Tunable Collective Modes in the Dilute Ising Magnet LiHo$_{0.045}$Y$_{0.955}$F$_4$

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Collections of quantum mechanical spins with dipolar interactions exhibit a complex set of states and excitations due to the long range and alternating sign of the dipolar potential. We use nonlinear ac magnetic susceptibility on the dilute dipole Ising magnet LiHo$_{0.045}$Y$_{0.955}$F$_4$ to study the behavior of coupled clusters of spins. Pump-probe spectroscopy excites Fano resonance behavior between coherent, isolated spin clusters and a background spin bath. The evolution of these clusters exhibits universal behavior as a function of several different tuning parameters such as static transverse field, ac pump field, and thermal connectivity to a heat reservoir. We discuss our results within the framework of many-body localization.