Dynamical process nonclassicality: Characterization, canonical Hamiltonian ensemble representation, and quantification

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The characterization, explanation, and quantification of quantumness, in particular the discrimination from classicality in terms of classical strategies, lie at the heart of quantum physics. Dephasing processes, caused by the non-dissipative information exchange between a quantum system and its environment, play a central role in that respect, as they control the transition between the quantum and the classical realm. Recently, it is shown that dephasing dynamics itself can exhibit classical or nonclassical traits, depending on the nature of the system-environment correlations and the related (im)possibility to simulate these dynamics with Hamiltonian ensembles—the classical strategy. Here we propose to extend this classification towards *quantifying* the nonclassicality of pure dephasing dynamics. In the spirit of the Wigner function, we generalize Hamiltonian ensembles to encompass quasi-probability distributions comprising negative values. By using Lie algebra representations, Fourier transforms on groups, and root space decompositions, we achieve to overcome the difficulty of pinning down the uniqueness of quasi-probability distributions, provided diagonal member Hamiltonians, and therefore lift such distributions as faithful representations of pure dephasing dynamics; moreover, we show how to retrieve these quasi-probability distributions. This allows us to quantify process-nonclassicality time-independently, in terms of the deviations of the corresponding quasi-probability distributions from classical probability distributions. We illustrate our method for qubit, qutrit, and qubit-pair pure dephasing and demonstrate how to implement our approach with quantum process tomography and quantum state tomography experiments.

[1] Hong-Bin Chen, Clemens Gneiting, Ping-Yuan Lo, Yueh-Nan Chen, and Franco Nori *Simulating Open Quantum Systems with Hamiltonian Ensembles and the Nonclassicality of the Dynamics*, Phys. Rev. Lett. **120**, 030403 (2018).

[2] Hong-Bin Chen, Ping-Yuan Lo, Clemens Gneiting, Joonwoo Bae, Yueh-Nan Chen, and Franco Nori *Quantifying the nonclassicality of pure dephasing*, Nat. Commun. **10**, 3794 (2019).