IIS-LEAP Workshop

NH2024

Organizers:

Dorje Brody
Eva-Maria Graefe
Naomichi Hatano
Ken-Ichiro Imura
Takano Taira

July 11 (Thu) and 12 (Fri), 2024

at LEAP (Kashiwa campus),
Institute of Industrial Science, the University of Tokyo

Program

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Oral Presentations

Oral presentation: July 11, 14:40–15:10

Non-Hermiticity and non-Markovianity of open quantum systems

Naomichi Hatano

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Abstract

I will review the origin of non-Hermiticity and non-Markovianity of open quantum systems based on the Feshbach formalism in the level of one-body Schrödinger equation. If the total system is Hermitian, a part of the total system is non-Hermitian because the part (the system) exchanges energy with the rest of the system (the environment), and hence the effective Hamiltonian of the system is non-Hermitian, not conserving the energy. If the dynamics of the total system is Markovian, the dynamics of the system is non-Markovian because the environment memorizes the state of the system in the past.

Oral presentation: July 11, 15:20–15:50

Markovian and Non-Markovian Properties of Particle Baths with Dirac Dispersion Relations

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Abstract

The time evolution of decaying particles to an environment is generally described by a linear integro-differential equation obtained by integrating out the degrees of freedom of the environment from the Schrödinger equation. When the solution to the equation satisfies the semi-group property, it is known generally as a Markov process[1] and it can be shown to admit exponential decay. Therefore in this talk, I will refer to the deviation from the exponential decay as non-Markovian. The deviation in the short time region become quadratic decay, leading to the quantum Zeno effect [2], and in the long term, oscillatory power law decay, known as long tails [3].

In this talk, we consider a two-level system with a particle bath that has a Dirac dispersion relation with two key physical parameters, namely the Dirac gap and the spectral upper and lower cut-off, allowing for manipulation of the spectral structure. It is known that non-exponential decay manifest only when the spectrum of the entire Hamiltonian is bounded[4], but the relationship between specific spectral structures and non-Markovian characteristics has been limited, with analysis mainly focused on the pole and branch point structure of the resolvent instead[5,6]. We will show that high energy structure such as spectral cutoff corresponds mainly to the short time quadratic decay whereas the low energy structure such as the Dirac gap strongly correspond to the long time bound state, with no contribution to the behavior of the short time decay. In the gapless case we observe a Markovian decay in infinite cutoff case, confirming the result [3,4]. This talk is based on the Ref. [7].

References

[1] Rivas, A., & Huelga, S. F. (2012). Open quantum systems.
[2] Misra, B., & Sudarshan, E. G. (1977). The Zeno's paradox in quantum theory. Journal of Mathematical Physics, 18(4), 756-763.
[3] Khalfin, L. A. (1958). Contribution to the decay theory of a quasi-stationary state. Sov. Phys. JETP, 6(6), 1053-1063.
[4] Chiu, C. B., Sudarshan, E. C. G., & Misra, B. (1977). Time evolution of unstable quantum states and a resolution of Zeno's paradox. Physical Review D, 16(2), 520.
[5] Garmon, S., Petrosky, T., Simine, L., & Segal, D. (2013). Amplification of non-Markovian decay due to bound state absorption into continuum. Fortschritte der Physik, 61(2-3), 261-275.
[6] Kofman, A. G., Kurizki, G., & Sherman, B. (1994). Spontaneous and induced atomic decay in photonic band structures. Journal of Modern Optics, 41(2), 353-384.
[7] Taira, T., Hatano, N., & Nishino, A. (2024). Markovianity and non-Markovianity of Particle Bath with Dirac Dispersion Relation. arXiv preprint arXiv:2406.17436.

Oral presentation: July 11, 16:50–17:20

Weak-coupling bound states in semi-infinite topological waveguide QED

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Abstract

The radiative properties of atoms (or quantum emitters) can be dramatically modified when placed in a structured photonic reservoir. In this presentation, we demonstrate that a quantum emitter coupled to a reservoir that exhibits topologically-protected surface states can induce hybridized bound states appearing in a forbidden band gap that, counter-intuitively, only exist in the weak-coupling regime. We discuss the dynamical properties of the system.

