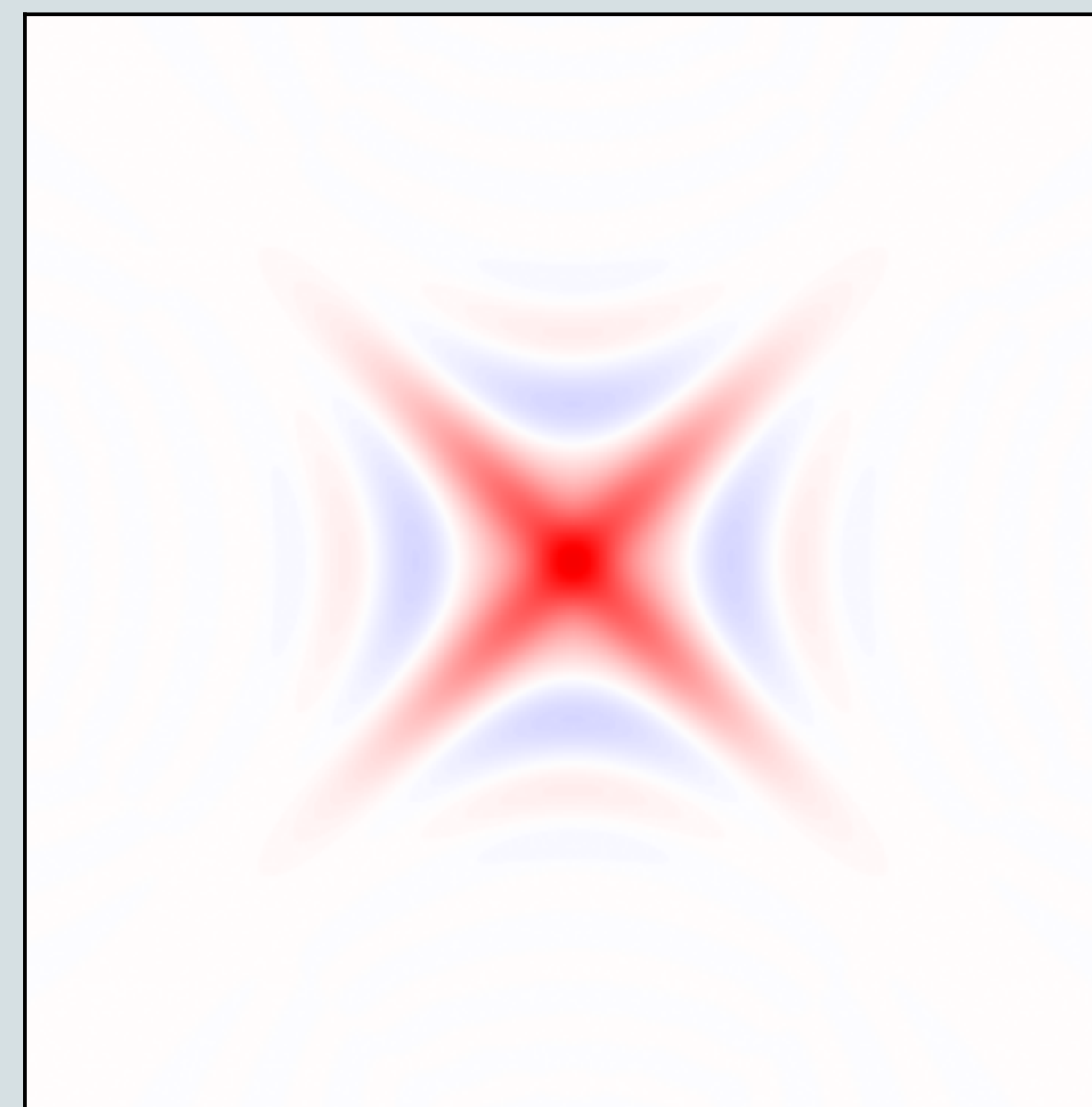


Preparation of conditionally squeezed states in qubit-oscillator systems

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 Phys. Rev. Res. 8, L012046 (2026)



We develop a protocol to prepare orthogonally squeezed vacuum states in a harmonic oscillator with a quadratic coupling to a qubit. The quadratic coupling has been shown to arise natively in a recently proposed optomechanical system [1]. We also analyze the properties of a bosonic error-correcting code based on the even and odd superpositions of orthogonally squeezed vacuum states.

Motivation

Bosonic error correction exploits the high dimensionality of the bosonic Hilbert space for error correction in a quantum computing context. There are different bosonic codes making use of different types of bosonic states, e.g. binomial, GKP and cat codes. Each code has different benefits and drawbacks in terms of preparation and control, error detection and correction, and logical operations. Developing new codes and protocols to prepare their states is therefore a task of high theoretical and practical relevance.

System

- Motivated by a recently proposed optomechanical system [1], we consider a Hamiltonian describing a qubit with a quadratic coupling to a harmonic oscillator. The qubit is subject to a time-dependent drive. The Hamiltonian is of the form

$$H(t) = \frac{\omega_q}{2} \sigma_z + \omega_m b^\dagger b + g(b^\dagger + b)^2 \sigma_z + H_d(t).$$

- We show that with a carefully chosen drive the Hamiltonian in a rotating frame can be reduced to an effective "conditional squeezing" Hamiltonian

$$H_{cs} = g_{cs}(b^2 + b^{\dagger 2}) \sigma_z.$$

State preparation

- The dynamics generated by H_{cs} takes an initial state (ignoring normalization) $|0\rangle \otimes [|e\rangle + |g\rangle]$ to the entangled state

$$S(\xi)|0\rangle \otimes |e\rangle + S(-\xi)|0\rangle \otimes |g\rangle,$$

$$\text{with } S(\xi) = \exp[(\xi^* b^2 - \xi b^{\dagger 2})/2] \text{ and } \xi = 2ig_{cs}t.$$

- By projecting on the $|+\rangle$ and $|-\rangle$ states of the qubit (a measurement in the X basis), one can prepare the even and odd superpositions of orthogonally squeezed vacuum states.

