Quantization of Dissipative Chaos: Ideas and Means

709. WE-Heraeus-Seminar

16 - 20 December 2019
at the Physikzentrum Bad Honnef/Germany

WILHELM UND ELSE
HERAEUS-STIFTUNG

Introduction

The Wilhelm und Else Heraeus-Stiftung is a private foundation that supports research and education in science with an emphasis on physics. It is recognized as Germany's most important private institution funding physics. Some of the activities of the foundation are carried out in close cooperation with the German Physical Society (Deutsche Physikalische Gesellschaft). For detailed information see https://www.we-heraeus-stiftung.de

Aims and scope of the 709. WE-Heraeus-Seminar:

Dissipative quantum systems are already a part of technological reality, their theory is well developed. What is still missing, however, is the relation between this type of quantum systems and their classical counterparts, which are dissipative dynamical systems. Although some steps in this direction have already been taken, progress remains limited. At the same time, the need for a "theory of dissipative quantum chaos" is out of question; its necessity is justified by both the experimental advances and the progress on the side of computational quantum physics of many-body open systems. The idea of our seminar is to create an interface between the two communities – researchers working in the field of open quantum systems and in classical dissipative chaos – and encourage them to make steps towards categorization of the regimes and phenomena appearing in open quantum systems, driven far from equilibrium, by using concepts and notions of classical dissipative chaos. In short, the key issue of the proposed seminar is the following question: How to "quantize" dissipative chaos? This problem branches into a multitude of intriguing questions like: Can one differentiate between different regimes of an open non-equilibrium quantum system, by defining "regular" and "chaotic" quantum "attractors"? Can one generalize the notion/idea of bifurcations (periodic doubling, tangent, etc) to quantum dissipative systems? What are (possible) quantum analogues of synchronization? Where does the road to answers begin? It starts from discussions and exchange of ideas. This is precisely the aim of the proposed seminar.

Scientific Organizers:

Prof. Dr. Sergej Flach	Center for Theoretical Physics of Complex Systems Institute for Basic Science Daejeon, Korea E-mail: sergejflach@googlemail.com
Prof. Dr. Jürgen Kurths	HU Berlin and PIK Potsdam, Germany E-mail: kurths@pik-potsdam.de
Prof. Dr. Mikhail Ivanchenko	Lobachevsky University, Russia E-mail: ivanchenko.mv@gmail.com

Program

Program

Sunday, 15 December 2019

17:00 – 21:00	Registration	
From 18:30	*BUFFET SUPPER and informal get-together*	

Monday, 16 December 2019

08:00	*BREAKFAST*	
09:00 – 09:15	Scientific organizers	**Opening and welcome**
09:15 – 10:00	Sergey Gonchenko	**Three forms of dynamichal chaos**
10:00 – 10:45	Alexander Hramov	**Hyperchaotic behavior in driven interacting Rydberg atoms**
10:45 – 11:00	*COFFEE BREAK*	
11:00 – 11:45	Boris Fine	**Statistical ensembles realized in many-body quantum systems with and without monitoring**
11:45 – 12:30	Alexey Ustinov	**Microwave driven quantum metamaterials**
12:40	**Conference Photo** (in the front of the lecture hall)	
12:45	*LUNCH*	

Program

Monday, 16 December 2019

14:30 – 16:00	Colloquium Sergey Denisov	**Two approaches to dissipative Quantum Chaos**
16:00 – 16:30	*COFFEE BREAK*	
16:30 – 17:00	Igor Yusipov	**Quantifying dissipative quantum chaos by Lyapunov exponents and quantum jumps statistics**
17:00 – 17:45	Juzar Thingna	**Symmetries in Open Quantum Systems**
17:45 – 18:15	Alexander Schnell	**Floquet Engineering in presence of dissipation**
18:30	*DINNER*	

Program

Tuesday, 17 December 2019

08:00	*BREAKFAST*	
09:00 – 09:45	Dario Poletti	**Asymptotic Floquet states of interacting open quantum systems and period-doubling in period-1 steady states**
09:45 – 10:30	Arkady Pikovsky	**Phase locking vs frequency entrainment in synchronization under common noise**
10:30 – 11:00	*COFFEE BREAK*	
11:00 – 11:45	Peter Hänggi	**Quantum Dissipation: A Primer**
11:45 – 12:30	Antonio Politi	**Chaotic dynamics of the discrete nonlinear Schroedinger equation**
12:40	*LUNCH*	
14:30 – 15:15	Emil Yuzbashyan	**Integrable time-dependent Hamiltonians**
15:15 – 15:45	Samuel Jacob	**Heat and Work in Quantum Scattering Theory**
15:45 – 16:15	*COFFEE BREAK*	
16:15 – 17:00	Igor Burmistrov	**Multifractality in disordered interacting electron systems**
18:00	*DINNER*	
19:00 – 21:00	**Poster Session I**	

Wednesday, 18 December 2019

08:00	*BREAKFAST*	
09:00 – 09:45	Daniel Leykam	**Making light of dissipative quantum systems**
09:45 – 10:30	Achilleas Lazarides	**Quantum order at infinite temperature, time crystals, and dissipation**
10:30 – 11:00	*COFFEE BREAK*	
11:00 – 11:45	Sarika Jalan	**Explosive Synchronization in Multilayer Networks**
11:45 – 12:15	Tobias Becker	**Lindbladian approximation beyond the ultra weak coupling assumption**
12:30	*LUNCH*	
14:00 – 19:00	**Excursion** (a tour to the Christmas market in Bonn)	
19:00	*HERAEUS DINNER at the Physikzentrum (cold & warm buffet, with complimentary drinks)*	

Program

Thursday, 19 December 2019

08:00	*BREAKFAST*	
09:00 – 09:45	Eva-Maria Graefe	**A PT-symmetric kicked top**
09:45 – 10:30	Karol Życzkowski	**Quantum chaos for open systems: Universal spectra of random Lindblad operators**
10:30 – 10:45	*COFFEE BREAK*	
10:45 – 11:30	Eli Barkai	**Introduction to the quantum first detection problem**
11:30 – 12:00	Dariusz Chruściński	**Information flow versus divisibility for classical and quantum dynamical maps**
12:00 – 12:30	Aniket Patra	**Driven-Dissipative Dynamics of Coupled Atomic Clocks**
12:30	*LUNCH*	
14:00 – 14:45	Andre Eckardt	**Driven-dissipative ordering and universal non-equilibrium dynamics in open quantum gases**
14:45 – 15:30	Sølve Selstø	**Absorbers as tools – and measuring devices**
15:30 – 16:00	José Vieira	**Quadratic models for heat reservoirs**

Thursday, 19 December 2019

16:00 – 16:30	*COFFEE BREAK*	
16:30 – 17:15	Yuri Maistrenko	**Multistability in dynamical networks: from solitary oscillators to spatial chaos**
17:15 – 17:45	Ihor Vakulchyk	**Quantum trajectories approach to dissipative boundary conditions for time-dependent atomic problems**
18:00	*DINNER*	
19:00 – 21:00	**Poster session II**	

Program

Friday, 20 December 2019

08:00	*BREAKFAST*	
09:00 – 09:45	Dmitry Turaev	**Adiabatic control of quantum mechanical systems**
09:45 – 10:15	Jessica Eastman	**Controlling chaos in the quantum regime using adaptive measurements**
10:15 – 10:45	*COFFEE BREAK*	
10:45 – 11:30	David Luitz	**Spectral features of generic open quantum many-body systems**
11:30 – 11:45	Sergej Flach Jürgen Kurths Mikhail Ivanchenko	**Closing remarks and poster awards**
12:00 – 13:30	*LUNCH*	

