Workshop “Focus Week on Non-equilibrium Quantum Dynamics”

Dates: September 30 – October 4, 2024
Venue: Kavli IPMU Lecture Hall, Kashiwa campus, UTokyo

1 Program

Sept. 30	Title	Speaker
9:00-9:25	Registration	
9:25-9:30	Opening remarks	Masahito Yamazaki
9:30-10:30	A detailed portrait of many-body dynamics on a quantum computer	Derek S. Wang
10:30-11:00	Coffee break	
11:00-12:00	What is thermal equilibrium and how do we get there?	Hal Tasaki
12:00-14:00	Lunch break	
14:00-15:00	Fermionic Bricks in the Wall	Kareljan Schoutens
15:00-15:30	Tea time	
15:30-16:30	Aspect of Floquet physics in closed quantum systems	Krishnendu Sengupta
16:30-17:30	Free probability approaches to quantum many-body dynamics	Silvia Pappalardi

Oct. 1	Title	Speaker
9:30-10:30	Controlling ultrafast Rydberg dynamics with ultracold atoms in optical tweezers	Takafumi Tomita
10:30-11:00	Coffee break	
11:00-12:00	Exploring Non-Hermitian Phenomena in Ultracold Fermions	Gyu-Boong Jo
12:00-12:10	Group photo	
12:10-14:00	Lunch break	
14:00-15:00	Anyons and Edge Transport in Quantum Hall Systems	Masayuki Hashisaka
15:00-15:30	Tea time	
15:30-16:30	Gong show	
16:30-17:30	Poster session	

Oct. 2	Title	Speaker
9:30-10:30	Exact correlation functions of quantum integrable circuits from algebraic geometry	Yunfeng Jiang
10:30-11:00	Coffee break	
11:00-12:00	Novel quantum dynamics with superconducting qubits	Pedram Roushan
12:00-14:00	Lunch break	
14:00-15:00	Entanglement and tensor networks in the generalised Landau paradigm	Frank Verstraete
15:00-15:30	Tea time	
15:30-	Free time	

Oct. 3	Title	Speaker
10:00-11:00	Coffee break	
11:00-12:00	Understanding Phases and Transitions in Mixed States	Jong Yeon Lee
12:00-14:00	Lunch break	
14:00-15:00	A variety of partially solvable models: From closed spin chains to open spin chains	Chihiro Matsui
15:00-15:30	Tea time	
15:30-16:30	Non-Hermitian Topology in Hermitian Topological Matter: Wannier Localizability and Detachable Topological Boundary States	Kohei Kawabata
16:30-17:30	Poster session	

Oct. 4	Title	Speaker
9:30-10:30	Driven Dirac systems and novel quantum anomalous states	Takashi Oka
10:30-11:00	Coffee break	
11:00-12:00	Physics of tridiagonal matrices	Pratik Nandy
12:00-12:10	Closing remarks	Masaki Oshikawa

2 Invited talks

Talk 1

Speaker: Derek S. Wang (IBM Quantum)

Title: A detailed portrait of many-body dynamics on a quantum computer

Abstract: Interacting many-body quantum systems and their dynamics, while fundamental to modern science and technology, are formidable to simulate and understand. However, by discovering their symmetries, conservation laws, and integrability one can unravel their intricacies. Here, using up to 124 qubits of a fully programmable quantum computer, we uncover local conservation laws and integrability in one- and two-dimensional periodically-driven spin lattices in a regime previously inaccessible to such detailed analysis. We focus on the paradigmatic example of disorder-induced ergodicity breaking, where we first benchmark the system crossover into a localized regime through anomalies in the one-particle-density-matrix spectrum and other hallmark signatures. We then demonstrate that this regime stems from hidden local integrals of motion by faithfully reconstructing their quantum operators, thus providing a detailed portrait of the system's integrable dynamics. Our results demonstrate a versatile strategy for extracting hidden dynamical structure from noisy experiments on large-scale quantum computers.

Talk 2

Speaker: Hal Tasaki (Gakushuin U.)

Title: What is thermal equilibrium and how do we get there?

Abstract: We present a simple, rigorous example (which is essentially a free fermion chain) of an isolated macroscopic (but finite) quantum system that exhibits thermalization (in a phenomenological sense) from any pure initial state in the microcanonical energy shell. The essential ingredients of the proof are the large-deviation type strong ETH (energy eigenstate thermalization hypothesis) bound and the absence of degeneracy in the energy spectrum. As far as we know, this is the first concrete realization of the philosophy on the foundation of equilibrium statistical mechanics proposed by von Neumann in 1929.

Talk 3

Speaker: Kareljan Schoutens (U. Amsterdam)

Title: Fermionic Bricks in the Wall

Abstract: We study brick wall quantum circuits enjoying a global fermionic symmetry. The constituent 2-qubit gate, and its fermionic symmetry, derive from a 2- particle scattering matrix in integrable, supersymmetric quantum field theory in 1+1 dimensions. Our 2-qubit gate, as a function of three free parameters, is of so-called free fermionic or matchgate form, allowing us to derive the spectral structure of both the brick wall unitary U_F and its, non-trivial, hamiltonian limit H_γ in closed form. We find that the fermionic symmetry pins H_γ to a surface of critical points, whereas breaking that symmetry leads to non-trivial topological phases. We explore quench dynamics for this class of circuits.