Quantum error correction

- One can encode a logical qubit into the even and odd superpositions of orthogonally squeezed vacuum states in the following way

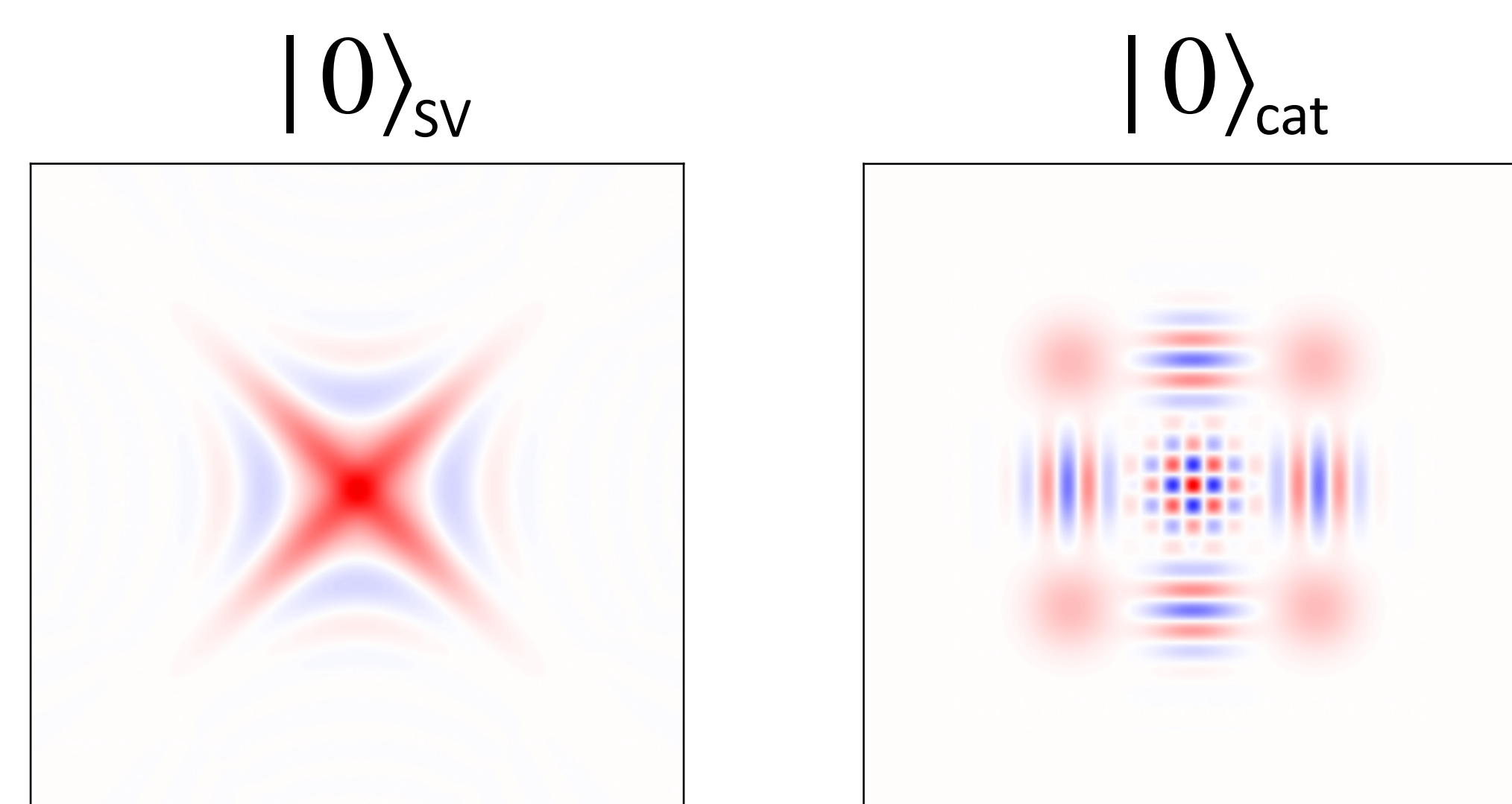
$$|0\rangle_L \propto [S(\xi) + S(-\xi)]|0\rangle,$$

$$|1\rangle_L \propto [S(\xi) - S(-\xi)]|0\rangle.$$

- It is easy to show that the two logical states have the following structure in Fock space

$$|0\rangle_L = \sum_k c_{4k} |4k\rangle; \quad |1\rangle_L = \sum_k c_{4k+2} |4k+2\rangle.$$

- The squeezed vacuum (SV) code is conveniently classified as a bosonic rotation code [2] with 2-fold symmetry. The analogy can be seen by comparing it with e.g. the four-component cat code:



- This classification allows for a better understanding of its properties and comparison with related codes, as well as a symmetry-dependent code-agnostic set of logical operations.

- [1] J. Manninen, R. H. Blick, and F. Massel, Phys. Rev. Res. 6, 023029 (2024).
 [2] A. L. Grimsmo, J. Combes, B. Q. Baragiola, PRX 10, 011058 (2020).

This work was supported by the Norwegian National Security Authority. F.M. acknowledges financial support from the Research Council of Norway (Grant No. 333937) through participation in the QuantERA ERA-NET Cofund in Quantum Technologies.



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