Full counting statistics and cumulant evolution in infinite temperature quantum spin chains

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We investigate the spin-transfer statistics in one-dimensional anisotropic Heisenberg (XXZ) spin models. We introduce a novel tensor-network approach, with which we extract high-order cumulants directly from the generating function at unprecedently long times. We can validate our approach against quantum trajectory simulations – which give access to the full distribution but are limited to shorter times – allowing us to compare cumulants up to the sixth order for S=1/2 and S=1 spin chains.

S=1/2 spin chains are integrable, and at the isotropic point (Δ=1) the variance of the spin transfer is characterized by algebraic growth in time with a superdiffusive z=3/2 exponent as for a Kardar-Parisi-Zhang (KPZ) universal scaling. Fluctuations are weakly non-Gaussian (e.g., excess kurtosis ≠ 0) but incompatible with a Baik-Rains distribution, in agreement with recent experiments on quantum simulators [2] and with theoretical predictions for classical magnets [3]. In the easy-plane regime (Δ<1) transport is ballistic with asymptotically Gaussian distribution. In the XX limit (i.e., Δ=0), we can compare our simulations with exact results, obtained by fermionizing the spin chain. Remarkably, in the diffusive easy-axis regime (Δ>1), we find distinctively non-Gaussian fluctuations, and cumulants consistent with those obtained from Mainardi-Wright family distributions [3]. For non-integrable S=1 spin chains, we find a distinctively different scenario. The spin transfer in the easy-plane regime displays a ballistic-to-diffusive crossover. Interestingly, at the isotropic point, a resilient KPZ scaling is observed, suggesting near-integrability. The dynamical exponent drifts away from the universal value z=3/2 logarithmically in time, possibly towards a z=2 diffusive regime – although we cannot numerically rule out a z=5/3 Fibonacci-ratio exponent [4]. In all regimes, we find fluctuations asymptotically consistent with Gaussianity.

References

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[3] Krajnik *et al.*, PRL **132**, 017101 (2024)
[4] Popkov et al., PNAS **112** 12645 (2015)

Figures

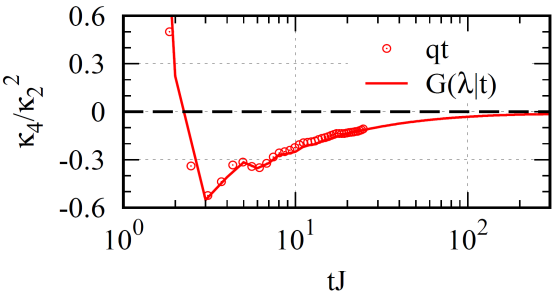

Figure 1: Excess kurtosis for S=1/2 XX chain (Δ=0): quantum trajectories and generating function.