Talk 4

Speaker: Krishnendu Sengupta (IACS)

Title: Aspect of Floquet physics in closed quantum systems

Abstract: In this talk, we shall discuss two aspects of a periodically driven closed quantum system. First, we shall discuss the existence of signatures of Hilbert space fragmentation (HSF) in a driven interacting fermi chain in its prethermal regime at special drive frequencies. We provide analytical expression for these drive frequencies, show that such prethermal regime can be exponentially long in the large drive amplitude regime, and discuss feasibility of realization of such systems in experiments. Second, we shall discuss a class of two-rate periodic drive protocol for closed quantum systems where the drive frequencies have integer ratio. We show that for protocols obeying certain conditions, there is a large class of non-integrable models where one obtains an exact Floquet flat band. Near these flat bands, heating in these driven systems is significantly reduced which may be useful, for example, in application to qubit manipulation and quantum state preparation.

Talk 5

Speaker: Silvia Pappalardi (U. Köln)

Title: Free probability approaches to quantum many-body dynamics

Abstract: Understanding how to characterize quantum chaotic dynamics is a longstanding question. In this talk, I will discuss recent developments that identify Free Probability – a generalization of probability theory to non-commuting objects — as a unifying mathematical framework to describe correlations of chaotic many-body systems. I will show how the full version of the Eigenstate Thermalization Hypothesis, the established framework for quantum dynamics that encompasses all the correlations, can be rationalized and simplified using the language of Free Probability. This approach uncovers unexpected connections between quantum chaos and concepts in quantum information theory, such as unitary designs.

Talk 6

Speaker: Takafumi Tomita (IMS)

Title: Controlling ultrafast Rydberg dynamics with ultracold atoms in optical tweezers

Abstract: Rydberg atoms, with their giant electronic orbitals, exhibit dipole-dipole interaction reaching the GHz range at a distance of a micron, making them a prominent contender for realizing ultrafast quantum operations. However, such strong interactions have never been harnessed so far because of the stringent requirements on the atom position fluctuation and the necessary excitation strength. Here, we introduce novel techniques to enter this regime and explore it with two strongly-interacting single atoms. This interaction is the key to the realization of an ultrafast two-qubit gate for cold-atom quantum computers. The techniques demonstrated here open the path for ultrafast quantum simulation and computation operating at the speed-limit set by dipole-dipole interactions.

Talk 7

Speaker: Gyu-Boong Jo (HKUST)

Title: Exploring Non-Hermitian Phenomena in Ultracold Fermions

Abstract: Ultracold fermions, traditionally prepared in well-isolated environments with minimal dissipation, have recently emerged as a novel platform for investigating non- Hermitian physics and broader open quantum systems. This exploration is facilitated through precise control of dissipation mechanisms. In this presentation, I will elucidate the methods for realizing such non-Hermitian systems using atomic ensembles, and discuss our recent experimental observations. These include the demonstration of the non-Hermitian skin effect in two dimensions and chiral spin transfer near exceptional points. Furthermore, I will outline our ongoing research into novel quantum dynamics that extend beyond conventional non-Hermitian frameworks within these open quantum systems.

Talk 8

Speaker: Masayuki Hashisaka (ISSP, UTokyo)

Title: Anyons and Edge Transport in Quantum Hall Systems

Abstract: Recent experiments verified abelian anyonic statistics of quasiparticles in Laughlin's fractional quantum Hall state of Landau level filling $\nu = 1/3$, about 40 years after the theoretical proposal in the 1980s. The experiments were achieved due to the progress in the long-standing theoretical and experimental research on edge transport in quantum Hall systems. In this talk, I will introduce some of our experiments and discuss recent developments in anyons and edge-transport research.

Talk 9

Speaker: Yunfeng Jiang (Yau Center, Southeast U.)

Title: Exact correlation functions of quantum integrable circuits from algebraic geometry

Abstract: In this talk, I will discuss some exact results on correlation functions of strings of spin operators for an integrable quantum circuits. These observables can be used for error calibration and mitigation of quantum simulation platforms. In the first part, I will discuss the method for the computation which includes algebraic Bethe ansatz and computational algebraic geometry. In the second part, I will present the exact results in both real space and Fourier space and discuss their physical implications.

Talk 10

Speaker: Pedram Roushan (Google Quantum AI)

Title: Novel quantum dynamics with superconducting qubits

Abstract: In recent years, superconducting qubits have emerged as one of the leading platforms for quantum computation and simulation. We utilize these Noisy Intermediate Scale Quantum (NISQ) processors to study quantum dynamics. I will present some of our recent works in studying robustness of bound states of photons [1], universality classes of dynamics in the 1D Heisenberg chain [2], and braiding of non-Abelian excitations [3]. These works point to the subtleties of non-equilibrium dynamics of highly entangled states in many-body systems; they provide evidence that in the absence of full-fledged quantum processors, the NISQ processors have challenged and guided our conventional wisdom.

[1] Morvan et al., Nature **612**, 240–245 (2022)
[2] Rosenberg et al., Science **384**, 48-53 (2024)
[3] Andersen et al., Nature **618**, 264–269 (2023)

Talk 11

Speaker: Frank Verstraete (Cambridge)

Title: Entanglement and tensor networks in the generalised Landau paradigm

Abstract:

Talk 12

Speaker: Jong Yeon Lee (UIUC)

Title: Understanding Phases and Transitions in Mixed States

Abstract: With the rapid development of quantum simulator platforms, understanding the stability of quantum phases in the presence of environmental coupling has become increasingly important. As a pure quantum state evolves into a mixed state due to decoherence, traditional notions of quantum phases need to be reconsidered.

In this talk, I will present recent progress on mixed-state phases from an information-theoretic perspective, which contrasts sharply with conventional descriptions that rely on order parameters and fail to capture mixed-state phases. The presentation will be divided into three parts: (i) spontaneous symmetry breaking in mixed states, (ii) symmetry-protected topological states under decoherence and the extraction of long-range entangled states, and (iii) decohered topological orders and intrinsic error thresholds. If time permits, I will discuss how fault tolerance can be incorporated into this framework using a newly developed spacetime SPT (symmetry-protected topological) picture, highlighting the deep connection between fault tolerance and phase stability in open quantum systems.