End of the seminar and *FAREWELL COFFEE* / Departure

Posters

Posters

P01	Andrey Andreev	**Chaos and hyperchaos in quantum coherent chains**
P02	Tianqi Chen	**Transport through a single-site Bose-Hubbard model strongly coupled to two reservoirs**
P03	Carlo Danieli	**Ergodization times and dynamical glass in classical Josephson junction chains**
P04	Christian Duffin	**Controlling a Quantum System via its Boundary Conditions**
P05	Pezhman Ebrahimzadeh	**Minimal Network of Oscillators: Synchrony, Chimera and beyond**
P06	Nikita Frolov	**Model-free approach for data-driven generalized synchronization inference based on feed-forward neural network**
P07	Aleksandr Gonchenko	**Examples of Lorenz-like attractors in three-dimensional diffeomorphisms**
P08	Joseph Hall	**Chaos in a PT-Symmetric Kicked Rotor**
P09	Yagmur Kati	**Density Resolved Wave Spreading**
P10	Alexey Kazakov	**On the merger of a chaotic attractor with a chaotic repeller leading to the mixed dynamics**
P11	Pedro G. Lind	**Can we use quantum states to store classical Big Data?**
P12	Volodymyr Maistrenko	**Chimera and solitary states in 3D oscillator networks with inertia**

Posters

P13	Rohith Manayil	**Homodyne measure of nonclassicality for singlemode quantum states of light in the presence of decoherence**
P14	Arindam Mishra	**Extreme events and chimera in Josephson junction array**
P15	Paul Sanku	**Rate of decoherence and entanglement growth in coupled kicked rotors**
P16	Nataliya Stankevich	**Specific type of chaotic attractors with additional zero Lyapunov exponent in spectrum in flows**
P17	Sai Harshini Tekur	**Periodic projections in quantum spin chains**
P18	Alain Bertrand Togueu Motcheyo	**Homoclinic tangle and supratransmission threshold in discrete nonlinear lattice**
P19	Olga Vershinina	**Chaotic transitions in model open quantum systems**
P20	Evgeny Volkov	**Quasiperiodicity, chaos and the loss of symmetry in two quorum sensing coupled identical ring oscillators**
P21	Valentin Volokitin	**Is there Lindbladian?: A computer-aided search**

Abstracts of Lectures

(in chronological order)

Three forms of dynamical chaos

Sergey Gonchenko

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When it comes to dynamical chaos, one usually refers to one of its two quite different forms. In Hamiltonian systems, conservative chaos is observed, which looks in the phase space as a ``chaotic sea" with elliptic islands inside it. Chaos in dissipative systems has a completely different nature, and it is associated with strange attractors. The aim of the lecture is to draw attention to yet another, third, form of chaos, the so-called ``***mixed dynamics***". This type of chaos is characterized fundamentally by ***principal inseparability*** from each other in the phase space of attractors, repellers and conservative elements of dynamics (e.g., elliptic points, KAM-curves, etc.). The fact that, in the case of mixed dynamics, attractors can intersect with repellers seems, at first glance, very strange and contrary to common sense. In the recent work with D. Turaev [1], we made some attempt to resolve this contradiction by changing the concept of attractor, however, keeping its property of ``being closed invariant and stable set", but nevertheless allowing it to intersect with a repeller along some invariant set, the so-called ***reversible core*** which does not attract or repel anything. It should be noted that mixed dynamics are often observed in applications, for example, in nonholonomic models of rigid body motion. Relevant examples will also be considered in the lecture.

References

[1] Gonchenko S.V., Turaev D.V., On three types of dynamics and the notion of attractor //
Proceedings of the Steklov Institute of Mathematics, 2017, v.297, No.1, 116-137.

Hyperchaotic behavior in driven interacting Rydberg atoms

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We study the chain of coupled quantum coherent systems with energy pumping and dissipation. Examples of such systems include the coupled Rydberg atoms with laser driving and spontaneous emission. We found out that such system are able to demonstrate a spontaneous onset of chaotic and even hyperchaotic oscillations, which are characterized by one or several positive Lyapunov exponents. Remarkably, the number of the positive Lyapunov exponents grows with the number of the chain elements. Hence a large chain is able to demonstrate highly irregular behaviour. We investigate transition from regular to chaotic behaviour and show that appropriately chosen periodic stimuli can suppress even high-order chaos making the system behave regularly.

Statistical ensembles realized in many-body quantum systems with and without monitoring

Boris V. Fine[1]

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A pure state of an isolated many-body quantum systems is, in general, a superposition of exponentially many eigenstates. When not disturbed by external measurements, these superpositions may give rise to statistical ensembles that have rather nonintuitive properties, such as coexistence of many energy shells corresponding to different temperatures[1], or exponential suppression of the noise for the expectation values of quantum observables[2]. In the talk, I discuss how these ensembles may emerge dynamically[3] and how their commonly expected properties are recovered once the system becomes monitored through random measurements[4]. I also discuss a new numerical technique of hybrid quantum-classical simulations that allows one to obtain dynamical correlations of practical interest from exponentially suppressed quantum noise[5,6].

References

[1] B. V. Fine, *Typical state of an isolated quantum system with fixed energy and unrestricted participation of eigenstates*, Phys. Rev. E **80**, 051130 (2009)

[2] T. A. Elsayed, B. V. Fine, *Regression relation for pure quantum states and its implications for efficient computing*, Phys. Rev. Lett. **110**, 070404 (2013)

[3] K. Ji and B. V. Fine, *Non-thermal statistics in isolated quantum spin clusters after a series of perturbations*, Phys. Rev. Lett. **107**, 050401 (2011)

[4] W. Hahn, B.V. Fine, *Stability of quantum statistical ensembles with respect to local measurements*, Phys. Rev. E **94**, 062106 (2016)

[5] G. A. Starkov, B. V. Fine , *Hybrid quantum-classical method for simulating high-temperature dynamics of nuclear spins in solids*, Physical Review B **98**, 214421 (2018)

[6] G. A. Starkov, B. V. Fine , *Free induction decays in nuclear spin-1/2 lattices with small number of interacting neighbors: the cases of silicon and fluorapatite* arXiv:1911.00990 (2019)

Microwave driven quantum metamaterials

Alexey V. Ustinov

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Presently developed platforms for building quantum computers offer a variety of techniques to experiment with open driven quantum systems. Superconducting qubits are the most advanced technology for quantum computing. These qubits are electronic circuits which can be easily scaled up in number. Putting many qubits together in the form of an array makes it possible to experimentally study the quantum dynamics of an open quantum system with many degrees of freedom. In this talk, I will present an overview of our recent experiments with arrays of up to 90 superconducting qubits [1] coupled to a cavity or a waveguide. We dub these arrays as *quantum metamaterials*. In general, metamaterials are artificial engineered media of meta-atoms that enable tailored interactions with electromagnetic waves. Being driven by microwave fields, quantum metamaterials are expected to form collective super- and sub-radiant states. While modern technology does not allow making the transition frequencies of superconducting meta-atoms (qubits) exactly the same, their frequency spread can be traded against their coupling strength to propagating electromagnetic fields. We have observed quantum synchronization in arrays of different types of superconducting qubits, achieving strong coupling between electromagnetic field and mesoscopic ensembles of qubits [2,3]. Superconducting quantum technology thus unlocks an emerging new field of quantum metamaterials making it possible to explore driven collective quantum dynamics [4].

References

[1] J. Brehm, et al. , to be published (2019)
[2] P. Macha, et al., Nature Commun. **5**, 5146 (2014)
[3] K. V. Shulga, et al., JETP Lett. **105**, 47 (2017)
[4] K. V. Shulga, et al., Nature Commun. **9**, 150 (2018)

Two approaches to dissipative Quantum Chaos

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The agenda of the emerging theory of dissipative Quantum Chaos (dQC) is to relate regimes occurring in open quantum systems, when the latter are driven out of equilibrium, to phenomena of classical dissipative chaos. There are many ways to move towards this goal; I will discuss two of them, which seem to be most unintuitive at the moment.

