Static and Dynamical Properties of Many-Body Localised Phases

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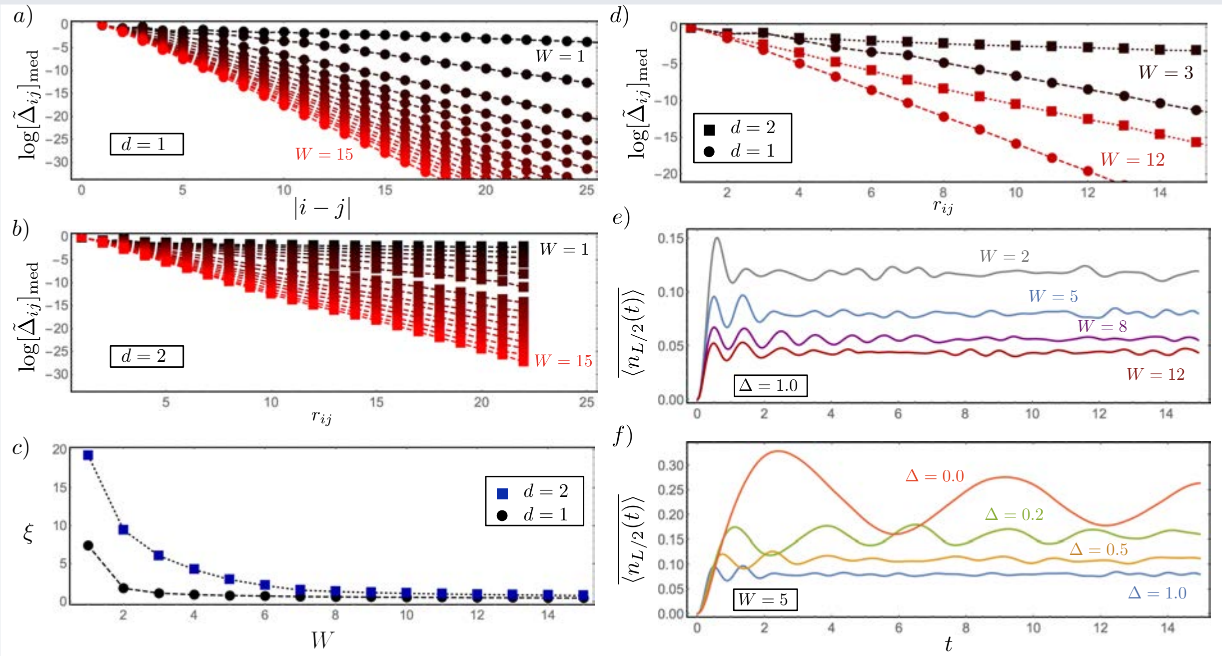
The concepts of thermodynamic equilibrium and ergodicity are two central building blocks of our understanding of interacting classical and quantum systems. Violations of these established paradigms, for example close to a glass transition, often result in unconventional dynamical and transport properties. In the quantum world ergodicity breakdown has been known to occurr in presence of quenched random disorder since the seminal work of Anderson, yet it was longly believed that the resulting localization phenomenon could not survive in presence of interactions and finite temperature.

In this respect the theoretical prediction in 2006 that interacting quantum systems can fail to thermalize and approach thermal equilibrium in presence of a sufficiently strong disorder came as a surprise and triggered a new wave of interest around disordered quantum systems. Many Body Localization (MBL) is a unique quantum phenomenon where quenched disorder and quantum mechanical interactions conspire to break ergodicity in a surprising way, leading to materials with unusual properties. MBL systems are near-perfect insulators, with an extremely slow internal dissipation of energy. This gives MBL materials very long 'memories', results in a peculiar logarithmic scaling of the entanglement entropy and prevents the material from reaching thermal equilibrium. Even the very concept of temperature breaks down: a material which does not thermalise even within itself cannot be said to have a temperature. This insensitivity to temperature and consequent robustness of MBL phases combined with their unusual quantum mechanical properties means that they have a wide range of potential technological applications, but so far our theoretical understanding is still in its infancy.



We have developed a new renormalization group inspired technique known as the flow equation approach to study these systems on system sizes an order of magnitude larger than most conventional numerical methods. Using a continuous unitary transform to diagonalise the Hamiltonian, we are able to study the interactions between so-called *l*-bits (the building blocks of an MBL material) and show they decay exponentially with distance in both one and two dimensions. This is the first time MBL has been investigated in two dimensions using a microscopic model. The decay of *l*-bit interactions is shown in panels *a*) and *b*) above for *d*=1 (*L*=100) and *d*=2 (*L*=12x12) respectively, averaged over 100 disorder realizations. The associated localization lengths are shown in panel *c*). A comparison is shown in panel *d*) – the system is significantly less localised in *d*=2.

We have also studied the density dynamics in the middle of a *d*=1 chain after a quantum quench (panels *e*) and *f*) above, system size *L*=64, averaged over 500 disorder realisations), where we have shown the crucial effects of disorder and interactions on the long-time memory of the material: stronger interactions and greater disorder both lead to longer memories of the initial state. This technique has a wide range of future applications, and our findings are of immediate relevance to recent and ongoing experiments.

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