Talk 13

Speaker: Chihiro Matsui (UTokyo)

Title: A variety of partially solvable models: From closed spin chains to open spin chains

Abstract: Non-thermal energy eigenstates of thermalizing isolated quantum systems have been intensively studied these days, as counter examples for the strong eigenstate thermalization hypothesis. These states are called "quantum many-body scars (QMBS)", which exhibit specific properties such as low entanglement entropies and persistent oscillations. Surprisingly, many of QMBS are exactly solvable states of non-integrable Hamiltonians. This fact strongly motivates us to study partially solvable quantum systems. We show that partial solvability of a quantum many-body system can be maintained even when the system is coupled to boundary dissipators under certain conditions. We propose two mechanisms that support partially solvable structures in boundary dissipative systems: The first one is based on the restricted spectrum generating algebra, while the second one is based on the Hilbert space fragmentation. From these structures, we derive exact eigenmodes of the Gorini-Kossakowski-Sudarshan-Lindblad equation for a family of quantum spin chain models with boundary dissipators, where we find various intriguing phenomena arising from the partial solvability of the open quantum systems, including persistent oscillations (quantum synchronization) and the existence of the matrix product operator symmetry. We discuss how the presence of solvable eigenmodes affects long-time behaviors of observables in boundary dissipative spin chains based on numerical simulations using the quantum trajectory method. This talk is based on the collaboration work arXiv:2409.03208.

Talk 14

Speaker: Kohei Kawabata (ISSP, UTokyo)

Title: Non-Hermitian Topology in Hermitian Topological Matter: Wannier Localizability and Detachable Topological Boundary States

Abstract: Non-Hermiticity gives rise to distinctive topological phenomena absent in Hermitian systems. However, connection between such intrinsic non-Hermitian topology and Hermitian topology has remained largely elusive. Here, considering the bulk and boundary as an environment and system, we demonstrate that anomalous boundary states in Hermitian topological insulators exhibit non-Hermitian topology [1, 2]. We study the self-energy capturing the particle exchange between the bulk and boundary, and show that it detects Hermitian topology in the bulk and induces non-Hermitian topology at the boundary. As an illustrative example, we reveal the non-Hermitian topology and concomitant skin effect inherently embedded within chiral edge states of Chern insulators. We also identify the emergence of hinge states within effective non-Hermitian Hamiltonians at surfaces of three-dimensional topological insulators. Furthermore, we comprehensively classify our correspondence across all the tenfold symmetry classes of topological insulators and superconductors.

Based on this correspondence and K-theory, we complete the tenfold classification of Wannier localizability and detachable topological boundary states [3, 4]. While topology can impose obstructions to exponentially localized Wannier functions, certain topological insulators are exempt from such Wannier obstructions. The absence of the Wannier obstructions can further accompany topological boundary states that are detachable from the bulk bands. Here, we elucidate a close connection between these detachable topological boundary states and non-Hermitian topology. Identifying topological boundary states as non-Hermitian topology, we demonstrate that intrinsic non- Hermitian topology leads to the inevitable spectral flow. By contrast, we show that extrinsic non-Hermitian topology underlies the detachment of topological boundary states and clarify anti-Hermitian topology of the detached boundary states.

References:
[1] F. Schindler, K. Gu, B. Lian, and K. Kawabata, PRX Quantum **4**, 030315 (2023).
[2] S. Hamanaka, T. Yoshida, and K. Kawabata, arXiv:2405.10015.
[3] D. Nakamura, K. Shiozaki, K. Shimomura, M. Sato, and K. Kawabata, arXiv:2407.09458.
[4] K. Shiozaki, D. Nakamura, K. Shimomura, M. Sato, and K. Kawabata, arXiv:2407.18273.

Talk 15

Speaker: Takashi Oka (ISSP, UTokyo)

Title: Driven Dirac systems and novel quantum anomalous states

Abstract: Floquet engineering, which involves controlling systems through time-periodic driving, provides a powerful method for coherently manipulating quantum materials and realizing dynamical states with novel functionalities. This presentation reports our recent experimental and theoretical findings on the dynamical states realized in Dirac electrons under various fields.

Circularly Polarized Laser [1]: Nonlinear optical response experiments suggest the generation of chiral gauge fields and the creation of emergent Weyl points.

AC-Magnetic Fields [2]: We demonstrate the emergence of π-Landau levels and the chiral anomaly-induced homodyne effect when Dirac electrons are subjected to a time-oscillating magnetic field $B\cos(\Omega t)$.

Propagating Fields [3]: Dirac electrons in a propagating wave $V\cos(Qx - \Omega t)$ exhibit sensitivity to the field speed $v = \Omega/Q$. We classify these states and explore the associated topological phase transitions.

References:
[1] N. Yoshikawa et al., arXiv:2209.11932; Y. Hirai et al., arXiv:2301.06072
[2] S. Kitamura and T. Oka, arXiv:2407.08115
[3] T. Oka, arXiv:2407.21458

Talk 16

Speaker: Pratik Nandy (RIKEN & Kyoto U.)

Title: Physics of tridiagonal matrices

Abstract: Eigenvalues of Hermitian matrices encapsulate the core statistical and dynamical characteristics of quantum systems. Typically, this involves diagonalizing the Hamiltonian, where the diagonal elements represent the eigenvalues of the Hamiltonian. In this talk, I introduce an alternative approach: tridiagonalizing the Hamiltonian. I will discuss the properties of the tridiagonal matrix elements, highlighting that both chaotic and integrable systems share certain features, yet exhibit distinct statistical behaviors in these elements. If time permits, I will also show how these properties can be extended to non-Hermitian systems through singular value decomposition.

