Dynamical Gauge Fields with Bosonic Codes in Nonlinear Resonators

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Dynamical gauge theories are crucial for understanding particle interactions mediated by gauge bosons. However, they are challenging to simulate using classical methods. The idea of a quantum simulator has led to research efforts to use low-energy, engineered quantum devices to replicate high-energy physics phenomena [1]. A promising approach in quantum computation is to introduce quantum error correction, which involves extending the original Hilbert space and endowing it with local symmetries that define the code space. However, qubit-based QEC is challenging due to vast physical resource overheads and scalability issues. Bosonic codes offer a solution that exploits multi-particle redundancy in bosons.

In this talk, I will showcase the potential of bosonic codes in simulating dynamical gauge fields. Our approach involves encoding both matter and dynamical gauge fields in a network of resonators that are coupled through three-wave mixing nonlinearity. By operating the gauge resonators as Schrödinger Cat states, we establish a mapping to a Z2 dynamical lattice gauge theory. Our research explores the optimal conditions that enable the system to maintain the required gauge symmetries. Our results demonstrate the potential of realizing high-energy models using bosonic codes.

References

[1]. E. Altman et al. Quantum Simulators: Architectures and Opportunities (2021). PRX Quantum 2, 017003

[2] del Pino, J. & Zilberberg, O. : Dynamical Gauge Fields with Bosonic Codes (2023). Phys. Rev. Lett. **130**(17), 171901

Figures

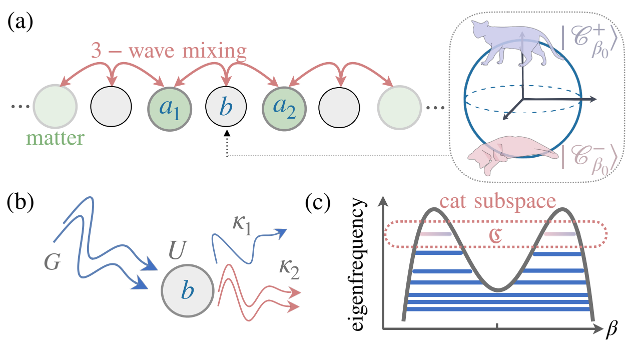

Figure 1: (a) A chain of resonators labeled as matter (type a) and gauge (type b) modes are coupled through three-wave mixing. This setup can mimic a 1+1D lattice gauge theory (LGT) when gauge resonators adopt cat states with specific parity and amplitude. (b) The link site is represented by a Kerr parametric resonator experiencing a (parametric) two photon drive. (c) Drive and nonlinearity create cat states as ground states in a dynamic potential shaped by the parametric drive and the Kerr nonlinearity.

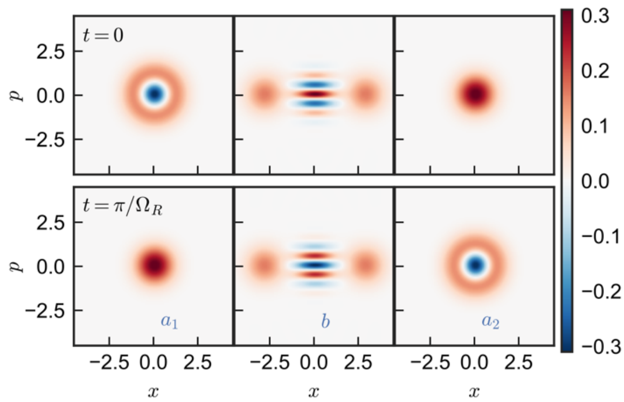

Figure 2: Quasiprobability distributions at bosonic sites reveal the Z2 matter-gauge dynamics, manifesting as exchange between Fock states (matter) and cat states (encoded gauge field states).