Digitized counterdiabatic quantum critical dynamics

Narendra N. Hegade*
Anne-Maria Visuri, Alejandro Gomez Cadavid, Balaganchi A. Bhargava, Sebastián V. Romero, András Grabarits, Pranav Chandarana, Enrique Solano, Adolfo del Campo

*** *Kipu Quantum GmbH, Greifswalderstrasse 212, 10405 Berlin, Germany***

narendra.hegade@kipu-quantum.com

Abstract

We experimentally demonstrate that a digitized counterdiabatic quantum protocol reduces the number of topological defects created during a fast quench across a quantum phase transition. To show this, we perform quantum simulations of one- and two-dimensional transverse-field Ising models driven from the paramagnetic to the ferromagnetic phase. We utilize superconducting cloud-based quantum processors with up to 156 qubits. Our data reveal that the digitized counterdiabatic protocol reduces defect formation by up to 48% in the fast-quench regime—an improvement hard to achieve through digitized quantum annealing under current noise levels. The experimental results closely match theoretical and numerical predictions at short evolution times, before deviating at longer times due to hardware noise. In one dimension, we derive an analytic solution for the defect number distribution in the fast-quench limit. For two-dimensional geometries, where analytical solutions are unknown and numerical simulations are challenging, we use advanced matrix-product-state methods. Our findings indicate a practical way to control topological defect formation during fast quenches and highlight the utility of counterdiabatic protocols for quantum optimization and quantum simulation in material design on current quantum processors.

Figures

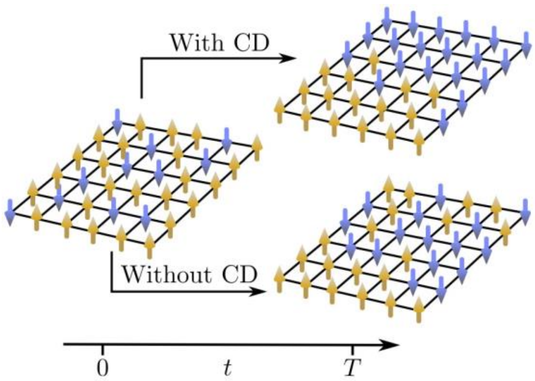

Figure 1: A schematic illustration of the initial state and the final states resulting from CD assisted evolution and digitized annealing without CD.

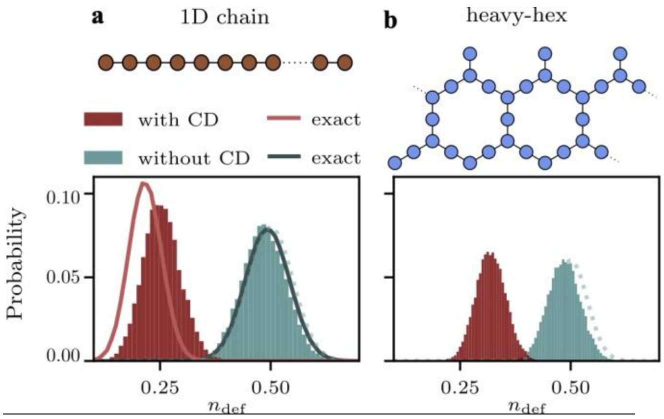

Figure 2: Measured distributions of the defect density at the final evolution time for (a) 1D chain with 100 spins (b) 2D heavy-hexagonal lattice of 156 sites.

References

[1] A. del Campo and W. H. Zurek, Int. J. Mod. Phys. A, 29 (2014) 1430018.
[2] M. V. Berry, J. Phys. A: Math. Theor., 42 (2009) 365303.
[3] N. N. Hegade et al., Phys. Rev. Appl., 15 (2021) 024038.
[4] Visuri, Anne-Maria, et al., arXiv preprint arXiv:2502.15100 (2025).