3 Posters

List of poster presentations

#	Speaker
PS-1	Juan Pablo Bayona Pena (YITP)
PS-2	Yoshiki Fukusumi (NCTS)
PS-3	Dongsheng Ge (Osaka U.)
PS-4	Naomichi Hatano (UTokyo)
PS-5	Taishi Kawamoto (YITP)
PS-6	Masaya Kunimi (TUS)
PS-7	Linhao Li (Ghent U.)
PS-8	Somnath Maity (RIKEN)
PS-9	Pasquale Marra (UTokyo)
PS-10	Toranosuke Matsubara (TokyoTech)
PS-11	Teruaki Nagasawa (Nagoya U.)
PS-12	Takahiro Orito (ISSP, UTokyo)
PS-13	Soshun Ozaki (UTokyo)
PS-14	Jitendra Pal (IIT Roorkee)
PS-15	HaRu Park (KAIST)
PS-16	Fumika Suzuki (Los Alamos)
PS-17	Sei Suzuki (Saitama Medical U.)
PS-18	Jun Takahashi (ISSP, UTokyo)
PS-19	Kazuaki Takasan (UTokyo)
PS-20	Mizuki Yamaguchi (UTokyo)
PS-21	Kazuki Yamamoto (TokyoTech)
PS-22	Takaharu Yoshida (TUS)
PS-23	Hironobu Yoshida (UTokyo)

PS-1: Juan Pablo Bayona Pena (YITP)

Title: Entanglement Spectrum Dynamics as a Probe for Non-Hermitian Bulk-Boundary Correspondence in Periodic Systems

Abstract: In recent years, it has been established that open quantum systems may exhibit extreme spectral sensitivity to boundary conditions known as the non-Hermitian (Liouvillian) skin effect. In such systems, in stark contrast with their Hermitian counterpart, the topological transition point in periodic boundary conditions does not coincide with those in open boundary conditions. Here we ask a question that may initially seem peculiar : Can a topological transition in open boundary conditions be detected in a periodic boundary-conditioned system? In this work, we provide a surprising, affirmative answer. We propose the time evolution of the entanglement spectrum under periodic boundary conditions as a dynamical probe of non-Hermitian bulk-boundary correspondence for systems featuring Lindbladian skin effects. In particular, we analyze the unconditional quench dynamics across topological phase transitions of an open fermion chain that are dissipation-engineered to exhibit a single-particle Lindblad spectrum identical to those of the non-Hermitian Su-Schrieffer-Heefer (SSH) model. We observe crossings in the single-particle entanglement spectra for quantum quenches between topological phases of an initially isolated SSH model to those of its non-Hermitian counterpart. Remarkably, we find that the entanglement spectrum crossings, which signal non-Hermitian topological phase transitions, remain unaffected by boundary conditions. They manifest distinctly through the examination of two-point correlations within a subregion of the periodic system. We demonstrate that these spectral crossings are robust features that signal a pronounced response to boundary conditions— a hallmark of non-Hermitian topological phenomena.

PS-2: Yoshiki Fukusumi (NCTS)

Title: Emergent integrable quantum fluid at the edge of topological matter

Abstract: Bulk-edge correspondence (or CFT/TQFT correspondence) is one of the most fundamental aspects of topologically ordered systems. In modern understanding, one can relate theories appearing at bulk or boundary as subalgebra structure of fusion rule of the (Z_N gauged) bulk conformal field theory. In this presentation, we revisit the structure of bulk-edge correspondence with emphasis on the (emergent) integrable structure of the theories appearing at the edges. By introducing the modern interpretation of integrability (or integrable deformation) in quantum field theory, we test the robustness of the notion of the bulk-edge correspondence and their implications to quantum fluid dynamics of edge theories and related mixed state thermalization problems. The presentation is based on our ongoing project and arXiv:2405.05178.

PS-3: Dongsheng Ge (Osaka U.)

Title: Boundary-induced transitions in Möbius quenches of holographic BCFT

Abstract: Boundary effects play an interesting role in finite-size physical systems. In this work, we study the boundary-induced properties of 1+1-dimensional critical systems driven by inhomogeneous Möbius-like quenches. We focus on the entanglement entropy in BCFTs with a large central charge and a sparse spectrum of low-dimensional operators. We find that the choice of boundary conditions leads to different scenarios of dynamical phase transitions. We also derive these results in a holographic description in terms of intersecting branes in AdS3, and find a precise match.

PS-4: Naomichi Hatano (UTokyo)

Title: Quantum transport on Bethe lattices with non-Hermitian sources and a drain

Abstract: We here consider quantum transport on the tight-binding model on the Bethe lattice of a finite generation, or the Cayley tree, which may model the energy transport in a light-harvesting molecule. As a new feature to analyze the quantum transport, we add complex potentials for sources on the peripheral sites and for drain on the central site. We find that the eigenstates that can penetrate from the peripheral sites to the central origin site are quite limited to the number of generation. All the other eigenstates are localized around the peripheral sites and cannot reach the central site. The former eigenstates can carry the current, which reduces the problem to the quantum transport on a PT-symmetric linear chain. The current takes the maximum value at the exceptional point, which emerges because of the non-Hermiticity due to the complex potentials.

