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

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Open quantum systems exchange energy or particles with their environments and constitute a generic setting in all fields of physics. One prevalent scenario involves a system of interest embedded in thermal reservoirs, a situation that is not only of fundamental relevance. Indeed, the optimization and design of advanced quantum technologies demands efficient, versatile, and precise theoretical simulation schemes that go beyond perturbative treatments of the reduced density such as Lindblad and Master equations. Crucial questions are thus: Is it possible to derive a uniform framework in form of an *exact* time-local equation for quantum dissipation that is numerically efficient and applicable for arbitrary bath spectral densities and across the whole temperature range? Can one relate other established approaches to this uniform theoretical framework through 'simple' transformations?

We recently developed a theoretical platform (QD-MESS) which provides positive answers to both questions [1]. It is directly derived from the Feynman-Vernon path integral expression and exploits that the reservoir can be modelled in a mathematically consistent way through a *finite* set of harmonic modes with complex-valued frequencies and complex valued amplitudes. The consequences are far-reaching: In Fock state representation, this leads to an extended version of the Hierarchical Equations of Motion (HEOM) approach for any given bosonic [2, 3] and fermionic [4] noise spectra. Further, equations of motion in phase space, stochastic unravelings, and pseudomode-Lindbladian formulations can be derived via appropriate 'rotations' in Fock space. Recent applications to spin-systems will be discussed.

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