First, it is an attempt to build a spectral theory of the dQC. More precise, it is an attempt to use the ideology and machinery of the existing spectral theory of Hamiltonian QC and random matrix theory in order to develop a theory addressing spectral properties of generators of open quantum evolution (often called 'Lindbladians') and of their eigenstates (asymptotic density matrices).

Second, it is a generalization of the concept of Lyapunov exponents to Markovian quantum evolution by implementing different unravellings of the corresponding Master equations into ensembles of stochastic quantum trajectories.

Currently these two approaches do not overlap. It is interesting therefore to discuss whether they are - and how they could be - related.

Quantifying dissipative quantum chaos by Lyapunov exponents and quantum jumps statistics

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Quantum systems, when interacting with their environments, may exhibit nonequilibrium states that are tempting to be interpreted as quantum analogs of chaotic attractors. However, different from the Hamiltonian case, the toolbox for quantifying dissipative quantum chaos remains limited. In particular, quantum generalizations of Lyapunov exponents, the main quantifiers of classical chaos, are established only within the framework of continuous measurements. We propose an alternative generalization based on the unraveling of quantum master equation into an ensemble of “quantum trajectories” [1].

We find that in chaotic regime (with positive quantum lyapunov exponent) there appears an intermediate power-law statistics in distribution between quantum jumps. It suggest the way for detecting dissipative quantum chaos in experiment, for example, by photon counting statistics.

We illustrate the results with two models: 1) Periodically modulated open quantum dimer; 2) Kerr-nonlinear cavity which is periodically modulated in time by coherently pumping the intra-cavity photonic mode.

References

[1] I. I. Yusipov, Chaos **29**, 063130 (2019)

Symmetries in Open Quantum Systems

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[3]Massachusetts Institute of Technology, Chemistry Department. Cambridge, Massachusetts 02139, USA.

Controlling nonequilibrium properties of quantum systems holds the key to many promising quantum technologies. I'll introduce the power of symmetry as a resource to manipulate quantum Non-Equilibrium Steady States (NESS). In the first part, I'll talk about the role of symmetries in steady state quantum transport and how this concept can be exploited to control quantum currents. I'll then introduce a novel scheme to identify symmetries in presence of a weak disorder. The scheme will identify key signatures in the dynamical quantum currents that are unique to symmetric systems and give us vital information about the underlying molecular symmetries [1]. In the second part, I'll introduce magnetic fields that can be used to break the open system symmetries in quantum networks. In the absence of a magnetic field the open system symmetries are preserved and help modulate the NESS based on the symmetry decomposition of the initial state. The presence of a magnetic field breaks symmetries in preferential directions with all symmetries being broken only in the presence of an anisotropic field [2]. These results demonstrate the importance of symmetry not only as an organizing principle in physics but also as a tool to control quantum systems [3].

References

[1] J. Thingna, D. Manzano, and J. Cao, Scientific Reports **6**, 28027 (2016).
[2] J. Thingna, D. Manzano, and J. Cao, arXiv:1909.09549 (2019).
[3] D. Manzano and P.I. Hurtado, Adv. Phys. **67**, 1 (2018).

Floquet Engineering in presence of dissipation

Alexander Schnell[1,2], André Eckardt[1,2] and Sergey Denisov[3,2]

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The stroboscopic evolution of a time-periodically driven isolated quantum system can always be described by an effective time-independent Hamiltonian. Whether this concept can be generalized to open Floquet systems, described by a Markovian master equation with time-periodic Lindbladian generator, remains an open question. By using a two level system as a model,

$$H(t) = \frac{\sigma_z}{2} + E\cos(\omega t - \varphi) \qquad \text{with jump operator} \qquad L = \sqrt{\gamma}\sigma_-,$$

we explicitly show the existence of two well-defined parameter regions [1], Fig. 1(a). In one region the stroboscopic evolution can be described by a Markovian master equation with a time-independent Floquet Lindbladian. In the other it cannot; but here the one-cycle evolution operator can be reproduced with an effective non-Markovian master equation that is homogeneous but non-local in time. Interestingly, we find that the boundary between the phases depends on when the evolution is stroboscopically monitored [Fig. 1(b)]. This reveals the non-trivial role played by the micromotion in the dynamics of open Floquet systems. Surprisingly, even though the Floquet Lindbladian is guaranteed to exist in the high-frequency limit, we show that a conventional Magnus high-frequency expansion leads to an unphysical generator [2, 3]. We discuss how the Floquet Lindbladian can neverthless be extracted from high-frequency expansions [2, 4] in the rotating frame and gain thereby some understanding of the nontrivial role of the micromotion.

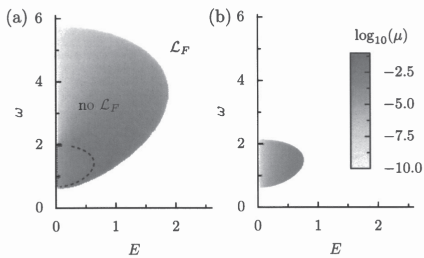

Fig. 1. Region where an effective Floquet Lindblad generator exists (white) and where no generator exists (blue) for driving phase (a) $\varphi = 0$ and (b) $\varphi = \pi/2$.

References

1. A. Schnell, A. Eckardt, S. Denisov, arXiv preprint, arXiv:1809.11121 (2018)
2. A. Schnell, S. Denisov, A. Eckardt, in preparation
3. F. Haddadfarshi, J. Cui, F. Mintert, Phys. Rev. Lett. 114, 130402 (2015)
4. A. Eckardt and E. Anisimovas, New J. Phys. 17, 093039 (2015)

Asymptotic Floquet states of interacting open quantum systems and period-doubling in period-1 steady states

M. Hartmann[1], M. Ivanchenko[2], S. Denisov[3], P. Hänggi[1]
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We investigate the asymptotic state of a periodically driven many-body quantum system which is weakly coupled to an environment. The combined action of the modulations and the environment steers the system towards a state being characterized by a time-periodic density operator. To resolve this asymptotic non-equilibrium state at stroboscopic instants of time, we use a dissipative Floquet map, evaluate the stroboscopic density operator as its eigen-element and elucidate how particle interactions affect properties of the density operator. We illustrate the idea with a periodically modulated Bose-Hubbard dimer and discuss the relations between the interaction-induced bifurcations in a mean-field dynamics and changes in the characteristics of the genuine quantum many-body state. We argue that Floquet maps provide insight into the system relaxation towards its asymptotic state and may help to understand whether it is possible (or not) to construct a stroboscopic time-independent generator mimicking the action of the original time-dependent one.

Thanks to this framework we then move on to study an interesting aspect of the classical-quantum correspondence principle. Nonlinear classical dissipative systems present a rich phenomenology in their "route to chaos", including period-doubling, i.e. the system evolves with a period which is twice that of the driving. However, typically the attractor of a periodically driven quantum open system evolves with a period which exactly matches that of the driving. Here we analyze a manybody open quantum system whose classical correspondent presents period-doubling. We show that by analysing the spectrum of the periodic propagator and by studying the dynamical correlations, it is possible to show the occurrence of period-doubling in the quantum (period-1) steady state. We also discuss that such systems are natural candidates for clean Floquet time crystals.

