Exploring Terahertz 2D Coherent Spectroscopy in Superconductors: From Higgs Echoes to Parametric Superconductivity

Jigang Wang

Ames National Laboratory, U.S. Department of Energy, Ames, Iowa 50011, USA

Department of Physics and Astronomy, Iowa State University, Ames, Iowa 50011, USA

Terahertz Two-Dimensional Coherent Spectroscopy (THz-2DCS) is an innovative tool for generating, studying, and controlling emergent quantum states by utilizing a pair of intense THz laser fields with tunable relative phases [1, 2]. In this talk, we will discuss recent examples demonstrating how THz-2DCS offers strategic advantages in controlling and characterizing exotic quantum pathways, high-order nonlinearity, quantum interference of multiple excitations, and driven many-body correlations in both s-wave and d-wave superconductors. For the first example, we reveal an unconventional quantum echo arising at the Higgs mode frequency in a BCS superconductor. We apply this Higgs echo spectroscopy to identify distinctive quantum pathways attributed to Higgs mode anharmonicity and rephasing [3,4]. Second, we report the discovery of parametrically driven superconductivity in iron-based superconductors, characterized by a unique bi-Higgs collective mode as Floquet-like sidebands at twice the Higgs frequency [2,4]. Third, we discuss the distinguishing THz 2DCS evidence for a d-wave pairing symmetry in an infinite-layer nickelate, underscoring its unconventional superconductivity [5,6]. Our results establish this experimental technique in superconductivity and quantum materials research, particularly highlighting its power to illuminate many-body correlation functions and collective modes.

1. M. Mootz et al., *Communication Physics,* 5**,** 47 (2022).
2. L. Luo et al., *Nature Physics*, 19, 201 (2023).
3. C. Huang, et al., "Discovery of an Unconventional Quantum Echo by Interference of Higgs Coherence" *arXiv:2312.10912*
4. M. Mootz, et al., *Phys. Rev. B.*, 109, 014515 (2024)
5. B. Chen et al., *Nature Materials*, 23, 775 (2024)
6. B. Chen, et al., "Evidence for highly damped Higgs mode in infinite-layer nickelates," *arXiv:2310.02589*