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Prethermal time crystalline phases and noise-induced dynamics on digital quantum computers.

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We explore the emergence of exotic non-equilibrium phases such as prethermal discrete time crystals (DTCs) and discrete time quasicrystals (DTQCs) in two-dimensional quantum many-body systems simulated on IBM's digital quantum computers. Using superconducting qubit architectures arranged in programmable geometries, including heavy-hex, Kagome, and Lieb lattices, we implement kicked Ising models with periodic driving and investigate the relaxation dynamics of initially prepared product states. In the first part, we demonstrate the realization of robust prethermal DTCs and DTQCs on a 133-qubit heavy-hexagonal lattice, where periodic-doubling oscillations and incommensurate amplitude modulations emerge before thermalization. These results highlight the potential of digital quantum computers to simulate large-scale Floquet dynamics beyond the reach of classical computation [1]. In the second part, we show that quantum noise, typically regarded as detrimental, can in fact stabilize novel prethermal DTC phases. Using ancilla-mediated constructions of Kagome and Lieb lattices, we identify two distinct types of noise-induced DTCs: one enabled by symmetry charge pumping at the boundaries, and another supported purely by random gate fluctuations. These effects are further validated through noisy matrix-product state simulations [2]. Together, these findings point to a new role for quantum noise as an active ingredient in engineering and probing emergent spatiotemporal orders, and they establish a path towards quantum simulation of prethermal phases in higher dimensions.

[1] K. Shinjo, K. Seki, T. Shirakawa, R.-Y. Sun, and S. Yunoki, "Unveiling clean two-dimensional discrete time quasicrystals on a digital quantum computer", arXiv:2403.16718.
[2] K. Shinjo, K. Seki, and S. Yunoki, to be submitted.

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