Universität Münster

Aktuelle Fragen
der Nanophysik

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From solitons to correlations: Non-equilibrium spin dynamics across multiple scales

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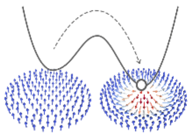
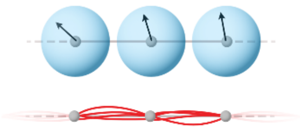
Although magnetism fundamentally arises from complex quantum many-body interactions, it is often possible to describe phenomena in ordered materials using classical emergent frameworks at various length and energy scales. This perspective facilitates the analysis of a wide range of static and dynamic nonlinear phenomena, including topological solitons, spin textures, parametric resonance, ultrafast switching, auto-oscillations, and chaos. Typically, each emergent level is achieved by coarse-graining microscopic details, which provides predictive power and introduces new conceptual tools, such as torques, conserved topological charges, and solitons. However, when magnetic systems are driven far from equilibrium, this established hierarchy of emergent descriptions can break down, resulting in fundamentally new multiscale effects that challenge existing conceptual frameworks.

In this talk, I will present three complementary mechanisms that exemplify this breakdown from distinct perspectives. First, driving a topological soliton with high-frequency microwave radiation can push the magnetic system into a far-from-equilibrium state where slow soliton dynamics and fast magnon dynamics become strongly coupled, resulting in self-induced Floquet modes [1]. Second, strong laser excitation of chiral magnets can induce significant thermal fluctuations, resulting in the ultrafast nucleation of solitons known as skyrmions. While the skyrmion number is typically considered conserved at the emergent level, in the ultrafast regime, their collective dynamics can be described by independent thermally activated nucleation and annihilation events [2]. Lastly, at even shorter spatiotemporal scales, perturbing antiferromagnets can drive them into strongly excited states where classical nonlinear magnetism fails, and quantum correlations become significant. Although numerical quantum many-body techniques can capture certain nonlinear spin dynamics, these methods are computationally intensive and often obscure the connection between nonlinear dynamics and their geometric origin in the angular-momentum algebra of spins. To address this challenge, we propose a semiclassical spin-correlation theory that evolves spin correlations on lattice bonds rather than on individual spins [3]. This approach incorporates nonlinear dynamics beyond classical models while preserving the geometric structure associated with the intrinsic nonlinearity of spins.





1 - Heins, Körber et al., Science 391, 6781pp. 190-194 (2026), DOI: 10.1126/science.adq9891
2 - Lieferink, Körber et al., PRL 136, 146705 (2026), DOI: 10.1103/brnt-2m9l
3 - Körber et al. (2025), arXiv:2512.11466