PS-5: Taishi Kawamoto (YITP)

Title: Finite Scaling of Eigenstate Thermalization from Black Hole Horizon

Abstract: The eigenstate thermalization hypothesis (ETH) provides a sufficient condition for thermalization and equilibration from any initial states in isolated systems with a large number of degrees of freedom. One part of this statement is that for large systems, the diagonal matrix elements of typical observables in the Hamiltonian eigenstate basis, that is, the expectation values of the energy eigenstates, depend smoothly on the corresponding energy values. This statement is highly related to the fact that the variance of the energy eigenstate expectation values is small. Indeed, it is conjectured that this variance shows power-law decay with respect to the Hilbert space dimension. On the other hand, in general relativity, it is expected that heavy objects undergo gravitational collapse. Additionally, it is known that gravitational systems with black holes exhibit maximally chaotic properties. By using the holographic principle, or specifically the AdS/CFT correspondence, these facts imply that holographic theories dual to higher-dimensional Einstein gravity will show chaotic behavior and also thermalization from high-energy states. Thus, we expect that holographic theories exhibit ETH, although there is no definitive proof for this. In this talk, we discuss that the variance of the eigenstate expectation values of primary and descendant operators shows power-law decay with respect to the Hilbert space dimension. This fact is derived from the quantum mixing properties of holographic theories with black hole gravitational duals. We also discuss the consequences of this scaling on thermalization. This talk is based on work in progress.

PS-6: Masaya Kunimi (TUS)

Title: Construction of asymptotic quantum many-body scar states in the quantum spin model with the Dzyaloshinskii-Moriya interaction

Abstract: Quantum many-body scar (QMBS) states are special energy eigenstates of nonintegrable Hamiltonians that exhibit nonergodicity. These states have a small amount of entanglement despite being high-energy excited states. Recently, Gotta et al. proposed a novel class of nonergodic quantum states, dubbed asymptotic QMBS (AQMBS) states [1], which are characterized by the following properties: (i) they are orthogonal to any exact QMBS state, (ii) they have a small amount of entanglement, and (iii) the energy variance goes to zero in the thermodynamic limit. Motivated by the previous work, we analytically construct AQMBS states in the DH model [2], which contains the Dzyaloshinskii-Moriya interaction term and Zeeman field term and can be realized in Rydberg atom quantum simulators [3]. In this poster, we will discuss the details of the AQMBS states.

[1] L. Gotta et al., Phys. Rev. Lett. **131**, 190401 (2023).
[2] S. Kodama et al., Phys. Rev. B **107**, 024403 (2023).
[3] M. Kunimi et al., arXiv:2306.05591 (2023).

PS-7: Linhao Li (Ghent U.)

Title: Anomaly in open quantum systems and its implications on mixed-state quantum phases

Abstract: We develop a systematic approach to characterize the 't Hooft anomaly in open quantum systems. Owing to nontrivial couplings to the environment, symmetries in such systems manifest as either strong or weak type. By representing their symmetry transformation through superoperators, we incorporate them in a unified framework that enables a direct calculation of their anomalies. In the case where the full symmetry group is $K \times G$, with K the strong symmetry and G the weak symmetry, we find that anomalies of bosonic systems are classified by

$H^{d+2}(K \times G, U(1))/H^{d+2}(G, U(1))$ in d spatial dimensions. To illustrate the power of anomalies in open quantum systems, we generally prove that anomaly must lead to nontrivial mixed-state quantum phases as long as the weak symmetry is imposed. Analogous to the "anomaly matching" condition ensuring nontrivial low-energy physics in closed systems, anomaly also guarantees nontrivial steady states and long-time dynamics for open quantum systems governed by Lindbladians. Notably, we identify a novel (1+1)-D mixed-state quantum phase that has no counterpart in closed systems, where the steady state shows no nontrivial correlation function in the bulk, but displays spontaneous symmetry breaking order on the boundary, which is enforced by anomalies. We further establish the general relations between mixed-state anomalies and such unconventional boundary correlation. Finally, we explore the generalization of the "anomaly inflow" mechanism in open quantum systems. We construct $(1+1)$-D and $(2+1)$-D Lindbladians whose steady states have mixed-state symmetry-protected-topological order in the bulk, with corresponding edge theories characterized by nontrivial anomalies.

PS-8: Somnath Maity (RIKEN)

Title: Kinetically constrained models constructed from dissipative quantum dynamics

Abstract: We propose a construction of kinetically constrained models using the Markovian quantum dynamics under strong dissipation. Using the Gorini-Kossakowski-Sudarshan-Lindblad (GKSL) formalism, we show that strong dissipation leads to the emergent decoherence-free subspaces, within which constrained quantum many-body unitary dynamics can take place. We argue that the unitary dynamics constructed by the GKSL dynamics is more tightly constrained than that constructed by the strongly interacting Hamiltonian, where the interactions have the same form with the GKSL jump operators. As an example, we demonstrate that a one-dimensional spin system with two-site dissipation leads to the kinetically constrained "PXQ" model, which exhibits the free domain-wall motion with an additional frozen-block structure. Under the uniform magnetic field, the PXQ model shows the domain-wall localization, similar to the Wannier-Stark localization. We then couple two PXQ chains with the magnetic field and inter-chain interaction. We discover that, while localization of the domain walls persists despite the interactions for typical parameter regimes, a non-trivial partial delocalization appears for a certain parameter line.

