Simulating the Complete Quantum Mechanics of Very Large Driven-Dissipative Bose-Hubbard Systems

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Methods for numerically simulating large driven-dissipative quantum systems are of increasing importance due to ongoing experimental progress in a number of platforms such as polariton condensates, nanopillars, photonic lattices, or transmon qubits. We demonstrate the positive-P method known otherwise from quantum optics to be ideal for this purpose across a wide range of parameters, focusing on the archetypal driven-dissipative Bose-Hubbard model. For example, full quantum dynamics of a nonuniform 256×256 lattice of sites is demonstrated (bottom of figure). Accessible parameters include regimes where interactions and dissipation are significant, and antibunching or strong two-particle interference occurs. Also, cases with many low-occupied modes for which common semiclassical approximations can break down.

The presence of dissipation alleviates instabilities in the positive-P method that were known to occur for closed systems, allowing the simulation of full quantum dynamics up to and including the steady-state. In the accessible regime (top figure), numerical effort scales merely linearly with the number of sites, quadratically with the precision, and doesn't care about symmetry or its lack. We also find that the regions of applicability of the positive-P and truncated Wigner approaches are mutually complementary. Together these approaches cover the majority of parameter space in the dissipative Bose-Hubbard model.

Moreover, it is shown that phase-space approaches such as these provide a simple and physically intuitive way to calculate many unequal time correlations, allowing their investigation in a non-perturbative and scalable way.

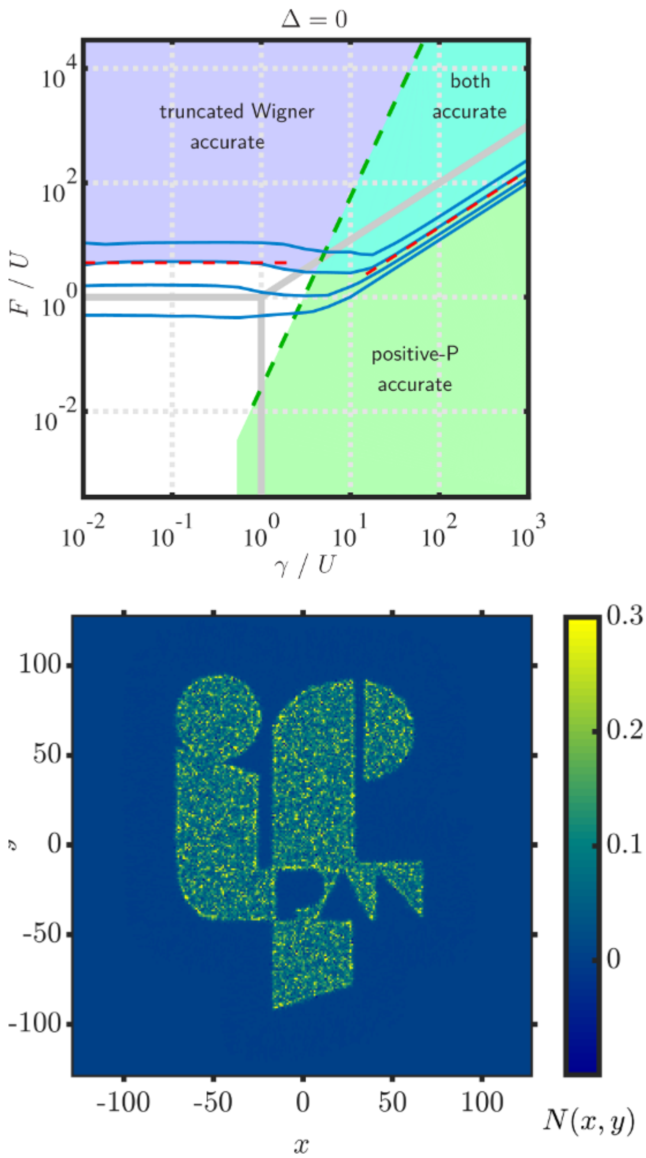

Figure 1: Top: applicability of positive-P and truncated Wigner methods as a function of the relative strengths of dissipation γ, interaction U and driving F; Bottom: Full quantum simulation of a nonuniformly driven 256×256 site Bose-Hubbard lattice

References

[1] P Deuar, A Ferrier, M Matuszewski, G Orso and M H Szymańska, PRX Quantum **2**, 010319 (2021)

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