Driven-dissipative quantum spin systems: Fate of their entanglement and the origins of the classical Landau-Lifshitz equation

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The driven-dissipative many-body systems remain one of the most challenging *unsolved* problems of quantum physics. When “body” is spin, such as of electrons or of engineered ones like qubits, these many-body systems underlie spintronics, magnonics, and quantum computing technologies. In this talk, I will first explain conditions [1] under which quantum spins interacting with a dissipative environment can transition toward classical dynamics governed by the celebrated Landau-Lifshitz-Gilbert (LLG) equation. The extended LLG equation for classical spin dynamics, which includes non-Markovian and spatially nonlocal damping of quantum origin, can be rigorously derived from Schwinger-Keldysh quantum field theory (SKFT) [2] by integrating out fermionic or bosonic baths and by neglecting quantum fluctuations of spin fields. It explains [2] how to properly bring light into the LLG equation and predict optically excited magnons. For antiferromagnetic two-dimensional semiconductors like CrSBr, it can explain [3] ultrafast optical excitation of magnons once the excitonic bath as mediator is included. In the case of fully quantum spin dynamics, by combining SKFT with two-particle irreducible effective (2PI) action formalism and 1/N expansion, both of which have been developed originally in elementary particle physics, we describe [4] time evolution of spin in archetypical open quantum system—the spin-boson model (which is also of great importance for understanding decoherence of idle superconducting qubits). Despite only a class of Feynman diagrams being resummed to infinite order by 2PI, where those diagrams are generated by expansion in 1/N (N is the number of Schwinger bosons to which spin is mapped) instead of expansion in the system-bath coupling, our SKFT can track numerically exact non-Markovian simulations from tensor networks (TN) methods. It also provides access to longer times and higher spatial dimensions where TN fails due to the emergence of the “entanglement barrier.” These newly developed methods make it possible to understand, for the first time, the fate of entanglement in open quantum spin liquids [5].

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