Workshop “From Quantum Matter to Quantum Information” Strongly Interacting Many Body Physics with Circuit Quantum Electrodynamics Networks

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In its infancy circuit quantum electrodynamics (cQED) has quickly started reproducing fundamental quantum optical experiments, e.g. observation of vacuum rabi oscillations in frequency and time domain, with unprecedented cooperativity. This was possible because of the large coupling strength of the quasi one-dimensional microwave field of the superconducting transmission line resonators to the macroscopic dipole moment of superconducting qubits.

Since then cQED has matured to a discipline of experimental physics capable of performing fundamental quantum information tasks and is currently on the verge of crossing the border between few- to many body physics [1]. This opens up a exciting realm of completely new physical phenomena. Because of the ubiquitous influence of the electromagnetic environment however the number of microwave photons is not conserved which separates cQED systems from other quantum simulators involving atoms, e.g. cold atoms in optical latices. Instead cQED is ideally suited for exploring quantum many-body physics in the driven dissipative regime where the interplay of constant injection of microwave photons and the unpreventable loss of microwave photons into the electromagnetic environment generates a whole new class of steady- but not equilibrium states.

We propose a network of capacitively coupled superconducting resonators. Each resonator gains nonlinearity by intersecting it with a Josephson Junction[2]. The spectrum of individual resonators shows the ultrastrong coupling of the Josephson junction to the resonator modes and nonlinearities well above decay rates are attainable. This approach can be scaled up by increasing the number of nonlinear resonators. Alternatively one could also increase the number of degrees of freedom on a single site by incorporating more than one Josephson Junction into the resonator. The multiple Josephson Junction resonator shows completely decoupled behavior of single Josephson junctions as well as collective modes depending on the chosen parameter range.

Instead of using the nonlinearity of the Josephson junction as a onsite nonlinearity we also consider a setup where the Josephson junctions provide a means of nonlinear coupling between lattice sites[3]. We find superfluid-, staggered- and even oscillating phases in the driven dissipative steady state phase diagram of this Bose-Hubbard model with cross Kerr coupling(c.f. fig.1a). Additionally we provide the derivation of the effective Bose-Hubbard Hamiltonian starting from the microscopic model of a readily realizable cQED setup(c.f. fig.1b).

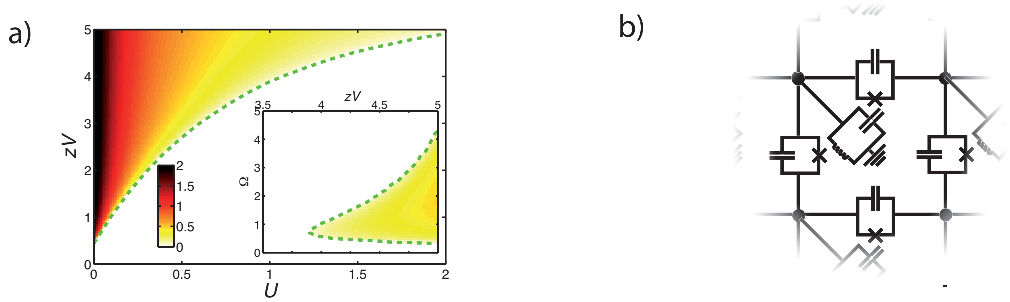

Fig. 1a) Phase diagram of the Bose Hubbard model with nonlinear Cross-Kerr coupling. Plot of the difference in the numbers of photons on adjacent lattice sites as a function of cross Kerr nonlinearity V and onsite nonlinearity U
Fig. 1b) cQED setup for Bose Hubbard lattice with nonlinear Kerr coupling terms

References

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