Contribution ID: **132** Type: **not specified**

Interference-caged quantum many-body scars: the Fock space topological localization and interference zeros

Tuesday, 26 August 2025 15:35 (20 minutes)

We propose a general mechanism for realizing athermal finite-energy-density eigenstates—termed interference-caged quantum many-body scars (ICQMBS)—which originate from exact many-body destructive interference on the Fock space graph. These eigenstates are strictly localized to specific subsets of vertices, analogous to compact localized states in flat-band systems. Central to our framework is a connection between interference zeros and graph automorphisms, which classify vertices according to the graph's local topology. This connection enables the construction of a new class of topological ICQMBS, whose robustness arises from the local topology of the Fock space graph rather than from conventional conservation laws or dynamical constraints. We demonstrate the effectiveness of this framework by developing a graph-theory-based search algorithm, which identifies ICQMBS in both a one-dimensional spin-1 XY model and two-dimensional quantum link models (QLM) across distinct gauge sectors. In particular, we discover the proposed topological ICQMBS in the two-dimensional QLM and provide an intuitive explanation for previously observed order-by-disorder phenomena in Hilbert space (ODBDHS). Our results reveal a synergy between graph theory, flat-band physics, and quantum many-body dynamics, and lay the foundation for a general mechanism of localization in Hilbert space—grounded not in symmetry, but in interference and topology.

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Session Classification: Contributed talks

Track Classification: Invited talk