Spontaneous Magnon Decays from Nonrelativistic Time-Reversal Symmetry Breaking in Altermagnets

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Quasiparticles are central to condensed matter physics, but their stability can be undermined by quantum many-body interactions. Magnons, quasiparticles in quantum magnets, are particularly intriguing because their properties are governed by both real and spin space. While crystal symmetries may be low, spin interactions often remain approximately isotropic, limiting spontaneous magnon decay. Textbook wisdom holds that collinear Heisenberg magnets follow a dichotomy: ferromagnets host stable magnons, while antiferromagnetic magnons may decay depending on dispersion curvature. Up to now, relativistic spin-orbit coupling and noncollinear order that connect spin space to real space, were shown to introduce more complex magnon instability mechanisms [1].

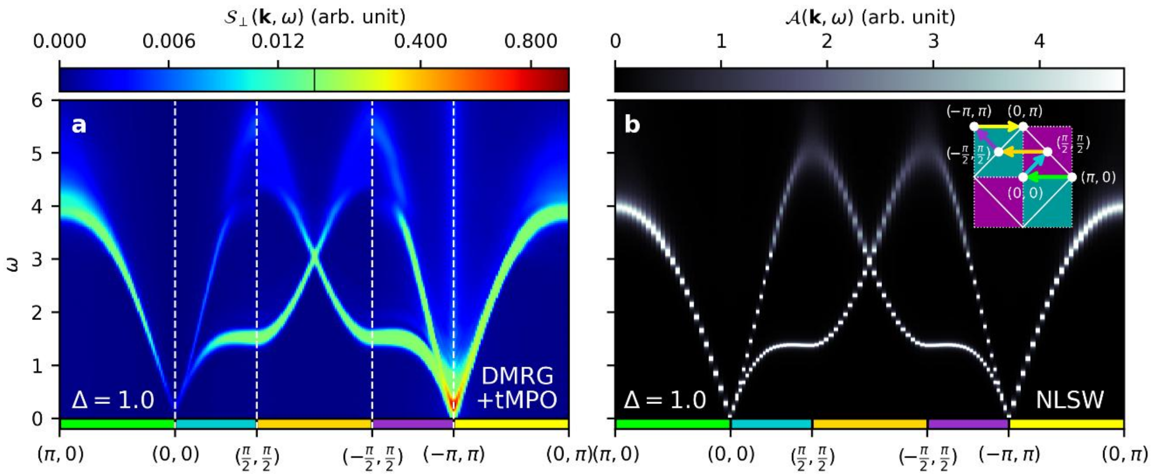

Figure 1. Magnon spectrum of a *d*-wave altermagnet as obtained from (**a**) density matrix renormalization group with time-evolution of matrix product operators (DMRG+tMPO) and (**b**) nonlinear spin-wave (NLSW) theory. Spontaneous quasiparticle decays cause a spectral broadening, which is most pronounced at the $(\frac{\pi}{2}, \frac{\pi}{2})$ point, where the spin splitting is largest.

In our recent work [2], we show that even in nonrelativistic isotropic collinear systems, this conventional dichotomy is disrupted in altermagnets. Altermagnets, a newly identified class of collinear magnets, exhibit compensated spin order with nonrelativistic time-reversal symmetry breaking and even-parity band splitting [3]. Using perturbative nonlinear spin-wave theory and nonperturbative quantum simulations, we reveal that even weak band splitting opens a decay phase space, driving quasiparticle breakdown (see the spectral smearing in **Figure 1**). We provide a comprehensive analysis of magnon decays in *d*-wave, *g*-wave, and *i*-wave altermagnets, identifying *d*-wave altermagnets as the most intriguing: their upper magnon branch undergoes the strongest decays, while their lower magnon branch features an "island of stability" near the Brillouin zone origin, where magnons acquire an infinite lifetime. Our predictions can be tested using state-of-the-art neutron spin echo experiments, positioning altermagnets as a compelling platform for exploring unconventional spin dynamics and spontaneous quasiparticle decay.

References

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