Ultrafast pair distribution function as a probe of hidden states in quantum materials

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Understanding how materials evolve under non-equilibrium conditions requires experimental tools capable of capturing both local structural changes and their ultrafast dynamics. Ultrafast X-ray pair distribution function (uf-PDF) analysis—based on total scattering measurements enabled by femtosecond X-ray free-electron lasers (XFELs)—now allows direct access to transient local structures beyond the constraints of crystallographic symmetry and long-range order. Here, we will discuss how resolving hierarchical structural evolution on femtosecond to picosecond timescales provides critical insight into transient states and hidden orders that often govern the functional behavior of complex quantum materials [1].

Recent advances have demonstrated that high-quality total scattering data and corresponding PDFs can be obtained from a single ~30 fs XFEL pulse over an extended Q-range. This capability further enables detailed structural analysis of crystalline, nanocrystalline, amorphous, and liquid systems alike [2]. These developments open new frontiers for time-resolved investigations of lattice instabilities, correlated electron phenomena, and the competition between intertwined orders in quantum materials [3].

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