References

[1] M. Hartmann, D. Poletti, M. Ivanchenko, S. Denisov, P. Hänggi, New J. Phys. **19**, 083011 (2017)

[2] R.R.W. Wang, Bo. Xing, G.G. Carlo, D. Poletti, Phys. Rev. E 97, 020202 (2018)

Phase locking vs frequency entrainment in synchronization under common noise

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In the theory of synchronization, two notions are commonly used: phase locking and frequency entrainment. Here it is reported on a situation, where phase locking is accompanied by frequency anti-entrainment [1-3]. We consider a Kuramoto model of globally coupled oscillators, with an additional common noise action. Theory of synchronization is based on the Ott-Antonsen ansatz, allowing for a derivation of a closed stochastic Langevin equation for the order parameter. Solution of this equation shows, that for repulsive coupling, in the phase locked states with a large order parameter the frequencies of oscillators are pulled apart.

References

[1] A. V. Pimenova, D. S. Goldobin, M. Rosenblum, and A. Pikovsky, Sci. Reports 6, 38158 (2016)
[2] D. S. Goldobin , A. V. Pimenova, M. Rosenblum, and A. Pikovsky, Eur. Phys. J. Special Topics v. 226, 1921?1937 (2017)
[3] A. V. Dolmatova, D. S. Goldobin, and A. Pikovsky, Phys Rev E, v. 96, 062204 (2017)

Quantum Dissipation: A Primer

Peter Hänggi

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We present the topic of describing dissipation within the realm of *quantum mechanics*. A survey of different approaches are introduced and commented. The issue of quantum dissipation is exemplified using the archetype problem of a damped harmonic quantum oscillator (at weak and strong coupling). The role of quantum fluctuations is discussed, using both, the nonlinear generalized quantum-Langevin equation and the path integral approach. We discuss the consequences of the time-reversal symmetry for an open dissipative quantum dynamics and, foremost, point to a series of subtleties and possible pitfalls. We elucidate the issue with some applications such as dissipative quantum decay and quantum stochastic resonance.

Pertinent References

[1] H. Grabert, P. Schramm, and G.-L. Ingold, *Quantum Brownian motion: The functional integral approach*, Phys. Rep. **168**, 115–207 (1988).

[2] *Floquet approach for quantum dissipation*.

(a) M. Grifoni and P. Hänggi, *Driven Quantum Tunneling*, Phys. Rep. **304**, 229-354 (1998)

(b) S. Kohler, J. Lehmann and P. Hänggi, *Driven quantum transport on the nanoscale* Phys. Rep. **406**. 379-443 (2005).

[3] History, *subtleties and pitfalls*

P. Hänggi and G. L. Ingold, *Fundamental aspects of quantum Brownian motion*, Chaos **15**, 026105 (2005).

Chaotic dynamics of the discrete nonlinear Schroedinger equation

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The discrete nonlinear Schroedinger (DNLS) equation is a well-known model often used to provide a semiclassical description of cold atoms in periodic potentials.
The model, per se, describes a Hamiltonian, i.e. conservative, dynamics, which, at variance with the continuous Schroedinger equation, may be chaotic. I plan to first briefly review the chaotic properties for different values of the two conserved quantities (energy and norm) and then to explore the effect of an additional dissipation, typically added on the boundaries to account for the interaction with an external thermal bath. The effect of the dissipation (accompanied by thermal fluctuations) will be discussed both when the chain is characterized by a (statistically) homogeneous regime and in the presence of (at least) one tall breather, which strongly slows down internal relaxation [1].

References

[1] S. Iubini, L. Chirondojan, G.-L. Oppo, A. Politi, and P. Politi, Phys. Rev. Lett. **122** 084102, (2019)

Integrable time-dependent Hamiltonians

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In the emerging field of coherent many-body dynamics, we seek to understand the behavior of an isolated quantum many-body system driven far from equilibrium by changing its Hamiltonian in time. In this talk, I will identify a general class of many-body and matrix Hamiltonians for which this problem is exactly solvable. In particular, I will outline a way to make the parameters (e.g., the interaction strength) of certain quantum integrable models time-dependent without breaking their integrability.

Interesting many-body models that emerge from this approach include a superconductor with the interaction strength inversely proportional to time, a Floquet BCS superconductor, and the problem of molecular production in an atomic Fermi gas swept through a Feshbach resonance as well as various models of multi-level Landau-Zener tunneling. I will solve the non-stationary Schrodinger equation exactly for all these models and discuss some interesting physics that emerges at large times.

References

[1] E. A. Yuzbashyan, Ann. Phys. 392, 323 (2018)
[2] N. A. Sinitsyn, E. A. Yuzbashyan, V. Y. Chernyak, A. Patra, C. Sun, Phys. Rev. Lett 120, 190402 (2018)
[3] A. Patra and E. A. Yuzbashyan, J. Phys. A 48, 245303 (2015)

Heat and Work in Quantum Scattering Theory

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We study the interaction between a discrete quantum system X and massive wavepackets Y in an arbitrary kinetic state using quantum scattering theory (QST). We show that X thermalises and decoheres under repeated scattering with Thermal states of Y, interpreted as a thermal mixture of wavepackets effusing a reservoir. Conversely, Gaussian states of Y (whose energy width is narrow compared to the energy scales of X) lead only to decoherence and can be interpreted as a work source in the resonant scattering regime. We apply our theory to a 2-level system X scattering with Y, showing how general energy and entropy changes in QST lead to kinematic notions of heat and work, and how these changes are modified in the presence of quantum coherence.

Multifractality in disordered interacting electron systems

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In this talk I review our recent theoretical results for multifracal behavior in the presence of electron-electron interactions in disordered electron systems. In particular, I will focus on the three specific cases: (i) a vicinity of noninteracting critical point in the presence of irrelevant short ranged interaction; (ii) a vicinity of non-interacting critical point in the presence of a relevant weak short-ranged interaction; (iii) a vicinity of interacting critical point corresponding to Anderson-Mott transition. The talk is based on the papers [1-6].

References

1. I.S. Burmistrov, I.V. Gornyi, A.D. Mirlin, Phys. Rev. Lett. **111**, 066601 (2013)
2. I.S. Burmistrov, I.V. Gornyi, A.D. Mirlin, Phys. Rev. B **89**, 035430 (2014)
3. I.S. Burmistrov, I.V. Gornyi, A.D. Mirlin, Phys. Rev. B **91**, 085427 (2015)
4. I.S. Burmistrov, I.V. Gornyi, A.D. Mirlin, Phys. Rev. B **93**, 205432 (2016)
5. E. V. Repin, I. S. Burmistrov, Phys. Rev. B **94**, 245442 (2016)
6. I. S. Burmistrov, I. V. Gornyi, A. D. Mirlin, JETP Letters **106**, 272 (2017)

Making light of dissipative quantum systems

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Classical photonic systems such as coupled waveguides and resonators provide a convenient platform for studying the boundary between classical and quantum dissipative chaos. For example, classical chaos is ubiquitous in coupled semiconductor laser arrays [1], and by tailoring the coupling and losses of different array elements we can emulate various non-Hermitian Hamiltonians and Lindblad master equations [2]. I will present an overview of some recent advances in the photonic emulation of non-Hermitian and dissipative quantum systems, namely:

- Topological classification of non-Hermitian wave systems [3,4].
- Use of Lindblad master equations to describe the dynamics of ensembles of systems with static disorder, where disorder-induced fluctuations play the role of a reservoir [5].
- Emuation of dissipative quantum dynamics using leaky waveguide arrays [6], and how to use the resulting dissipative dynamics to measure topological invariants.

References

[1] J. Ohtsubo, Springer Series in Optical Sciences **111** (2017).

[2] S. Mukherjee, D. Mogilevtsev, G. Y. Slepyan, T, H. Doherty, R. R. Thomson, and N. Korolkova, Nature Commun. **8**, 1909 (2017).

[3] D. Leykam, K. Y. Bliokh, C. Huang, Y. D. Chong, and F. Nori, Phys. Rev. Lett. **118**, 040401 (2017).

[4] Z. Gong, Y. Ashida, K. Kawabata, K. Takasan, S. Higashikawa, and M. Ueda, Phys. Rev. X **8**, 031079 (2018).

