Transition from Integrability to Chaos in the XXZ Chain via ETH and Submatrix Analysis

Shivam Mishra[1] and Ravi Prakash[1]

[1]Department of Physics, Motilal Nehru National Institute of Technology (MNNIT), Prayagraj, India 211004

Abstract

The Eigenstate Thermalization Hypothesis (ETH) provides a framework for understanding thermalization in isolated quantum many-body systems by analyzing the structure of observable matrix elements in the energy eigenbasis. We investigate the transition from integrability to chaos in the spin-$1/2$ XXZ chain, perturbed by a local magnetic field, which breaks integrability and drives the system toward quantum chaos. This transition is probed through spectral correlations (both short- and long-range), ETH, and eigenstate entanglement entropy. Although correlations among matrix elements in an operator are crucial for dynamics, we show that submatrices extracted from the full local operator, written in the energy eigenbasis, exhibit random matrix-like properties in their statistical properties of matrix elements and spectral correlations. We study the crossover from integrability to chaos through the spectral correlations of submatrices taken from the local operator. These submatrices capture all transitions at the level of spectral fluctuations, both short-range through spacing ratio distributions and long-range via the spectral form factor, as well as in eigenstates through eigenstate entanglement entropy.

Keywords: Quantum chaos, Eigenstate Thermalization Hypothesis, Eigenstate entanglement entropy, Spectral statistics