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Multifractal and hyperuniform analysis of quasicrystalline patterns in bosonic systems with and without disorder

The multifractal and hyperuniform analyses are two of the methods to quantify the properties of a nonuniform spatial pattern. Most of nonuniform spatial patterns are either multifractal or hyperuniform. The vertices of random systems are multifractal, while those of all crystals and most quasicrystals are hyperuniform. A quasicrystal can be obtained as projection of a periodic lattice in higher dimensions called a hypercubic lattice onto lower dimensions. The Ammann-Beenker quasicrystal is an example of a two-dimensional quasicrystal, which is projection of a hypercubic lattice in four dimensions. We investigate the effects of quasiperiodicity on physical quantities by using the multifractal and hyperuniform analyses.

In this study, we consider the physical quantities in the Bose-Hubbard model on the Ammann-Beenker tilings. The system shows Mott insulating phase and superfluid phase. In both of these phases, the distribution of the physical quantities is found to be hyperuniform. Moreover, analyzing the order metric that quantifies the complexity of nonuniform spatial patterns, we find that the Ammann-Beenker tilings show a significantly large order metric at a phase boundary, in stark contrast to periodic square lattices. Our results suggest that hyperuniformity is a useful method to differentiate crystalline and quasicrystalline systems.

Next, we introduce on-site random potentials in our model, leading to a Bose glass phase. Contrary to the Mott insulating and superfluid phases, we find that the Bose glass phase is multifractal. To the best of our knowledge, this is the first report of a phase transition between hyperuniform and multifractal phases.