Universal Stochastic Dynamics of Monitored Fermions: From Free to Interacting Systems

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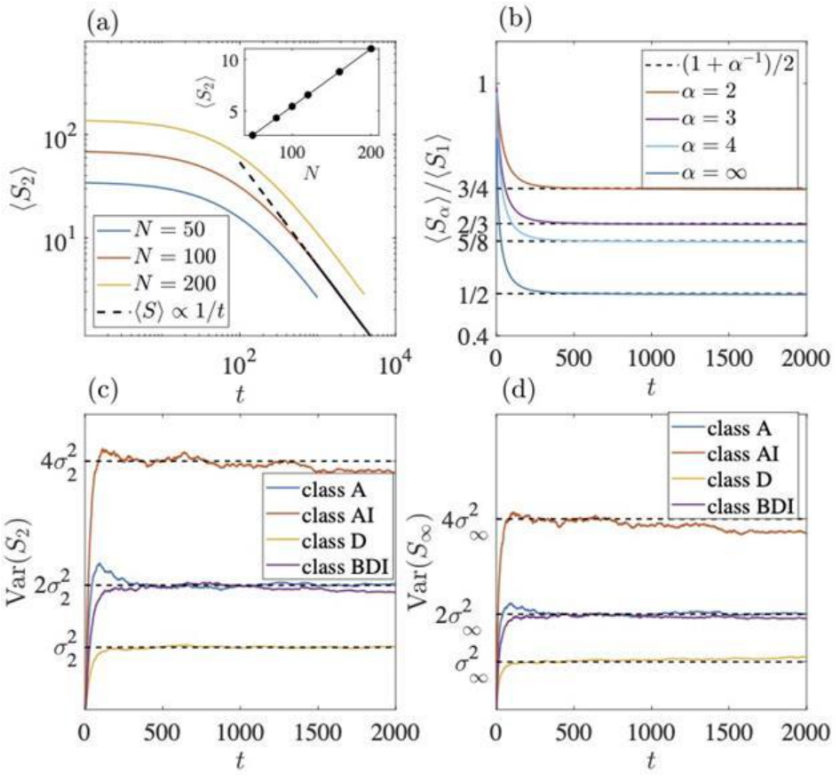
We study the dynamics of monitored quantum systems, focusing on the stochastic evolution of mixed states under the competition between unitary dynamics and continuous measurement. For monitored free fermions, we show that the full density-matrix spectrum obeys universal Fokker–Planck equations, which provide an exact and unified description of purification dynamics in the chaotic regime. This framework reveals several remarkable universal features, including an even–odd effect in purification for complex fermions, exact long-time behavior of the entropy, universal short-time entropy fluctuations, and a symmetry-based classification of nonunitary dynamics. In particular, the entropy fluctuations play the role of a nonunitary counterpart of universal conductance fluctuations in mesoscopic transport. These results establish a close connection among monitored dynamics, random-matrix theory, and Anderson localization physics.



Numerical simulation of monitored dynamics in different symmetry classes. (a), (b) Entropy $\langle S_2 \rangle$ as a function of time t in the dynamics of N fermions [$N = 200$ for (b)]. Inset of (a): $\langle S_2 \rangle$ at $t = 1000$ as a function of N. (c), (d) Variance $\mathrm{Var}(S)$ in different symmetry classes. The dashed lines are the analytical results (0.06309 for S_2 and 0.04841 . . . for S_∞).

Motivated by this stochastic description of monitored free systems, we then discuss a new direction: the effect of many-body interactions introduced via a spinless Hubbard model, where exact diagonalization and tensor networks are applied. In particular, we examine how interactions modify purification dynamics, entropy scaling, and sample-to-sample fluctuations, and whether signatures analogous to the free-fermion even–odd effect and universal entropy fluctuations survive in the many-body setting. This also opens a route toward clarifying how monitored dynamics interpolate between exactly solvable free-fermion behavior and genuinely many-body measurement-induced phenomena.

Reference:

[1] Z. Xiao, T. Ohtsuki, K. Kawabata, Physical Review Letters 134, 140401 (2025).