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Adiabatic Quantum Operations with UltraStrongly Coupled Artificial Atoms

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Ultrastrong coupling (USC) between light and matter has been recently achieved in architectures of solid state artificial atoms coupled to cavities. Such architectures may provide new building blocks for quantum state processing, where ultrafast operations could be performed. However faster dynamics has a cost. Indeed USC breaks the symmetry associated with the conservation of the number of excitations, leading to a series of new physical effects of great fundamental interest but detrimental for quantum state processing. In particular the highly entangled nature of the eigenstates, dressed by a potentially very large number of virtual photons, leads to leakage of excitation via the dynamical Casimir effect (DCE) and via decay. In this work we analyze quantum operations between two artificial atoms ultrastrongly coupled to a cavity, operating as a virtual bus. We show that an adiabatic protocol similar to STIRAP may overcome the problem of leakage. Ideally the cavity is never populated and thus it is expected to greatly reduce the impact of DCE and decay. We show that high fidelity operations can be performed for moderate couplings in the USC regime and fidelities higher than the ones obtained in the strong coupling regime (SC, where the rotating wave approximation holds) can be obtained. Moreover, optimal control theory allows for properly crafted controls that extend the high fidelity region to even larger couplings. The protocol is extremely robust agaist DCE, in the absence of decoherence yields almost 100% fidelity for remote state transfer and multiqubit entanglement generation. It is also resilient to decay due to leakage from the cavity, which is the main decoherence mechanism for present USC architectures. In this more realistic scenario it is seen that for larger coupling (entering the deep strong coupling regime) the fidelity decreases due to the interplay between decoherence and DCE. Our results suggest that adiabatic manipulations, may be a promising tool for quantum state processing in the USC regime.

Presenter: GIANNELLI, Luigi (Dipartimento di Fisica e Astronomia "Ettore Majorana", Universitá di Catania)

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