ROEMER **PhD**

Multifractality as Defining Feature of Many-Body Localisation

Quantum physics often surprises with phenomena that challenge classical intuition. For example, a system of many interacting classical particles, evolving under its own internal dynamics, is known to eventually reach a thermal equilibrium. In the realm of quantum mechanics this is not necessarily true: a single particle, subject to energetic disorder, will refuse to evolve in time and to explore the host system. Rather, due to quantum interference, it will remain spatially confined, leading to a non-thermalising behaviour known as Anderson localisation (AL) [1]. The fate of AL in the presence of many-body interactions, as is the case in any real material, has been an intriguing question for many years. Recent research showed that AL would be robust under the effect of short-range interactions, giving rise to an insulating phase with exactly zero conductivity below a certain critical temperature. The phenomenon was named many-body localisation (MBL) [2]. In the MBL state an isolated quantum system never reaches thermal equilibrium under its own internal dynamics, and thus cannot be described by standard quantum statistical mechanics. This implies that the system retains information about its initial state for arbitrarily long times - a quantum information storage potentially very relevant for the development of quantum technology devices.

MBL has become an important research field, developing cutting-edge experimental advances for the engineering and manipulation of isolated quantum systems [2]. But controversies and open questions remain. Mostly numerical evidence in support of an MBL transition in 1D systems has been reported. Experimentally, several studies with cold atoms in optical lattices claim to have observed features of MBL; but not yet clearly in electronic systems. Recent theoretical work suggests that the MBL phase may be just a metastable regime which appears localised but thermalises in a very long time scale [3]. The reported transitions would then be just finite-size/finite-time effects. On the other hand, there is a very recent mathematical proof of the existence of MBL in a certain class of 1D systems with short-range interactions. The main challenge in characterising MBL is of course related to the exponentially growing number of states in Hilbert space even for modest spatial dimensions. This severely limits the applicability of standard finite-size scaling approaches and restricts the times towards which a system can be evolved. What is required is a better starting description of the states in Hilbert space. Our approach offers this description by using a generalised multifractal analysis and an innovative scaling approach for Anderson localisation [1]. This approach will lead to an unambiguous picture of the MBL phenomenology in Hilbert space, a high-precision estimation of the phase diagram and critical properties of a model of interacting disordered fermions, a characterisation of the MBL features in experimentally accessible real-space observable in electronic systems, and it will help resolve the controversy on the existence of intermediate phases in MBL and AL in random networks.

For further information, see http://www.warwick.ac.uk/go/DisQS. The work will be done together with Dr. Animesh Datta.

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