Schwinger-Keldysh nonperturbative quantum field theory for driven-dissipative spin systems

Branislav K. Nikolic, Felipe Reyes-Osorio, and Federico Garcia-Gaitan

University of Delaware, Department of Physics & Astronomy, 217 Sharp Lab, Newark, USA

The driven-dissipative many-body systems remain one of the most challenging unsolved problems in quantum mechanics. When “body” is spin, such many-spin systems underlie spintronics, magnonics and quantum computing. 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 such classical spins, which includes non-Markovian and spatially nonlocal damping of quantum origin, can be rigorously derived from Schwinger-Keldysh (SK) quantum field theory (QFT) [2] by neglecting quantum fluctuations of spin fields. Its application [3] to spin waves explains recent experiments where quantum sensing has measured 100-fold increase of damping in yttrium iron garnet (one of the key materials in magnonics) due to metallic overlayer. In the case of fully quantum spin dynamics, by combining SK QFT with two-particle irreducible effective (2PI) action formalism and 1/N expansion, both of which have been developed originally in elementary particle physics, we derive [4] time evolution of spin in archetypical open quantum system, the spin-boson model of great importance for understanding superconducting qubit decoherence. Despite only a class of Feynman diagrams being effectively resummed to infinite order by 2PI, where those diagrams are generated by expansion in 1/N (where N in the number of Schwinger bosons to which spin is mapped) instead of expansion in coupling constant, our SK QFT can track numerically exact simulations (such as from hierarchical equations of motion or tensor networks) of the spin-boson model. This signifies that our SK QFT is nonperturbative and, furthermore, it can go reach regimes where numerically exact simulations become problematic due to long time evolution, specific temperature, more than one spin and ultimately emergence of “entanglement barrier.”

This work was supported by the U.S. National Science Foundation through the University of Delaware Materials Research Science and Engineering Center, Grant No. DMR-2011824.

[1] F. Garcia-Gaitan and B. K. Nikolić, Phys. Rev. B 109, L180408 (2024).

[2] F. Reyes-Osorio and B. K. Nikolić, Phys. Rev. B 109, 024413 (2024).

[3] F. Reyes-Osorio and B. K. Nikolić, arXiv:2312.09140 (2023).

[4] F. Reyes-Osorio, F. Garcia-Gaitan, D. J. Strachan, P. Plecháč, S. R. Clark, and B. K. Nikolić, arXiv:2405.00765 (2024).