Oral presentation: July 11, 17:30–18:00

Lindbladian PT phase transition: Emergence of time crystals and critical exceptional points

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Abstract

In this talk, we show that a Lindladian parity-time (PT) symmetry can generically produce persistent periodic oscillations, including continuous-time crystals, which are exotic phases of matter with no equilibrium counterpart, in one-collective spin models. Furthermore, we demonstrate that a transition point from the dynamical phase is associated with spontaneous PT symmetry breaking and typically corresponds to a critical exceptional point by making an analogy to non-reciprocal phase transitions, which attract much recent attention in the context of active matter.

Oral presentation: July 12, 9:30–10:00

Common misconceptions and pitfalls of working with non-Hermitian Hamiltonians

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Abstract

T.B.A.

Oral presentation: July 12, 10:10–110:40

Dissipative Superfluidity in a Molecular Bose-Einstein Condensate

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Abstract

Motivated by recent experimental realization of a Bose-Einstein condensate (BEC) of dipolar molecules, we develop superfluid transport theory for a dissipative BEC to show that a weak uniform two-body loss can induce phase rigidity, leading to superfluid transport of bosons. We also introduce a generalized f-sum rule is shown to hold for a dissipative superfluid as a consequence of weak $U(1)$ symmetry. We also demonstrate that dissipation enhances the stability of a molecular BEC with dipolar interactions.

Oral presentation: July 12, 11:20–11:50

Decoherence, information gain, and phase-space measurement

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Abstract

It is a widely-held view that the phenomenon of decoherence is associated with the loss of information from the system into its environment. In this talk I will show the contrary that if a quantum system decoheres in the basis of a preferred observable, then the system necessarily gains information about that observable. I then show that decoherence — the decay of the off-diagonal elements of the density matrix — follows from the conservation of the diagonal elements. I then consider a generalisation of decoherence whereby the diagonal elements are not conserved. Such a situation arises when Zurek's "reproducibility" condition is relaxed, and emerges naturally, for example, when the phase-space position of the system is monitored by the environment. Here I show explicitly what happens to the state of a quantum system under phase-space monitoring, examining the Lindblad equation that unravels such monitoring, and solve it for the associated Wigner function on phase space.

References

[1] Brody, D.C. & Hughston, L.P. (2024): 'Decoherence implies information gain'. https://arxiv.org/abs/2402.16740
[2] Brody, D.C., Graefe, E. M. & Melanathuru, R. (2024): 'Phase-space measurements, decoherence and classicality'. https://arxiv.org/abs/2406.19628

Oral presentation: July 12, 12:00–12:30

Decoherence in quantum active particles: towards classical active particles?

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Abstract

The main aim of the present work is to introduce decoherence to the quantum active particle proposed by Yamagishi *et al.* [1] to numerically take the classical limit and observe dynamics of the particle, comparing with that of a classical active Brownian particle [2]. In the present talk, we start with a brief review on the research area of quantum active matter, which has been just started in the past few years, and proceed to explain our quantum active particle [1]. Next, we discuss how to numerically take the classical limit of the model. In order to introduce the decoherence, we stochastically project out the off-diagonal elements of the density matrix with a probability p. In the quantum limit ($p = 0$), two peaks of the wave function ballistically expand linearly in time, whereas in the classical limit ($p = 1$), the Gaussian probability distribution expands proportionally to the square root of time. We have found that even a small probability of the projection makes the quantum dynamics converge to the classical dynamics after a long time. We will finally compare our results with ones obtained by Schweitzer and others in classical systems [2].

References

[1] M. Yamagishi, N. Hatano and H. Obuse, arXiv:2305.15319 (2023).
[2] F. Schweitzer, W. Ebeling and B. Tilch, Phys. Rev. Lett. **80**, 5044 (1998).