PS-9: Pasquale Marra (UTokyo)

Title: Nonlocal dynamical probe of Majorana zero modes in quantum wires

Abstract: Majorana zero modes are topologically-protected quasiparticle zero modes localized at the vortex cores of two-dimensional (2D) or at the ends of one-dimensional (1D) topological su- perconductors which have been proposed as potential building blocks for topological quantum computing. In particular, 1D topological superconductors can be realized in semiconducting nanowires with strong spin-orbit coupling proximitized with a conventional superconductor or arrays of magnetic atoms deposited on a conventional superconductor substrate in the presence of a time-reversal- symmetry breaking field, e.g., Zeeman. Besides these "ideal" topologically-protected Majorana zero modes, realistic systems may exhibit localized states with zero or near-zero energy below the quasiparticle excitation gap, induced by several different mechanisms such as random disorder, smooth potentials, finite-size effects, or quasiperiodic potentials. Although these near-zero states may have experimental signatures very similar to those produced by Majorana zero modes, they may appear in the topologically trivial phase, not necessarily at the opposite ends of the quantum wire, but typically near inhomogeneities or impurities, or may lack exponential

localization. In light of the above, stronger evidence of topologically nontrivial Majorana modes has been provided by the observation of their nonlocal signatures in the differential conductance, in tunneling spectroscopy, in multiterminal setups, or the observation of their thermodynamical response in systems out of equilibrium. Hence, finding robust signatures distinguishing between "ideal" Majorana zero modes and other localized states has been the focus of intense research.

Here, we consider 1D topological superconductors with a localized driving, which is modeled as a time-dependent electric field localized at one edge of the system, with a gaussian localization profile, modeling an electromagnetic beam. Considering different scenarios, i.e., homogeneous systems in the trivial and nontrivial topological phase, systems with smooth inhomogeneities or with strong disorder, we calculate the dynamical evolution of the electronic charge along the full length of the system. We found that there are measurable fluctuations of the charge at the edge opposite to the driving only in the nontrivial regime with Majorana zero modes localized at the opposite edges of the system. Indeed, the local perturbation propagates dynamically from one edge to the opposite edge of the wire only if Majorana zero modes are localized at the opposite edges. These charge fluctuations can be measured, in principle, by coupling the edges of the system with quantum dots, or by detecting the emitted electromagnetic radiation. This allows one to discriminate Majorana modes against the presence of other near-zero states induced by inhomogeneities or disorder. This nonlocal and dynamical signature can be experimentally measured in realistic 1D topological superconductors, such as proximitized nanowires or atomic chains on the surface of a conventional superconductor, by measuring the dynamical response at one edge while driving the system at the opposite edge.

PS-10: Toranosuke Matsubara (TokyoTech)

Title: Measurement-induced phase transition for free fermions in a quasiperiodic potential

Abstract: We study dynamics of continuously monitored free fermions in a quasiperiodic potential. We find that entanglement phase transitions from the log-law to the area-law are induced by the measurement. Furthermore, we find that similar transitions are also induced by increasing the strength of potential.

PS-11: Teruaki Nagasawa (Nagoya U.)

Title: On the generic increase of observational entropy in isolated systems

Abstract: Von Neumann derived entropy from thermodynamic discussions. At the same time, he proved the quantum H-theorem and introduced observational entropy (macroscopic entropy), which is different from von Neumann entropy. In recent years, the importance of observational entropy has been revisited and actively studied. In this talk, we introduce a theorem in which the random time-evolving observational entropy in an isolated system reaches a maximum value. First, consider the case of Haar-random. Next, consider the more physical approximate unitary 2-design case. It can also be shown that "coarse" measurements are important to obtain those results.

PS-12: Takahiro Orito (ISSP, UTokyo)

Title: Measurement-only dynamical phase transition of topological and boundary order in toric code and gauge-Higgs models

Abstract: Quantum many-body states can undergo phase transition due to projective measurements as a backaction. As a concrete example, we focus on a circuit dynamics of cylinder geometry whose gates solely consist of local measurement, and the initial state is prepared as the ground state of the toric code. We report that project measurements can lead to the phase transition, realizing a distinct phase of matter. Specifically, we report a phase transition, toric code-Higgs phase transition, due to local measurements for bulk qubits. A signal of this phase transition can be observed as the emergence of long-range spin-glass order on the boundaries of the cylinder, emerging spontaneous symmetry breaking of Z_2 symmetry [1]. We also report that the topological entanglement entropy characterizes the toric code-Higgs/confined phase transitions[2]. *This work was supported by JSPS KAKENHI Grant Numbers JP23KJ0360 (Takahiro Orito) and JP23K13026(Yoshihito Kuno).

[1] Y. Kuno, T. Orito, and I. Ichinose, PRB **109**, 054432 (2024)

[2] T. Orito, Y. Kuno, and I. Ichinose, Phys. Rev. B **109**, 224306 (2024)

PS-13: Soshun Ozaki (UTokyo)

Title: Disorder-free Sachdev-Ye-Kitaev models: Integrability and a precursor of chaos

Abstract: We introduce two disorder-free variants of the Sachdev-Ye-Kitaev (SYK) model, demonstrate their integrability, and study their static and dynamical properties. We find that out-of-time-order correlators (OTOCs) in these models exhibit exponential-like growth at early times while random-matrix behaviors in level statistics and the spectral form factor are absent. Our findings illustrate that the SYK variants represent simple but nontrivial examples of disorder-free quantum many-body systems displaying chaos-like behavior of OTOCs. We also discuss the dynamics of the SYK variants in the presence of dissipation.

PS-14: Jitendra Pal (IIT Roorkee)

Title: Integrability and non-integrability for holographic dual of Matrix model and non-Abelian T-dual of $\mathrm{AdS}_5 \times S^5$

Abstract: In this paper we study integrability and non-integrability for type-IIA supergravity background dual to deformed plane wave matrix model. From the bulk perspective, we estimate various chaos indicators that clearly shows chaotic string dynamics in the limit of small value of the parameter L present in the theory. On the other hand, the string dynamics exhibits a non-chaotic motion for the large value of the parameter L and therefore presumably an underlying integrable structure. Our findings reveals that the parameter L in the type-IIA background acts as an interpolation between a non-integrable theory to an integrable theory in dual SCFTs.

