

Two-dimensional coherent spectroscopy of disordered superconductors

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Two-dimensional coherent spectroscopy (2DCS) has recently emerged as a powerful probe of nonlinear optical responses in condensed matter systems, providing access to dynamical information beyond conventional linear and nonlinear spectroscopies. The 2DCS is also useful in detecting collective modes in an ordered phase of materials including quantum magnets and superconductors. The presence of those collective modes tells us key aspects of quantum phases, such as symmetries, fluctuations, and hidden orders.

In superconductors, there exists a Higgs mode [1,2], i.e., an amplitude mode of the superconducting order parameter, which does not linearly couple to electromagnetic fields in ordinary situations. Previously, the Higgs mode has been observed by a nonlinear response setup, e.g., Raman scattering, pump-probe spectroscopy, and third harmonic generation. On the other hand, it is not straightforward to extract the contribution of the Higgs mode separately, as individual excitations of quasiparticles also contribute to the signal at similar frequencies.

Motivated by recent experiments of 2DCS for superconductors [3,4], we theoretically analyze 2DCS signals of disordered superconductors [5]. We examine the behavior of 2DCS signals for narrow-band and broad-band pulse waveforms, and discuss the physical origin of the resonance and threshold structures observed in the 2D frequency map. We also mention our recent studies of 2DCS for antiferromagnets [6].

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