Oral presentation: July 12, 14:00–14:30

On the dynamics of one-dimensional lossy gases

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Abstract

I will discuss the problem of the dynamics of one-dimensional quantum gases subject to two-body losses. Employing a framework known as "time-dependent generalized Gibbs ensemble" I will show that the dynamics of both bosonic and fermionic gases subject to strong losses in the quantum Zeno regime deviates significantly from the expected mean-field decay rate. Finally, I will address the problem of the late-time dynamics and show the emergence of universal behaviours with the help of suitable non-Hermitian Hamiltonians.

Oral presentation: July 12, 14:40–15:10

Dual symmetry classification of non-Hermitian systems and Z2 point-gap topology of a nonunitary quantum walk

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Abstract

Non-Hermitian systems exhibit richer topological properties compared to their Hermitian counterparts. It is well known that non-Hermitian systems have been classified based on either the symmetry relations for non-Hermitian Hamiltonians or the symmetry relations for non-unitary time-evolution operators in the context of Floquet topological phases. In this work, we propose that non-Hermitian systems can always be classified in two ways; a non-Hermitian system can be classified using the symmetry relations for non-Hermitian Hamiltonians or time-evolution operator regardless of the Floquet topological phases or not. We refer to this as dual symmetry classification. To demonstrate this, we successfully introduce a non-unitary quantum walk that exhibits point gaps with a Z2 point-gap topological phase applying the dual symmetry classification and treating the time-evolution operator of this quantum walk as the non-Hermitian Hamiltonian.

Oral presentation: July 12, 15:40–16:10

Origin of Robust Z_2 Topological Phases in Stacked Hermitian system: Non-Hermitian Level Repulsion

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Abstract

The quantum spin Hall insulator with Z_2 topology has attracted great interest since its discovery. There is a widely accepted belief for Z_2 topological phases that a system composed of stacking two layers, where each layer has Z_2 non-trivial topology, should be topologically trivial. However, several research reports that the Z_2 topological phase survives in certain parameter regions in such stacked systems, while the reason has not yet been clarified.

In this work, we provide a systematic understanding that the robust Z_2 topological phase in a Hermitian system with chiral symmetry originates from level repulsions in the corresponding non-Hermitian system derived from Hermitization. We demonstrate this by treating a class DIII superconductor with Z_2 topology and the corresponding non-Hermitian system in AII† with Z_2 point-gap topology as an example. For the latter system, in the case of stacking two layers, the four-fold degeneracy of the spectrum breaks down to two-fold degeneracy due to the level repulsion between two Kramers pairs as expected. Remarkably, Z_2 point-gap topology at the energy E in point gaps emerged as the level repulsion remains non-trivial. Moreover, through Hermitization, the energy E of the non-Hermitian system takes the role of the chemical potential μ of the Hamiltonian for the DIII superconductors. Due to this correspondence, the energy region for the non-trivial Z_2 point-gap topology coincides with the range of μ where Z_2 topological phase of DIII stacked superconductor is non-trivial and zero-energy states appear. Our result provides the systematic understanding of robust Z_2 topology in Hermitian systems with chiral symmetry, as the level repulsion in the corresponding non-Hermitian systems. Moreover, this work provides an important example to clarify an advantage of viewing the Hermitian world from the non-Hermitian perspective.

Oral presentation: July 12, 16:20–16:50

General criterion for non-Hermitian skin effects and Fock space skin effects

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Abstract

Non-Hermiticity enables macroscopic accumulation of bulk states, named non-Hermitian skin effects. They are well-established for single-particle systems, but their proper characterization for general systems is elusive. In this talk, we propose a general criterion of non-Hermitian skin effects, which works for any finite-dimensional system evolved by a linear operator. The applicable systems include many-body systems. A system meeting the criterion exhibits enhanced non-normality of the evolution operator, accompanied by exceptional characteristics intrinsic to non-Hermitian systems. Applying the criterion, we discover a new type of non-Hermitian skin effect in many-body systems, which we dub the Fock space skin effect. We also discuss the Fock space skin effect-induced slow dynamics, which gives an experimental signal for the Fock space skin effect.