PS-15: HaRu Park (KAIST)

Title: Rigorous proof of the integrability and nonintegrability of the biquadratic spin-1 chain model

Abstract: Finding the local conserved quantities and/or proving the absence of local conserved quantities are related to integrability and nonintegrability respectively, and are important to determine the dynamics of system. Recently there were achievements in these topics for spin-1/2 system: the exact calculation of local conserved quantities in XYZ and Hubberd model, and the rigorous proofs of nonintegrability in XYZ model with magnetic field, mixed-field ising chain model, and PXP model. In this work, we extended this approach into spin-1 chain system with

biquadratic interaction. We showed that except the well-known integrable cases, every biquadratic spin-1 chain model, including Haldane spin-1 chain and AKLT model, have no local conserved quantity. Furthermore, we exactly calculated the local conserved quantities for integrable cases.

PS-16: Fumika Suzuki (Los Alamos)

Title: Extending the Kibble-Zurek mechanism to weakly first-order phase transitions

Abstract: Just as water freezes into ice, the theories of high energy physics predict that the universe has experienced phase transitions following the Big Bang, as it expanded and cooled. Signals stemming from such phase transitions would have influenced its evolution and may persist to this day, offering valuable insights into the early universe. W. H. Zurek has proposed that this mechanism can be tested in a laboratory using liquid crystals and developed a theory to predict the density of the signals (i.e., defects). It is called the Kibble-Zurek mechanism (KZM). KZM has found applications in fields such as cosmology and condensed matter physics. However, it is generally not suitable for describing first-order phase transitions. It has been demonstrated that transitions in systems like superconductors or charged superfluids, typically classified as second-order, can exhibit weakly first-order characteristics when the influence of fluctuations is taken into account. In our research, we extended the applicability of the KZM to cover weakly first-order phase transitions by combining it with nucleation theory. This result may not only deepen our understanding of diverse phase transitions in material science and condensed matter physics but also open doors to exploring various cosmological models.

Ref: Fumika Suzuki, and W. H. Zurek, Topological defect formation in a phase transition with tunable order, Phys. Rev. Lett. **132**, 241601 (2024)

PS-17: Sei Suzuki (Saitama Medical U.)

Title: The second law of thermodynamics of an energy eigenstate in isolated quantum chaotic systems

Abstract: In recent years, the thermodynamics of isolated quantum systems has received significant attention. In particular, research on the relaxation from an initial state to thermal equilibrium, known as thermalization, has advanced. The Eigenstate Thermalization Hypothesis (ETH), which proposes that energy eigenstates themselves possess properties equivalent to thermal equilibrium states, has been suggested and supported by numerical simulations. However, our understanding of the second law of thermodynamics remains limited. In the present work, we focus on the question of whether energy eigenstates satisfy the second law of thermodynamics. We do not make an assumption such as ETH but assume quantum chaotic models represented by random matrices. We prove Planck's principle as the second law of thermodynamics for an energy eigenstate in a rigorous manner. Since random matrices are regarded as simplified models of generic non-integrable systems, our theory on random matrices also provides insights into the second law in non-integrable systems.

PS-18: Jun Takahashi (ISSP, UTokyo)

Title: A Rigorous Semidefinite Programming Approximation for the Heisenberg Ground State Problem

Abstract: Computing the ground state of the AFM Ising model (on an arbitrarily given graph) is known to be NP-hard, which means that it is hopeless to have an efficient algorithm to compute the ground state for general graphs. This fact could be seen as a computational-complexity theoretic explanation of why spin glasses have slow relaxation, but also points to the possibility of using computational/algorithmic approaches for analyzing many-body systems. As a matter of fact, it is believed (proven under the unique games conjecture) that it is impossible to even have an *approximate* solution (i.e. low energy states rather than lowest energy) efficiently with approximation ratio better than 87.8...+ε %, while the semidefinite-programming based Goemans-Williamson algorithm achieves exactly 87.8...% approximation ratio. This nice "transition" behavior in the hardness of approximation at 87.8...% is well-understood in the classical case, but whether there are analogous transitions in the quantum case is very much open. The natural candidate model for the quantum case would be the AFM Heisenberg model since the ground state problem is QMA-hard, the quantum analogue of NP-hard, thus, is a natural quantum extension of the classical Ising model. In this presentation, I will explain how we construct the most natural semidefinite-programming for the quantum Heisenberg model [1] and explain its natural connections to frustration-free systems such as the Majumdar-Ghosh model and the Shastry-Sutherland model. I would also like to provide an open problem of how to "round" the semidefinite-programming solutions to a real quantum state using tensor networks.

[1] JT, Rayudu, Zhou, King, Thompson, Parekh, https://arxiv.org/abs/2307.15688

PS-19: Kazuaki Takasan (UTokyo)

Title: Activity-induced quantum phase transitions: A proposal for quantum active matter

