A Universal Framework for Quantum Dissipation: Minimally Extended State Space and Exact Time-Local Dynamics

Meng Xu[1], Vasilii Vadimov[2], Malte Krug[1], Jürgen T. Stockburger[1], and Joachim Ankerhold[1]

[1]*Institute for complex quantum systems, Ulm University, Albert-Einstein-Allee 11, D-89069 Ulm, Germany*

[2]*QCD Labs, QTF Centre of Excellence, Department of Applied Physics, Aalto University, P.O. Box 15100, FI-00076 Aalto, Finland*

With the impressive advances towards quantum technological realizations, the need for highly accurate, versatile, and computationally efficient approaches to simulate the dynamics of open quantum systems has triggered compelling activities. A particular challenge is to consistently account for subtle quantum correlations between system and surrounding such as retarded reservoir feedback (non-Markovianity) as well as system-reservoir hybridization. Hence, for schemes that go beyond the conventional Markov approximation a variety of methods across different sub-disciplines has been developed such as hierarchical equations of motion, Lindblad-pseudomode formulas, Chain-mapping approaches, phase space Fokker-Planck equations, stochastic unravelings, and quantum master equations. This diversity, while indicative of the field's relevance, has inadvertently led to a 'fragmentation' that hinders a cohesive advancement and application to current problems for complex systems.

How are different approaches related to each other? What are their strengths and limitations? A systematic overview and concise discussion is highly wanted. Here, we make use of a unified framework which very conveniently allows to link different schemes and, this way, may also catalyze further progress. In line with the state of the art, this framework is formulated not in fully reduced space of the system but in extended state space which in a minimal fashion includes effective reservoir modes. This in turn offers a comprehensive understanding of existing methods, elucidating their physical interpretations, interconnections, and applicability.

This work has been supported by the German Science Foundation (DFG) under AN336/12-1 (For2724), the State of Baden-Wüttemberg under KQCBW/SiQuRe, and the BMBF within the project QSolid as well as through the Academy of Finland Centre of Excellence program (project no. 336810) and THEPOW (project no. 349594), and the European Research Council under Advanced Grant no. 101053801 (ConceptQ).

[1] M.Xu,et al, Phys.Rev.Lett. 129 (2022) 230601

[2] M.Xu,et al, arXiv:2307.16790 (2023)

[3] V.Vadimov, et al, arXiv:2310.15802 (2023)