Abstract

In recent times out-of-time-order correlators (OTOC) have been established as a tool to understand butterfly effects, quantum information scrambling, and many-body localization. They can also be useful in determining different phases of quantum critical systems. OTOCs can identify the quantum chaos within a system undergoing time evolution; and therefore, they can distinguish between chaotic and regular dynamics. This motivates us to study OTOCs in integrable and nonintegrable periodically kicked quantum spin models. A periodically kicked quantum Ising spin system, known as the quantum Ising Floquet system, is a variant of the transverse Ising model. In place of constant transverse magnetic fields in the transverse Ising system, time-periodic fields are applied in the form of delta pulses in the quantum Ising Floquet spin system. It provides very interesting and peculiar dynamics separate from that of the transverse Ising system.

First, we explore the phase diagram of the Floquet transverse Ising model using the long-time average of OTOC as an order parameter. In the process, we present the exact analytical solution of the transverse magnetization OTOC using the Jordan-Wigner transformation. We also calculate the speed of correlation propagation and analyze the behavior of the revival time with the separation between the observables. To get the phase structure of the Floquet transverse Ising system, we use the longitudinal magnetization OTOC. We show the phase structure numerically in the transverse Ising Floquet system by using the long-time average of the longitudinal magnetization OTOC. In both the open and the closed chain systems, we find distinct phases, out of which two are paramagnetic (0-paramagnetic and π-paramagnetic), and two are ferromagnetic (0-ferromagnetic and π-ferromagnetic) as previously defined in the literature.

Next, we focus on different regimes of OTOC vs. time in the constant field transverse Floquet Ising system with and without longitudinal field. Three distinct regimes viz. char-

acteristic, dynamic, and saturation of OTOC vs. time, are analyzed carefully. In calculating OTOC, we take local spins in longitudinal and transverse directions as observables that are respectively local and non-local in terms of Jordan-Wigner fermions. We use the exact analytical solution of OTOC for the integrable model (without longitudinal field term) with transverse direction spins as observables and provide numerical solutions for other cases. OTOCs generated in both cases depart from unity at a kick equal to the separation between the observables when the local spins in the transverse direction and one additional kick is required when the local spins in the longitudinal direction. The number of kicks required to depart from unity depends on the separation between the observables and is independent of the Floquet period and system size. In the dynamic region, OTOCs show power-law growth in both models, the integrable (without longitudinal field) as well as the nonintegrable (with longitudinal field). The exponent of the power-law increases with increasing separation between the observables. Near the saturation region, OTOCs grow linearly with a very small rate.

Further, we calculate OTOCs using contiguous symmetric blocks of spins or random operators localized on these blocks as observables instead of localized spin observables. We find only the power-law growth of OTOC in integrable and nonintegrable regimes. In the non-integrable regime, beyond the scrambling time, there is an exponential saturation of the OTOC to values consistent with random matrix theory. This motivates the use of “pre-scrambled" random block operators as observables. A pure exponential saturation of OTOC in both integrable and nonintegrable systems is observed without a scrambling phase. Averaging over random observables from the Gaussian unitary ensemble, the OTOC is found to be the same as the operator entanglement entropy, whose exponential saturation has been observed in previous studies of such spin chains.

Finally, we utilize OTOCs as a quantifier for quantum information currents and propose a quantum information diode (QID) by exploiting the effect of nonreciprocal magnons

in a 2D Heisenberg spin system with Dzyloshinski Moriya interaction. QID is a device rectifying the amount of quantum information transmitted in opposite directions. We control the asymmetric left and right quantum information currents through an applied external electric field and quantify it through the left and right OTOC. To enhance the efficiency of the quantum information diode, we utilize a magnonic crystal. We excite magnons of different frequencies and let them propagate in opposite directions. Nonreciprocal magnons propagating in opposite directions have different dispersion relations. Magnons propagating in one direction match resonant conditions and scatter on gate magnons. Therefore, magnon flux in one direction is damped in the magnonic crystal. This fact leads to an asymmetric transport of quantum information in the quantum information diode. A quantum information diode can be fabricated from an yttrium iron garnet (YIG) film. This is an experimentally feasible concept and implies certain conditions: low temperature and small deviation from the equilibrium to exclude effects of phonons and magnon interactions. We show that rectification of the flaw of quantum information can be controlled efficiently by an external electric field and magnetoelectric effects.

Overall, this thesis is focused on studying OTOC in the quantum Ising spin Floquet systems to describe the phase structure and dynamics of the systems. Additionally, it describes an application of OTOC as a quantifier of quantum information current in proposed QID based on magnonic crystals.