Abstract: Active matter is an ensemble of self-propelled entities, such as flocks of birds and schools of fish, that has attracted much attention for its various phase transitions and pattern formations that are not present in equilibrium systems [1]. While the physics of active matter has been studied extensively in statistical physics and biophysics, most studies have been limited to classical systems, and the possibility of active matter in quantum systems has rarely been considered. However, recent developments in atomic-molecular-optical systems allow us to study the complex dynamics of quantum many-body systems in a highly controlled manner, and it may be possible to design quantum many-body systems that behave like active matter. Stimulated by this, the study of the quantum analog of active matter has been initiated very recently [2-6]. In particular, we have studied quantum phase transitions analogous to the nonequilibrium phase transitions of active matter [2,6]. In this poster, we would like to present our work on quantum active matter. We have studied two-component (spin-1/2) hard-core bosons with spin-dependent asymmetric hopping corresponding to the motility of each active particle. This is expected to be realized with ultracold atoms with a dissipative optical lattice. We have shown that this model can be regarded as a quantum generalization of classical active matter models defined on a lattice, and that it exhibits various phase transitions, including nonequilibrium phase transitions unique to active matter, such as motility-induced phase separation [2]. In more recent work [6], we have shown that the combination of activity and repulsive interaction induces ferromangnetism, based on both numerical and analytical arguments. This activity-induced ferromangnetism can be considered as a quantum counterpart of flocking. While the flocking transition in classical systems requires a microscopic alignment interaction, this mechanism does not require such an interaction and thus may be unique to quantum active matter. We believe that our works extending active matter physics to quantum systems help to broaden the perspective on nonequilibrium phases of matter beyond conventional paradigms.

[1] M. C. Marchetti et al., Rev. Mod. Phys. **85**, 1143 (2013).
[2] K. Adachi, KT, K. Kawaguchi, Phys. Rev. Research **4**, 013194 (2022).
[3] M. Yamagishi, N. Hatano, H. Obuse, arXiv: 2305.15319.
[4] Y. Zheng, B. Liebchen, H. Löwen, arXiv: 2305.16131.
[5] R. Khasseh, S. Wald, R. Moessner, C. A. Weber, M. Heyl, arXiv: 2308.01603.
[6] KT*, K. Adachi*, K. Kawaguchi, Phys. Rev. Research **6**, 023096 (2024). (*equally contributed)

PS-20: Mizuki Yamaguchi (UTokyo)

Title: Complete classification of integrability and non-integrability for spin-1/2 chain with symmetric nearest-neighbor interaction

Abstract: Quantum integrability and non-integrability are important notions in the physics of macroscopic systems, as this distinction is strongly related to the fate of thermalization and the validity of the Kubo formula. While there has been an accumulation of research on integrable systems, there were no analytical proofs for non-integrable systems for many years. Recent progress has yielded rigorous proofs of the non-integrability of several models, but no general classification has been provided. In this presentation, we rigorously prove that, apart from the known integrable systems, all the remaining spin-1/2 chains with symmetric nearest-neighbor interaction are non-integrable. This class of systems includes some systems predicted to be non-integrable from numerical calculations, as well as two known integrable systems: one solved by the algebraic Bethe ansatz, and the other mapped to free fermions by the Jordan-Wigner transformation. This result demonstrates that most systems are non-integrable, except for those with finely tuned parameters.

PS-21: Kazuki Yamamoto (TokyoTech)

Title: Competition between strong correlations and dissipation in non-Hermitian Anderson impurity models

Abstract: Strong correlations give rise to exotic phenomena which typically originate from the electron-electron interactions in quantum materials. One of the central problems that reflect strong correlations is the Kondo effect, where localized impurity spins are screened by conduction electrons realizing the Kondo singlet. Meanwhile, open quantum systems have witnessed a remarkable development in recent years. In particular, non-Hermitian (NH) physics naturally arises such as systems with gain and loss and has been intensively investigated thanks to the advancement in dissipation engineering with ultracold atoms. As the many-body physics of the Kondo effect in closed systems is well understood, here we ask the following question for open systems: how does the renormalization effect due to strong correlations affect the nature of dissipation? In this poster, we analyze the competition between strong correlations and dissipation in quantum impurity systems from the Kondo regime to the valence fluctuation regime by developing a slave-boson theory for a non-Hermitian Anderson impurity model with one-body loss [1]. Notably, in the non-Hermitian Kondo regime, strong correlations qualitatively change the nature of dissipation through renormalization effects, where the effective one-body loss is suppressed and emergent many-body dissipation characterized by the complex-valued hybridization is generated. We unveil the mechanism of a dissipative quantum phase transition of the Kondo state on the basis of this renormalization effect, which counterintuitively enhances the lifetime of the impurity against loss. We also find a crossover from the non-Hermitian Kondo regime to the valence fluctuation regime dominated by one-body dissipation. Our results can be tested in a wide variety of setups such as quantum dots coupled to electronic leads and quantum point contacts in ultracold Fermi gases.

[1] Kazuki Yamamoto, Masaya Nakagawa, and Norio Kawakami, arXiv:2408.03494.

PS-22: Takaharu Yoshida (TUS)

Title: Proposal for experimental realization of quantum spin chains with quasiperiodic interaction using Rydberg atoms

Abstract: Ultracold atom experiments provide platforms to study nonequilibrium dynamics in isolated quantum systems, such as many-body localization (MBL) in disordered interacting systems [1]. The MBL emerges due to diagonal quasiperiodicity. However, recent research reported that an anomalous localization regime called the many-body critical regime emerges in systems with off-diagonal quasiperiodic interactions [2]. In this poster, we propose a method for realizing a quantum spin model with quasiperiodic interactions using Rydberg atom quantum simulators and discuss the properties of the localization in our models.

[1] R. Nandshore and D. A. Huse, Annu. Rev. Condens. Matter Phys. **6**, 15 (2015).
[2] Y. Wang et al., Phys. Rev. Lett. **126**, 080602 (2021).

PS-23: Hironobu Yoshida (UTokyo)

Title: Uniqueness of the non-equilibrium steady state in open quantum many-body systems

Abstract: In this poster, I will present an algebraic criterion for the uniqueness of nonequilibrium steady states of Gorini-Kossakowski-Sudarshan-Lindblad equations describing the Markovian open quantum systems. We also discuss the degeneracy of steady states in the presence of symmetries.