When Does a Quantum System Return? Topology, Dark States, and Noise in Monitored Dynamics

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The recurrence time, the duration for a monitored system to return to its initial state, is a fundamental probe of quantum dynamics under repeated measurement. For strong stroboscopic monitoring, the mean return time is topologically quantized through the winding number of the monitored state, with subspace measurements yielding fractional quantization. Remarkably, this quantization survives on real, noisy hardware using restarts: on IBM quantum processors, we track a quantum walker on a triangle ring with complex edge weights and directly observe quantized return times and dark states the detector never sees. In interacting many-body spin systems, the recurrence time is fractionally quantized. We show that the quantized values count the dark states, an experimentally accessible probe of Hilbert-space fragmentation and ergodicity breaking. Even weak monitoring through an ancilla follows a simple scaling law in the measurement strength.

After many measurement rounds without restart, noise reshapes this structure: without restarting, after we observe a quantum Kac law connecting the return to the unmeasured steady state, connecting quantum quantization to a Kac law, with dark states controlling slow crossovers in between. A simple question: when does the system return? thus becomes a probe of topology, dark states, and the quantum-to-classical transition, and a practical benchmark for mid-circuit measurements on today's quantum computers.

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