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Quantum Cluster Embedding Study of Disordered and Strongly Correlated Systems

Quantum materials with strong electronic correlations lie at the heart of modern condensed matter physics, exhibiting rich phenomena such as unconventional superconductivity, Mott insulating behavior, and quantum criticality. Realistic modeling of these systems necessitates the inclusion of disorder, which plays a crucial role in driving metal-insulator transitions (MITs), inducing electron localization, and profoundly impacting transport, spectral, and thermodynamic properties. In this study, we employ quantum cluster embedding techniques within the framework of Dynamical Mean Field Theory (DMFT)—specifically, the Dynamical Cluster Approximation (DCA), Cellular DMFT (CDMFT), and the Typical Medium DCA (TMDCA)—to investigate the interplay of strong correlations and disorder in both two- and three-dimensional Anderson and Hubbard models. Our results reveal significant non-local correlation effects near the localization transition, highlighting the limitations of purely local theories in capturing the full complexity of disorder-driven and interaction-driven MITs. Through a comparative analysis of the different quantum cluster approaches, we benchmark their accuracy and efficacy in resolving key features of the phase transitions. This work demonstrates the essential role of non-local quantum embedding methods in understanding disordered, strongly correlated systems and provides insights into the mechanisms governing the emergence of insulating and metallic phases.
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