[5] C. Gneiting, arXiv:1812:10323 (2018).

[6] J. Hu and C. R. Menyuk, Adv. Opt. Photon. **1**, 58 (2009).

Quantum order at infinite temperature, time crystals, and dissipation

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Discrete time crystals is the name given to many-body systems displaying long-time dynamics that is sub-harmonic with respect to a driving frequency. While these were first discussed in closed quantum systems a few years ago, recent work (partly motivated by experiments) has focussed on including non-unitary effects such as due to an external environment ("dissipation"). In this talk I will describe one of the unitary models that display the phenomenon of interest, then discuss a general framework for subharmonic oscillations stabilised by dissipative dynamics. The unitary and non-unitary phenomena are conceptually distinct.

Explosive Synchronization in Multilayer Networks

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The network concept has been successfully applied to predict and understand behaviour of many real-world systems coming from various different fields such as biology, socio-economical systems, linguistic networks, and technological systems etc. Recent years have witnessed emergence of the multiplex network framework, which provides more accurate insights into the behaviors of complex systems possessing multiple types of relations among the same units. An example of multilayer system can be the transport system of a country or state in which cities or towns would be the nodes, and a distinct network of each bus, train and flight connectivity among the nodes (cities) denotes different layers.

Furthermore, first order discontinuous transition to synchronization, popularly known as explosive synchronization (ES), in a network has been shown to be originated from considering either degree-frequency correlation, frequency-coupling strength correlation, inertia or adaptively controlled phase oscillators. Here we show that ES is a generic phenomenon and can occur in any network by multiplexing it with an appropriate layer without even considering any prerequisite for the emergence of ES. We devise a technique which leads to the occurrence of ES in a network upon its multiplexing with a negatively coupled (or inhibitory) layer. The impact of various structural properties of positively coupled (or excitatory) and inhibitory layers along with the strength of multiplexing in gaining control over the induced ES transition is discussed. Analytical prediction for the spread of phase-distribution of each layer is provided, which are in good agreement with the numerical assessment. This investigation is a step forward in highlighting the importance of multiplex framework not only in bringing novel phenomena which are not possible in an isolated network but also in providing more structural control over the induced phenomena.

References

[1] Sarika Jalan*, Anil Kumar and Inmaculada Leyva, Chaos (Fast Track) 29 (4), 041102 (2019)

[2] Sarika Jalan*, Vasundhara Rathore, Ajay Deep Kachhvah and Alok Yadav, Phys. Rev. E 99, 062305 (2019)

[3] Ajay Deep Kachhvah and Sarika Jalan*, New Journal of Physics 21, 015006 (2019)

Lindbladian approximation beyond the ultra weak coupling assumption

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Master equations of Lindblad form for the description of open quantum systems have not only the advantage that they guarantee a completely positive trace preserving (CPT) evolution. They are also the starting point for efficient stochastic quantum trajectory simulations. For thermal environments, such Lindblad-type master equations are commonly derived by starting from the Redfield-equation obtained within Born-Markov approximation and by applying additionally also a rotating-wave (or secular) approximation. However, the latter requires ultra weak system-bath coupling that is small compared to the level splitting in the system, a condition which is hard to achieve in large systems that approach a continuous spectrum in the thermodynamic limit. Here, we describe an alternative approximation to the Redfield equation, which also leads to a master equation of Lindblad form. This approximation does not require ultra weak system bath coupling, but rather sufficiently large temperatures. It, thus, works on regimes, where the secular approximation breaks down. We test our results using the example of an extended Hubbard chain coupled to two baths of different temperature.

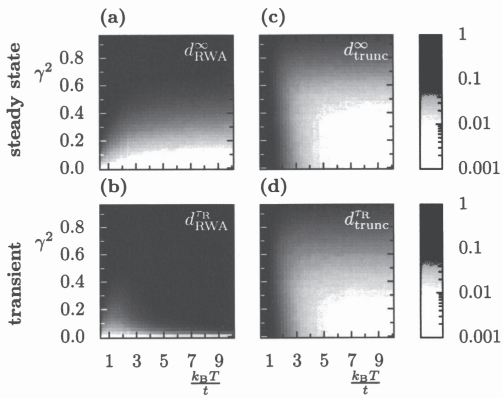

FIG. 1: Fermi Hubbard chain, $l = 8$, $N = 4$, $V = 2t$, coupled to thermal baths. Trace distance to the full Redfield result for the steady state (top) and for the transient dynamics (bottom) as a function of the system-bath coupling γ^2 and the bath temperature $T = T_1 = T_2$. In (a) and (b) we solve the master equation in the rotating-wave approximation by direct integration, whereas in (c) and (d) the new truncated master equation is taken.

A PT-symmetric kicked top

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A PT-symmetric version of the kicked top is introduced to study the interplay of quantum chaos with loss and gain. The classical dynamics arising from the quantum dynamics of the angular momentum expectation values are derived and analysed in some detail. Further, the statistics of the (complex) eigenvalues of the quantum system are studied and compared to those of PT-symmetric extensions of two additional systems: the triadic Baker map and the M-mode Bose-Hubbard model with unit filling factor and intermediate interaction strength.

Quantum chaos for open systems: Universal spectra of random Lindblad operators

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We analyze spectral properties of generic quantum operations, which describe open systems under assumption of strong and a strong coupling with an environment. In the case of discrete maps the spectrum of a quantum map displays a universal behaviour: it contains the leading eigenvalue $\lambda_1=1$, while all other eigenvalues are restricted to the unit disk. In the case of a generic dynamics in continuous time, we introduce an ensemble of random Lindblad operators, which generate Markov evolution in the space of density matrices of a fixed size. Universal spectral features of such operators, including the lemon-like shape of the spectrum in the complex plane, are explained with a non-hermitian random matrix model. The structure of the spectrum determines the transient dynamics of the quantum system and the convergence towards the generically unique invariant state. Demonstrated universality of the spectral features constitutes step towards categorization of dissipative quantum chaos.

References

[1] F. S. Denisov, T. Laptyeva, W. Tarnowski, D. Chruściński, and K. Życzkowski, Phys. Rev. Lett. **123,** 140403 (2019).

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Introduction to the quantum first detection problem

We consider quantum dynamics on a graph, with repeated strong measurements performed locally at a fixed time interval τ. For example a particle starting on node x and measurements performed on another node x'. From the basic postulates of quantum mechanics the string of measurements yields a sequence no,no,no, $\cdots$ and finally in the n-th attempt a yes, i.e. the particle is detected. Statistics of the first detection time $n\tau$ are investigated, and compared with the corresponding classical first passage problem. Dark states, Zeno physics, a quantum renewal equation, winding number for the first return problem (work of A. Grunbaum et al.), total detection probability, detection time operators and time wave functions are discussed.

References

[1] H. Friedman, D. Kessler, and E. Barkai *Quantum walks: the first detected passage time problem* **Phys. Rev. E. 95**, 032141 (2017). *Editor's suggestion.*

[2] F. Thiel, E. Barkai, and D. A. Kessler *First detected arrival of a quantum walker on an infinite line* **Phys. Rev. Lett. 120**, 040502 (2018).

Information flow versus divisibility for classical and quantum dynamical maps

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We study the relation between lack of information backflow and completely positive divisibility for general noninvertible quantum dynamical maps. Recently, these two concepts were shown to be fully equivalent for the so-called image nonincreasing dynamical maps [1]. It turns out that for a qubit dynamical maps this equivalence is universal [2]. Here we analyze this relation both for classical and quantum dynamical maps using powerful method of generalized inverses. Our analysis is illustrated by several examples.

