Over the past decade, the frontiers of quantum computing have broadened from exploring few-qubit devices to developing viable multi-qubit processors. One of the protagonists of the present era is the superconducting transmon qubit. As the field progresses with unbridled panache, the question of whether we have a comprehensive picture of the potential dangers acquires increasing urgency. In particular, it needs to be thoroughly clarified whether new and hitherto unconsidered obstacles associated with the multi-qubit nature can emerge.

This thesis introduces a novel perspective on multi-qubit processors. We fuse the field of quantum engineering and many-body physics by applying concepts from the theories of localization and quantum chaos to multi-transmon arrays. From a many-body perspective, transmon architectures are synthetic systems of interacting and disordered nonlinear quantum oscillators. While a certain amount of coupling between the transmons is indispensable for performing gate operations, a delicate balancing with disorder — site-to-site variations in the qubit frequencies — is required to prevent locally injected information from dispersing in extended many-body states. We analyze small instances of transmon quantum computers in exact diagonalization studies, using contemporary quantum processors as blueprints. Scrutinizing the spectrum, many-body wave functions, and qubit-qubit correlations for experimentally relevant parameters reveals that some of the prevalent transmon design schemes operate close to a region of uncontrollable chaotic fluctuations. Our concepts complement the few-qubit picture that is commonly exploited to optimize device configurations on small scales. Destabilizing mechanisms beyond this local scale can be detected from our fresh perspective. This suggests that techniques developed in the field of many-body localization should become an integral part of future transmon processor engineering.

UNIVERSITY OF COLOGNE

thp Institute for Theoretical Physics University of Cologne

Transmon-based quantum computers from a many-body perspective

C. Berke

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Christoph Berke • Dissertation