Interacting non-Hermitian quasiperiodic chains with power-law hopping: Spectrum, localization, topology, and the skin effect

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In this work, we study one-dimensional interacting non-Hermitian quasiperiodic lattices with asymmetric power-law hopping in the presence of time-reversal symmetry (TRS). In contrast to earlier works on short-range non-Hermitian quasiperiodic models with TRS, both with and without interactions, where the spectral, delocalization-localization, and topological transitions have been identified to coincide, we show that in this setting, the reality of the many-body eigenspectrum does not necessarily indicate a topologically trivial non-Hermitian many-body localization (NHMBL) regime. Instead, we uncover a topologically trivial intermediate regime in which the states are primarily multifractal and the spectrum remains fully real, thereby leading to the restoration of TRS of the eigenstates before the system crosses over into the NHMBL phase. Within this regime, interactions qualitatively reshape the non-interacting phenomenology, i.e., it destroys the single-particle mobility and multifractal edges of the non-interacting counterpart and rather generates many-body edges separating localized and extended states, comprising of both ergodic and non-ergodic ones. Furthermore, we unveil that due to the long-range nature of the asymmetric hopping, the entire topologically non-trivial ergodic phase under periodic boundary conditions does not generically map to boundary-localized skin modes under open boundary conditions. Whenever skin-like states occur, they are indeed many-body scale-free localized in nature. These unconventional phases and crossovers are corroborated by the long-time dynamics of local observables and density imbalance. Our results thus demonstrate that the interplay of interactions and long-range hopping in non-Hermitian quasiperiodic systems gives rise to a modified understanding of interconnections between the various phases that goes beyond the standard paradigm established for short-range non-Hermitian quasiperiodic models.