References

[1] D. Chruscinski, A. Rivas, and E. Størmer, Phys. Rev. Lett. **121**, 080407 (2018).
[2] S. Chakraborty and D. Chruscinski, Phys. Rev. A **99**, 042105 (2019)

Driven-Dissipative Dynamics of Coupled Atomic Clocks

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We study the dynamics of two mesoscopic ensembles of ultra-cold two level atoms, which are collectively coupled to an optical cavity and are being pumped incoherently to the excited state. Whereas the time independent steady states are well understood [1], little is known about the time dependent ones. We explore and categorize various time dependent steady states, e.g. limit cycles and chaotic behavior [2, 3]. We draw a non-equilibrium phase diagram indicating different steady-state behaviors in different parts of the parameter space. We discuss the synchronization of the two ensembles in the time dependent steady states. We show the onset of chaos via quasi-periodicity. We show that in a small parameter regime even the chaos gets synchronized in some hyper-planes of the state space. The rich time dependent steady-state behavior, especially the existence of chaos, opens up possibilities for several engineering applications.

[1] Minghui Xu, D. A. Tieri, E. C. Fine, James K. Thompson and M. J. Holland, Synchronization of Two Ensembles of Atoms, Phys. Rev. Lett. 113, 154101 (2014).
[2] A. Patra, B. L. Altshuler and E. A. Yuzbashyan, Driven-Dissipative Dynamics of Atomic Ensembles in a Resonant Cavity: Nonequilibrium Phase Diagram and Periodically Modulated Superradiance, Phys. Rev. A 99, 033802 (2019).
[3] A. Patra, B. L. Altshuler and E. A. Yuzbashyan, Driven-Dissipative Dynamics of Atomic Ensembles in a Resonant Cavity: Nonequilibrium Phase Diagram and Periodically Modulated Superradiance, arXiv:1811.02148 (2018).

Driven-dissipative ordering and universal non-equilibrium dynamics in open quantum gases

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Statistical mechanics provides a powerful framework for predicting equilibrium properties of matter. While the lack of such a universal concept for driven many-body systems makes their theoretical treatment difficult, it also allows for engineering non-equilibrium states of matter with novel properties beyond the strict constraints of thermodynamics. As an example, I will discuss ordering (Bose condensation) in non-equilibrium steady states of systems in thermal environments that are strongly driven by time-periodic forcing [1,2], temperature gradients [1-3], and pumping [4, 5]. Our work predicts robust excited-state and fragmented Bose condensation [1-5], Bose condensation in environments well-above the equilibrium critical temperature [3], and it explains experiments with photons in structured environments [4,5].
Finally, I will briefly report on our recent work on the relaxation dynamics of interacting Wannier-Stark systems coupled to thermal baths [6, 7]. Here we observe the striking effect that the system can lose memory of its initial state and exhibit universal non-equilibrium dynamics, long before it reaches thermal equilibrium [7].

References

[1] *Generalized Bose-Einstein condensation into multiple states in driven-dissipative systems*, D. Vorberg, W. Wustmann, R. Ketzmerick, A, Eckardt, PRL **111**, 240405 (2013).
[2] *Non-equilibrium steady states of ideal bosonic and fermionic quantum gases,* D. Vorberg, W. Wustmann, H. Schomerus, R. Ketzmerick, A. Eckardt, PRE **92**, 062119 (2015).
[3] *High-temperature nonequilibrium Bose condensation induced by a hot needle,* A. Schnell, D. Vorberg, R. Ketzmerick, A. Eckardt, PRL **119**, 140602 (2017).
[4] *Pump-power-driven mode switching in a microcavity device and its relation to Bose-Einstein condensation*, H.A.M. Leymann, D. Vorberg, T. Lettau, C. Hopfmann, C. Schneider, M. Kamp, S. Höfling, R. Ketzmerick, J. Wiersig, S. Reitzenstein, A. Eckardt, PRX **7**, 021045 (2017).
[5] *A unified theory for excited-state, fragmented, and equilibrium-like Bose condensation in pumped photonic many-body systems*, D. Vorberg, R. Ketzmerick, A. Eckardt, PRA **97**, 063621 (2018).
[6] *Bath-induced decay of Stark many-body localization*, L.-N, Wu & A. Eckardt, PRL **123**, 030602 (2019).
[7] *Prethermal memory loss and universal non-equilibrium dynamics in an interacting Wannier-Stark system coupled to a thermal bath,* L.-N. Wu & A. Eckardt., in prep.

Absorbers as tools – and measuring devices

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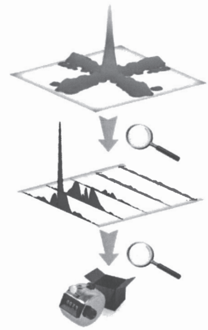
Simulating unbound quantum systems is challenging since they may extend arbitrarily far in space, thus necessitating a very large numerical grid. For one-particle systems, *absorbing boundary conditions* are frequently employed in order to truncate the numerical domain [1]. However, in a many-particle context, in which *the curse of dimensionality* complicates things further, we cannot introduce absorbing boundaries within the Schrödinger equation if we want to study the remainder of the system after absorption; any information on the remaining system is lost. *The Lindblad equation*, on the other hand, provides the proper framework for formulating quantum dynamics with a decreasing number of particles [2-4].



The Markovian act of absorption removes unbound particles from the system. However, by monitoring the physical properties of a particle as it is removed, we may retain a lot its information. This way, the dynamics of unbound many-body systems may be studied using a numerical grid considerably smaller than extension of the actual physical system – be it, e.g., an ionized atom [5], a decaying resonance [6] or electrons escaping a quantum dot [7]. This may be done at a surprisingly low cost in terms of information loss.

While the absorbing boundary conditions are usually introduced as artificial means of reducing the complexity of simulations, they can also be interpreted as a *detection* device [1]. In this way, this *lossy* evolution of the system as dictated by the Lindblad equation may serve to simulate the process of *measurement*.

References

[1] R. Kosloff, D. Kosloff, J. Comput. Phys. **63**, 363 (1986)
[2] V. Gorini, A. Kossakowski, E. C. G. Sudarshan, J. Math Phys. **17**, 821 (1976)
[3] G. Lindblad, Commun. Math. Phys. **48**, 119 (1976)
[4] S. Selstø, S. Kvaal, J. Phys. B **43**, 065004 (2010)
[5] S. Selstø, T. Birkeland, S. Kvaal, R. Nepstad, M. Førre, J. Phys. B **44**, 215003 (2011)
[6] S. Selstø, Phys. Rev. A **85**, 062518 (2012)
[7] S. Selstø, J. Phys. Cond. Matter **25**, 315802 (2013)

Quadratic models for heat reservoirs

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For the simple case of quadratic integrable Hamiltonians, we explore the conditions under which large environments behave like heat reservoirs. In the special case of environments for which these conditions are met, we study their behavior when forced to periodically collapse to a Gibbs state. In particular, we examine their suitability for modelling energy dissipation in periodically driven systems.

Multistability in dynamical networks: from solitary oscillators to spatial chaos

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Dynamical networks with Newtonian individual dynamics are characterized by the appearance of so-called *solitary states* in which one or a few oscillators split off from the main synchronized cluster and start oscillate with different averaged frequency (Poincare winding number). This striking behavior is not possible for standard Kuramoto model, however, it becomes generic as inertia is added [1].

Born in a homoclinic bifurcation, solitary state always co-exists with the fully synchronized state. At further parameter variation, more and more oscillators fall down in the shifted oscillations giving rise to a variety on new states of this kind. The number of co-existing stable solitary states becomes combinatorially large growing therefore exponentially with *N.* The latter means that network is characterized in this case by *spatial chaos* dynamics. Intriguingly, solitary states exist at different coupling topologies from local to global. All together they obey an essential part of the parameter space preserving also in both thermodynamic and conservative limits.

