Instabilities in the random-field XXZ chain

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Despite a solid understanding of single-particle Anderson localization (AL) in one-dimensional disordered systems, understanding many-body effects remains a major challenge. A famous example is the debated phenomenon of many-body localization (MBL) at high energy, notably in the Heisenberg spin chain under a strong random magnetic field [1].
We present a comprehensive shift-invert exact diagonalization study of the generic XXZ model in the full disorder (h) – interaction (Δ) plane, revealing two key findings:
(1) Near the AL limit, standard observables indicate that below a certain disorder threshold $h^* \sim 2\text{-}3J$, weak interactions necessarily lead to an ergodic instability. At strong disorder, the AL insulator instead directly turns into MBL. This result agrees with a simple interpretation of the avalanche theory.
(2) In a broad region of the phase diagram, the long-distance spin-spin correlations display fat-tailed distributions due to rare, large correlations. These rare events lead to an unexpected algebraic decay of the average correlations, even in a regime where standard observables suggest MBL. Only at much stronger disorder and weaker interactions does this intermediate regime give way to a more conventional localization, characterized by exponential decay with short correlation lengths for both typical and average correlators. This sheds light on the systemwide instabilities and raises important questions about the impact of rare but large long-range correlations on the stability of the MBL phase.

References

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Figures

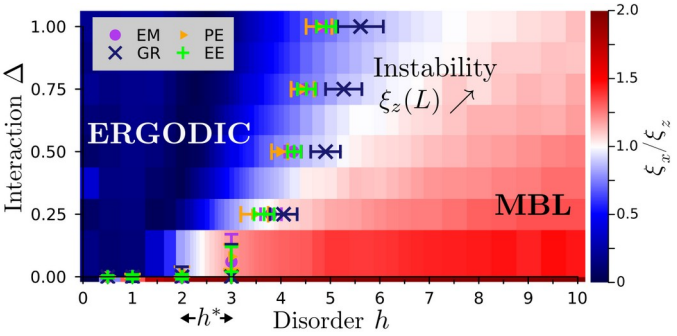

Figure 1:
Disorder – interaction phase diagram of the XXZ chain Hamiltonian at high energy (middle of many-body spectrum).
Symbols indicate the ergodic to MBL transition points obtained from standard observables. The transition line starts from the Anderson insulator ($\Delta = 0$) at a finite disorder strength $h*$. At stronger disorder, the heatmap shows the ratio of the transverse to longitudinal mid-chain correlation lengths. The region where $\xi x / \xi z \lesssim 1$ gives a rough approximation of the instability regime in which $\xi z\ (L)$ increases with L.