Collective Bogoliubov Excitations and Topology-Enhanced Response in Superconducting Qubit Networks

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Abstract: We report resonator-embedded superconducting qubit networks where collective microwave-photon condensation yields Bogoliubov excitations, while topology-controlled coupling enhances electromagnetic response. Together, experiments and modelling define design principles for quantum detectors and high-sensitivity superconducting microwave sensors.

Superconducting qubit networks (SQN) embedded in high-quality resonators are promising platforms for quantum sensing, because resonator-mediated qubit interactions generate collective microwave-photon states and nonlinear dynamics. Here we combine two complementary results: a ten-qubit proof-of-principle resonator-embedded detector [1] and a topology-oriented study showing how qubit arrangement can enhance network response [2].

In the experiment, ten capacitively shunted flux qubits are coupled to two high-quality factor microwave resonators- readout and signal resonators. Two-tone spectroscopy measurements performed at 15 mK reveal a red shift of the qubit excitation resonance frequency with pump power, the appearance of a secondary idler dip near a critical threshold, and a reproducible hysteresis loop under reverse sweeps. A nonlinear Gross-Pitaevskii-like model well reproduces the experimental power-dependent dip position curves and identifies the idler resonance as the second branch of Bogoliubov excitations above a Bose-Einstein like condensate of microwave photons (Fig. 1, left panel, red arrows) [1].

In parallel, exact diagonalization and linear-response calculations on five-qubit arrays show that topology is a genuine design parameter: cross-shaped arrays exhibit stronger flux susceptibility and larger circulating-current response than linear arrays under comparable coupling conditions (Fig. 1, right panel), owing to cooperative interactions between central and peripheral qubits [2]. Together, these results show that the physics of collective quantum phenomena enabling Bogoliubov excitations can be reinforced through topology engineering, opening a concrete route toward improved threshold detectors and stable operation of quantum computing [1,2].

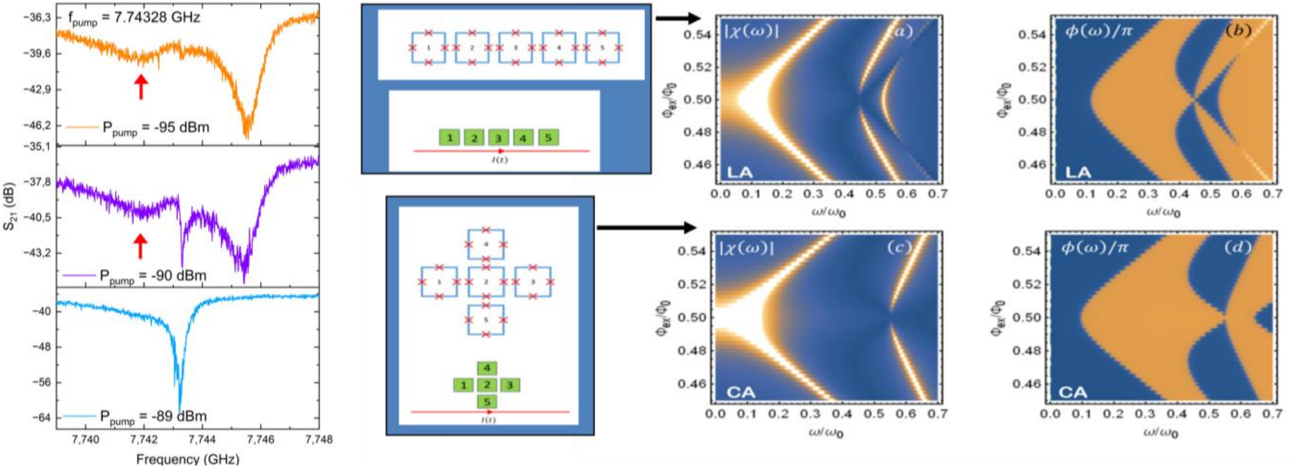

Fig. 1. Left panel: dependence of the transmission coefficient |S21| of the readout resonator on the probe frequency for three different values of pump signal power applied to the signal resonator [1]. Right panel: amplitude (Panel (a)) and phase (Panel (b)) of the response function (susceptibility $\chi(\omega)=|\chi(\omega)|e^{i\Phi}$) of a linear qubit array (LA) coupled to a transmission line via dominant inductive coupling with the 5th qubit. Panel (c) and (d) show the same quantities for a cross-shaped array (CA) [2].

Ref:

[1] P. Navez, V. Di Meo, B. Ruggiero, C. Gatti, F. Chiarello, A. D'Elia, A. Rettaroli, E.Enrico, L. Fasolo, M. Fistul, I. Eremin, A. Zagoskin, P. Vanacore, P. Silvestrini, and M. Lisitskiy *Bose condensation and Bogoliubov excitation in resonator-embedded superconducting qubit network* **arXiv preprint arXiv:2601.15101 (2026)**.

[2] J. Settino, G. G. Luciano, A. Di Bartolomeo, P. Silvestrini, M. Lisitskiy, B. Ruggiero, and F. Romeo *Topology-Enhanced Superconducting Qubit Networks for In-Sensor,* **Quantum Science and Technology 11(1),** p. 015019 **(2026)**.