An important technological example is supplied by power grids, where solitary states multiply co-exist with the desired synchronous behaviour. As a result, they can provoke a prompt desynchronization under sudden not small disturbances, leading eventually to a grid blackout [2].

References

[1] P. Jaros, D. Dudkovsky, S. Brezetsky, R. Levchenko, T. Kapitaniak, and Yu. Maistrenko. *Solitary states for coupled oscillators with inertia*. CHAOS **28**, 011103 (2018).

[2] F. Hellman, P. Schultz, P. Jaros, R. Levchenko, T. Kapitaniak, J. Kurths, and Yu. Maistrenko. *Network induced multistability: Lossy coupling and exotic solitary states.* arXiv:1811.11518 (2019)

Quantum trajectories approach to dissipative boundary conditions for time-dependent atomic problems

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Effective particle-absorbing potentials are frequently used for numerical modeling of infinite systems. One of the ways to realize this is Lidnbladian formalism and particle annihilation on the system's edge as dissipation. We apply this technique to study the destruction of two-particle atomic states by potential modulation. We develop quantum trajectories approach that effectively decouples two- one- and no-particle subspaces and use it to study the statistical properties of temporal escape processes.

Adiabatic control of quantum mechanical systems

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We show that a periodic emergence and destruction of an additional quantum number leads to an exponential growth of energy of a quantum mechanical system subjected to a slow cyclic variation of parameters. We also show how the state of a quantum mechanical system can be controlled with an arbitrarily good precision by an arbitrarily slow change of system's parameters.

Controlling chaos in the quantum regime using adaptive measurements

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The emergence of the classical limit from the quantum theory is well understood for regular dynamics. But what happens to the quantum system when the classical limit is chaotic? Quantum chaos is the study of such quantum systems. The emergence of chaos for dissipative systems is interesting because of the breakdown time between the classical and quantum systems. How can we reconcile this breakdown with the classical chaotic dynamics that we observe in nature?
By considering an open quantum system with interaction with an environment, we can see the emergence of dissipative chaos from the underlying quantum system. Going further, by continuously monitoring a quantum system whose dynamics are chaotic in the classical limit, we are able to observe the emergence of chaos for single quantum trajectories. But the choice of measurement strategy itself can determine the degree of chaos that we observe. Here I address the effect that continuous measurement has on the emergence of chaos and offer a real time feedback scheme that uses the measurement as a control knob in order to control the degree of chaos in the system. These results are verified by the numerical calculation of the maximal Lyapunov exponent in the quantum regime. By enhancing the degree of chaos we are also able to push the onset of chaos further into the quantum regime than was possible before. By suppressing chaos we generate highly non-classical states and regular motion.

Spectral features of generic open quantum many-body systems

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In this talk, I will discuss spectral properties of generic open quantum many-body systems from two perspectives.

The first part will discuss the spectra of ergodic many-body Hamiltonians, with a small non-Hermitian component [1]. In such systems, the interactions induce a nontrivial topology of the spectrum, due to an exponential-in-system-size proliferation of exceptional points which have the Hermitian limit as an accumulation (hyper)surface. The nearest-neighbor level repulsion characterizing Hermitian ergodic many-body systems is thus shown to be a projection of a richer phenomenology, where actually all the exponentially many eigenvalues are pairwise connected in a topologically robust fashion via exceptional points.

In the second part of the talk, I will discuss the spectra of purely dissipative Liouvillians with a notion of locality, where we find a sharp separation of the relaxation timescales according to the locality of observables [2]. The spectrum is composed of several dense clusters with random matrix spacing statistics, each featuring a lemon-shaped support wherein all eigenvectors correspond to n-body decay modes. This implies a hierarchy of relaxation timescales of n-body observables, which we verify to be robust in the thermodynamic limit.

References

[1] D. J. Luitz and F. Piazza, “Exceptional points and the topology of quantum many-body spectra” *Phys. Rev. Research*, **1**, 033051 (2019), arXiv:1906.02224

[2] K. Wang, F. Piazza, D. J. Luitz, ” Hierarchy of relaxation timescales in local random Liouvillians “, arXiv:1911.05740

Abstracts of Posters

(in alphabetical order)

Chaos and hyperchaos in quantum coherent chains

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Partially quantum coherent arrays of artificial atoms (e.g., superconducting qubits) may be used as analog simulators of other quantum systems when the behavior of the latter cannot be directly observed or modeled by classical means [1,2]

Here we theoretically investigate the dynamics of a 1D chain of interacting Rydberg atoms driven by an external electromagnetic field in the presence of decoherence and dissipation [3,4]. We find that even a small chain comprising between two and four elements is able to demonstrate chaotic behavior. Remarkably, in systems with five or more elements, a phenomenon known as hyperchaos emerges, a dynamical regime characterized by two or more positive Lyapunov exponents. The highly randomized nature of hyperchaos shares some similarities with thermalization even though the system is far from equilibrium.

We investigate the transition from periodic to chaotic and hyperchaotic dynamics and show the increase of the number of positive Lyapunov exponents as the number of atoms grows. Adding two or three atoms leads to the appearance of an additional positive Lyapunov exponent. This phenomenon originates from a weak correlation between the oscillations in distant atoms.

The possibility of external control and suppression of hyperchaos in the chain by external parametric effect is demonstrated [5].

References

[1] M. Walport, P. Knight, The quantum age: technological opportunities (2016)
[2] A. de Touzalin et al, Quantum manifesto. a new era of technology (2016)
[3] T.Lee, H. Haffner, M. Cross, Phys. Rev. A **84**, 031402(R) (2011)
[4] T.Lee, H. Haffner, M. C. Cross, Phys. Rev. Lett. **108**, 023602 (2012)
[5] K. A. Mirus, J.Sprott, Physical Review E **59** (1999)

Transport through a single-site Bose-Hubbard model strongly coupled to two reservoirs

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We investigate the non-equilibrium transport properties in a single-site Bose-Hubbard model coupled to two thermal baths at different finite temperatures for different coupling strengths. The effect of the bath can be modeled as two decoupled chains of harmonic oscillators using a thermofield-based transformation and star-to-chain mapping. This numerical method provides an exact analysis of the system in the strong system-bath coupling regime. We numerically explore the effect of on-site interactions as well as the strong system-bath couplings on the system properties using matrix product states (MPS). We also directly probe the non-Markovianity during the time evolution by studying the non-monotonicity of the trace distance between two different initial states.

References

[1] Chu Guo, Ines de Vega, Ulrich Schollwöck, and Dario Poletti, Phys. Rev. A **97**, 053610 (2018).

[2] I. de Vega and D. Alonso, Rev. Mod. Phys. **89**, 015001 (2017).

[3] I. de Vega and M.-C. Bañuls, Phys. Rev. A **92**, 052116 (2015).

[4] I. de Vega, U. Schollwöck, and F. A. Wolf, Phys. Rev. B **92**, 155126 (2015).

[5] J. Prior, A. W. Chin, S. F. Huelga, and M. B. Plenio, Phys. Rev. Lett. **105**, 050404 (2010).

Ergodization times and dynamical glass in classical Josephson junction chains

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Models of classical Josephson junction chains turn integrable in the limit of large energy densities or small Joseph-son coupling strength. Close to these limits, the Josephson coupling between superconducting grains induces a short range network. We compute distributions of finite-time averages of grain charges and extract the ergodization time TE which controls their convergence to ergodic delta distributions. We relate T_E to the statistics of the fluctuations in time of the grain charges, which are dominated by fat tails. The ergodization time T_E grows anomalously fast upon approaching the integrable limit as compared to the Lyapunov time T_Λ - the inverse largest Lyapunov expo-nent. The microscopic reason for the observed behavior - which we labeled dynamical glass - is rooted in a growing number of grains evolving over long time in a regular fashion due to low probability of resonant interactions with the neighboring ones. We conjecture that the observed dynamical glass is Josephson junction networks irrespective of their dimensionality.