Poster Presentations

Poster presentation: July 11, 16:00–16:50

Finding non-trivial eigenvalues of the Liouvillian in open quantum systems

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Abstract

In the past decade, Hatano and Ordonez [1,2] have suggested that time's arrow or macroscopic irreversibility, usually understood as a consequence of the loss of microscopic information, may be present even in the microscopic dynamics of open quantum systems. Using an open quantum dot, they demonstrated time-reversal symmetry breaking between the resonant and anti-resonant eigenstates of the Hamiltonian. In doing so, finding Hamiltonian eigenvalues with eigenstates outside the Hilbert space was required. In this work, we extend their methods and develop a new technique in finding eigenvalues of the Liouvillian superoperator, particularly those that are not expressible as a difference between two Hamiltonian eigenvalues — the non-trivial eigenvalues. We apply the Feshbach formalism step-wise to obtain an effective equation that is easy to approximate. We then take opposite limits and find that the Liouvillian does not have non-trivial eigenvalues. This implies that, in both limits, the time-reversal symmetry breaking in the evolution of density operators can be fully described by that of pure states. The dynamical asymmetry in time, established in the context of density operators in this work, can be extended further with the von Neumann entropy and eventually macroscopic irreversibility.

References
[1] N. Hatano and G. Ordonez, J. Math. Phys. **55**, 122106 (2014).
[2] G. Ordonez and N. Hatano, J. Phys. A: Math. Theor. **50**, 405304 (2017).

Poster presentation: July 11, 16:00–16:50

Non-Hermitian Quantum Absorption Refrigerator

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Abstract

In the research, we are interested in the non-Hermitian quantum absorption refrigerator at the exceptional points, which is a combination between non-Hermitian physics and quantum thermal machine. Due to the mathematical difficulty of non-Hermitian system, the research on non-Hermitian physics becomes a hot topic lately until some methods such as PT-symmetry are come up. Besides, the research on the non-Hermitian quantum devices is still a new topic and waiting to be explored.

In our research, we will focus on the evolution and operation of several quantum thermal machines at the Liouvillian exceptional points, for examining the effect of non-Hermiticity on the performance of quantum absorption refrigerator.

Poster presentation: July 11, 16:00–16:50

Higher-order exceptional point in many-body unidirectional Hatano-Nelson model

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Abstract

The many-body fermionic unidirectional Hatano-Nelson model has non-trivial Jordan canonical forms derived from the sl_2 algebra. In this talk, we will show that the Hamiltonian of the unidirectional Hatano-Nelson model can be regarded as a generator of the sl_2 algebra, and investigate the behavior of the model originating from the higher-order exceptional points, such as dynamics and the response to perturbations.

Poster presentation: July 11, 16:00–16:50

Markov-non-Markov decomposition of the time evolution of open quantum systems with the effective Liouvillian method

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Abstract

It is known that the Markovian time evolution of open quantum systems is described by the equation of motion called the Gorini-Kossakowski-Sudarshan-Lindblad (GKSL) equation. Meanwhile, a universal method of analyzing the non-Markovian dynamics has yet to be revealed. Hence there still exists a frontier in the non-Markovian region in studying open quantum systems.

Keeping the extension to the non-Markovian region in our minds, we propose the effective Liouvillian for open quantum systems, with which we mainly discuss the dynamics not in the time domain but in the Fourier-Laplace domain. Applying the effective Liouvillian to the Friedrichs model, we find that we can decompose the time evolution into the Markovian part governed by the GKSL equation and the non-Markovian part.

