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Title: Localization, fractality, and ergodicity in a monitored qubit

Abstract:
We study the statistical properties of a single two-level system (qubit) subject to repetitive ancilla-based measurements. This setup is a fundamental minimal model for exploring the intricate interplay between the unitary dynamics of the system and the nonunitary stochasticity introduced by quantum measurements, which is central to the phenomenon of measurement-induced phase transitions. We demonstrate that this “toy model” harbors remarkably rich dynamics, manifesting in the distribution function of the qubit's quantum states in the long-time limit. We uncover a compelling analogy with the phenomenon of Anderson localization, albeit governed by distinct underlying mechanisms. Specifically, the state distribution function of the monitored qubit, parameterized by a single angle on the Bloch sphere, exhibits diverse types of behavior familiar from the theory of Anderson transitions, spanning from complete localization to almost uniform delocalization, with fractality occurring between the two limits. By combining analytical solutions for various special cases with numerical approaches, we achieve a comprehensive understanding of the structure delineating the “phase diagram” of the model. We categorize and quantify the emergent regimes and identify two distinct phases of the monitored qubit: ergodic and nonergodic. Furthermore, we identify a genuinely localized phase within the nonergodic phase, where the state distribution functions consist of delta peaks, as opposed to the delocalized phase characterized by extended distributions. Identification of these phases and demonstration of transitions between them in a monitored qubit are our main findings [1].