# A nonlinear electromechanical system in the quantum regime

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Nonlinearity at the scale of zero-point motion opens new possibilities for quantum control of nanomechanical systems, but achieving this remains a formidable challenge. A first step in this direction was the recent demonstration of a mechanical Kerr nonlinearity in the quantum regime, achieved by dispersively coupling a mechanical oscillator to a transmon qubit via piezoelectric interaction [1]. However, the coupling in that experiment remained weak, resulting in only modest anharmonicity and pronounced spectral crowding [2].

In our work we operate in the dispersive ultrastrong coupling (USC), characterized by the ratio $g_{EM}/\omega_M > 0.1$, between a nanotube mechanical oscillator and a double-quantum-dot electronic two-level system (ETLS) (Fig.1). In this regime we demonstrate a mechanical Kerr nonlinearity at the scale of the zero-point mechanical motion with a theoretical mechanical anharmonicity of a = 1.4%. This regime also enables quantum non-demolition (QND) cavity-based readout of the mechanical motion, based on a quadratic optomechanical coupling. This nonlinear USC platform opens a new frontier for quantum nanomechanics, from macroscopic superpositions (3) to long-lived mechanical qubits (4).

References

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[2] A. Blais, et al. Reviews of Modern Physics, 93 (2), 025005 (2021).
[3] Oriol Romero-Isart. et, al. Physical Review A, 84 (2011).
[4] F. Pistolesi, et. al. Phys. Rev. X, 11, 031027 (2021).

Figures

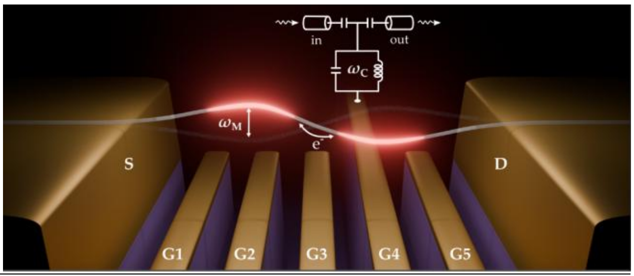


**Figure 1:** Simplified representation of a double-quantum dot (red) embedded in a vibrating carbon nanotube suspended above five gate electrodes G1-G5, one of which is galvanically connected to a superconducting microwave resonator for cavity readout.

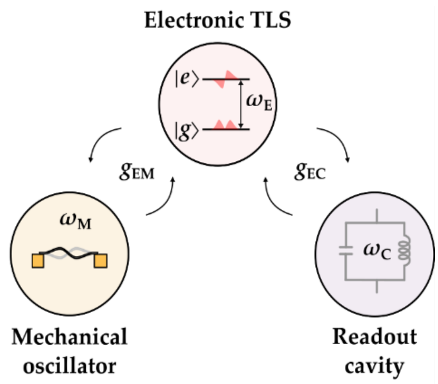


**Figure 2:** Schematic of the tri-partite system composed of a double quantum dot electronic two-level system ($\omega_E$~100 GHz), a mechanical oscillator ($\omega_M$~0.8 GHz) and a readout cavity ($\omega_C$~1 GHz). The electron-phonon and electron-photon coupling rates are denoted as $g_{EM}$~0.5 GHz and $g_{EC}$~0.05 GHz, respectively.