Poster presentation: July 11, 16:00–16:50

Exact analysis of dynamics of open quantum systems in the effective-Hamiltonian formalism

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Abstract

The Feshbach operator method [1] is an approach to derive the effective Hamiltonian of an open quantum system from the Schrödinger equation exactly. Using this method, the effective-Hamiltonian for a system interacting with an infinitely large environment generally becomes non-Hermitian. Thus,Hamiltonian in open quantum systems is fundamentally non-Hermitian Hamiltonians [2]. By using the Green's function of the effective-Hamiltonian, we can compute the time evolution of the system of interest exactly.

The survival probability, which often shows exponential decay, is frequently linked with the Markovian nature of time evolution. Indeed, applying the Markovian approximation of the dynamics of open quantum systems through the Gorini-Kossakowski-Sudarshan-Lindblad (GKSL) equation [3][4] to the natural emission of a two-level atom typically results in a precise exponential decay of the excited state's survival probability. However, a strictly exponential decay for all time domain occurs only if the system's energy spectrum has no upper or lower bounds [5].

We have applied the Feshbach operator method to the emission phenomena of a two-level system and derived the time evolution equations for the system of interest exactly. By using a two-level system as the system of interest and a single-particle system with either linear or quadratic energy dispersion relations as the environment, we have found that the time evolution equations for the system can be calculated more transparently. Linear dispersion relation without upper and lower energy bounds shows exact exponential decay over the entire time domain [6]. We elucidated this reason from the form of effective-Hamiltonian. Additionally, for a quadratic dispersion relation with a lower bound, we have shown that the short-time behavior exhibits a $t^{2/3}$ power-law decay. Conventionally, in the short-time regime where exponential decay does not occur, the quantum Zeno effect [7] has been understood to demonstrate second-order decay when the survival probability is expanded in time. Our results obtain decay forms beyond second-order, which were not possible with traditional methods.

References

[1] H. Feshbach, Ann. Phys. (New York) **5**, 357 (1958).
[2] N. Hatano and G. Ordonez, J. Math. Phys. **55**, 122106 (2014).
[3] V. Gorini, A. Kossakowski, and E.C.G. Sudarshan, J. Math. Phys. **17**, 821 (1976).
[4] G. Lindblad, Commun. Math. Phys. **48**, 119 (1976).
[5] L.A. Khalfin, Sov. Phys. JETP, **6**, 1053 (1958).
[6] T. Taira, N. Hatano, and A. Nishino, arXiv :2406.17436
[7] B. Misra and E.C.G. Sudarshan, J. Math. Phys. **18**, 756 (1977).

Poster presentation: July 11, 16:00–16:50

Evolution from an edge state to a resonance in topological CQED

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Abstract

It is well known that when the energy of an excited two-level atom or quantum emitter appears within the continuous energy spectrum associated with a quantum environment, the resonant state appears with complex eigenvalues. The two-level system then generally exhibits exponential decay with the decay rate determined by the imaginary part of the complex eigenvalue. A common example of this scenario would be an infinite tight-binding model (the environment) with an attached quantum emitter. In this work, we examine how this scenario is modified when the tight-binding chain is replaced with a dimerized lattice that exhibits the properties of a one-dimensional topological insulator, including topologically-protected surface states inside a gap. Therefore, a focus of our research is on the existence of surface states and how the dynamical properties of the initialized emitter state will change due to the interaction with such surface states. First, we review the finite SSH model which had two edge states and two continuous energy bands. We then study the infinite extension of the bare SSH chain and that these 2 surface states still exist in the infinite limit, although the distinction between trivial and topological phase of the model is lost. Then, when the quantum emitter is coupled to the infinite SSH chain, we show that one surface state survives while the other vanishes from the spectrum. Additionally, we demonstrate the spectrum contains four other (in general) non-zero energy eigenvalues. Two of these eigenvalues are associated with bound states, while the other two generalized eigenstates with eigenvalues appearing in the energy gap. These two eigenstates are either two anti-bound states or a resonance/anti-resonance pair, depending on the value the coupling g. We show that an exceptional point separates these two cases. We show that only when the parameter g corresponds to the exceptional point, this model has the particular zero-energy state which is localized completely on either the right or left side of the system.