

From Decoherence-Free Qubits with Giant Molecules in Waveguide QED

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Efficient coherent control and multi-directional release of quantum information are two key challenges to be addressed by any platform eligible for distributed quantum devices. In context of circuit and waveguide quantum electrodynamics, such challenges have to be addressed by developing systems of artificial atoms interconnected through microwave waveguides, working as quantum links, enabling for both noiseless quantum control and chiral photon emission. In this work we introduce a device—see Fig. 1—able to address both challenges at once, by harnessing the new paradigm of artificial giant molecules—systems of interacting artificial atoms. Going beyond the state-of-the-art [1,2,3], we show how the collective states of the molecule and photon interference can be combined to create single-photon decoherence free states, which are further used to encode a logical qubit. Through tunable parameters, we also show how to engineer effective chiral emission of a single-photon stored in the molecule, enabling for multi-directional photon control. The flexibility of artificial giant molecules, as demonstrated in our work [4], opens a broad avenue for new developments and applications beyond quantum information and chiral quantum optics.

References

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- [2] R. Holzinger et al, *Physical Review Letters* **129**, 253601 (2022).
- [3] O. Rubies-Bigorda et al, *Physical Review Letters* **134**, 213603 (2025)
- [4] W. Yang, J. J. García-Ripoll, and A. C. Santos (2026) coming soon on arXiv.

Figures

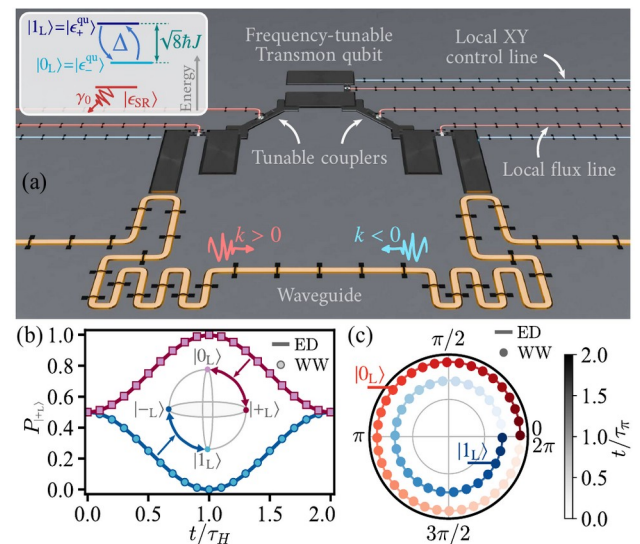


Figure 1: (a) Superconducting circuit enabling the implementation of the giant molecule. Tunable transmon qubits work as the atoms in the molecule, with intramolecular coupling modulated by tunable transmon couplers. Top-left inset: Three-level structure of the single-excitation sector, where we show how to encode the logical qubits. (b) Hadamard gate applied to logical DF states when starting the evolution from different superposition states. (c) Time-dependent accumulated phase for different basis state, corresponding to arbitrary phase gates.