Ref: Phys.Rev.Lett. **122** 054102 (2019).

Controlling a Quantum System via its Boundary Conditions

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We numerically study a particle in a box with moving walls. In the case where the walls are oscillating sinusoidally with small amplitude, we show that states up to the fourth state can be populated with more than 80 percent population, while higher-lying states can also be selectively excited. This work introduces a way of controlling quantum systems which does not rely on (dipole) selection rules.

References

[1] Dijkstra, A., and C. Duffin. "Controlling a quantum system via its boundary conditions." *European Physical Journal D* (2019).

Minimal Network of Oscillators: Synchrony, Chimera and beyond

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Chimera states can be realized in the smallest network of three identical oscillators introducing a phase-lag [1]. We observed the existence of the "weak" chimera states in experiment using coupled mechanical oscillators (metronomes) with a real-time model-in-the-loop coupling mechanism that allows for flexible and online change of coupling topology, strength and phase-lag. Varying the phase-lag parameter, the system exhibits several characteristic behaviors: synchrony, heteroclinic switching between chimera states, stable chimera states and rotating waves. The experimental results (marked by A, B, C, and D in Figure 1) are in agreement with numerical studies on the related system model

$$B\ddot{\theta}_i + c_\theta\dot{\theta}_i + mglsin\theta_i = M_N + H(\theta_i - \theta^*)\frac{\mu}{N}\sum_{j=1}^{N}\sin(\theta_i - \theta_j - \alpha).$$

The parameter region shows chimera states reside in a large region in the form of Arnold's tongue, coated by heteroclinic switchings (see Figure 1). The basins of attraction for these different behaviors suggest stability in the region for phase-lag smaller than pi/2 and high sensitivity to noise and initial conditions according to their riddling-like basins in the region of phase-lag larger than pi/2.

Our experimental setup is flexible regarding different coupling configurations and online change of phase-lag and magnitude of coupling. In a next step, the number N of the metronomes in the setup will be increased, and the effect of different coupling topologies on the system dynamics for N > 3 should be demonstrate.

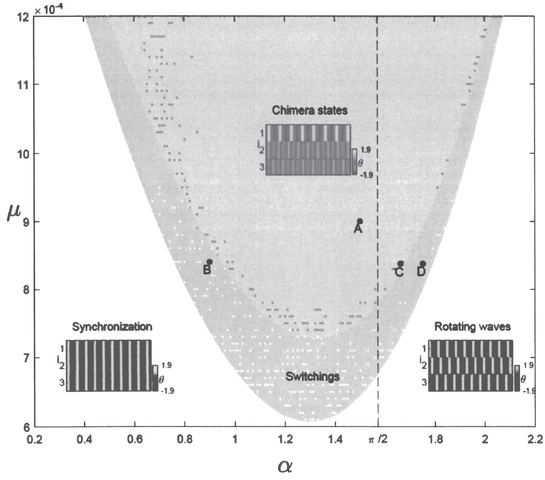

Figure 1: Parameter region of dependence of different spatiotemporal patterns on parameters μ and α. The white data points in the *Switchings* region indicate coexistence of the synchronous state (for α < π/2) and rotating waves (for α > π/2) with heteroclinic switchings. The sample points A, B, C, and D represent the experimental findings, which all match with the numerical results.

[1] Y. Maistrenko, S. Brezetsky, P. Jaros, R. Levchenko, and T. Kapitaniak, Phys. Rev.Lett. E 95, 010203 (2017)

Model-free approach for data-driven generalized synchronization inference based on feed-forward neural network

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Artificial neural networks (ANNs) are known to be a powerful tool for big data processing and classification [1]. They are widely used in computer science, nonlinear dynamics, robotics, and neuroscience for solving tasks of classification, forecasting, pattern recognition, etc. In neuroscience, ANNs allow recognizing specific forms of brain activity from multichannel electro- (EEG) or magnetoencephalographic (MEG) data and, therefore, widely used as a computational core in different brain-computer interfaces [2]. Another challenging problem is the analysis of connectivity structures in big multivariate data [3]. In particular, in neuroscience predicting the functional brain network using multichannel EEG/MEG signals uncovers mechanisms of neuronal interaction during various physiological or cognitive processes [4,5]. In this report we use recent advances in the area of machine learning known as feed-forward artificial neuronal network to formulate a method for detecting functional dependence in unidirectionally and bidirectionally coupled systems without additional information about them. We test our mathematical approach on the model coupled chaotic systems and demonstrate good agreement with the previous well-known results on generalized synchronization. Then, we apply our method for the first time to reveal functional connectivity structure in the thalamo-cortical network of epileptic brain based on a rodent ECoG data set.

References

[1] I. Goodfellow et al. Deep Learning, MIT Press (2016).
[2] I. Sturm, et al. Journal of neuroscience methods **274**, 141-145 (2016).
[3] A. M. Bastos, J.-M. Schoffelen, Front. Syst. Neurosci. **9**, 175 (2016).
[4] A. E. Hramov et al. Front Neurosci **11**, 674 (2017).
[5] A. E. Hramov et al. Chaos **28**, 033607 (2018).

Examples of Lorenz-like attractors in three-dimensional diffeomorphisms

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We observe some results on strange attractors of new type, the so-called discrete Lorenz attractors. Besides, in the talk we consider several examples of such attractors in 3D generalized Henon map and in models from applications, in particular, in nonholonomic models of Celtic stone.

Chaos in a PT-Symmetric Kicked Rotor

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PT-symmetric quantum mechanics has been of great interest to the research community over the recent decade. The condition of a Hamiltonian possessing PT-symmetry allows the relaxation of the familiar condition of hermiticity, while still ensuring the reality of the energy spectrum when the public symmetry is unbroken. On the other hand, when the PT-symmetry is broken the eigenvalues are either real or come in complex conjugate pairs. As such, a rich family of complex Hamiltonians is permitted that may be understood corresponding to a system with balanced gain and loss.

Thus far most theoretical investigations have focused on open counterparts of simple model systems, which are open counterparts of integrable and often even analytically solvable systems. However little investigation has been undertaken into the properties of PT-symmetric chaotic systems. In the present work this phenomenon is investigated through a PT-symmetric kicked rotor. This poster will present our current results in both the classical and quantum regimes of the system and forms part of an ongoing investigation into PT-symmetric quantum chaos.

Density Resolved Wave Spreading

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(Dated: October 18, 2019)

We report on the first density resolved wave packet spreading study, performed in the disordered Gross-Pitaevskii lattice. We introduce our method, in which wave spreading is controlled by the relation of two conserved quantities, and that greatly improves the observation of different spreading regimes. We give direct evidence for the observation of the regime of strong chaos, reconfirm the regime of weak chaos, and finally find a new ground state which depends on the disorder strength. Close to the ground state, wave packets get fragmented and trapped in a disorder induced, phase of disconnected, insulating puddles of matter. Based on our analysis, we identify a Bose Glass-like phase which shows slowing down of sub-diffusive spreading.

On the merger of a chaotic attractor with a chaotic repeller leading to the mixed dynamics

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In this work, we give a review on the phenomenon of the merger of Henon-like attractor with Henon-like repeller in few problems described by two-dimensional reversible maps. After such a merger dissipative dynamics associated with the existence of isolated Henon-like attractor and Henon-like repeller (Fig. 1a) are replaced by another type of chaos – the so-called mixed dynamics [1], when strange attractor of the system is increased in sizes by an explosion and starts to contain infinitely many area-expanding and are-preserving periodic saddle orbits in addition to area-contracting ones. On the corresponding two-dimensional map, a strange attractor intersects with a strange repeller but does not coincide with it, see Fig.1b.

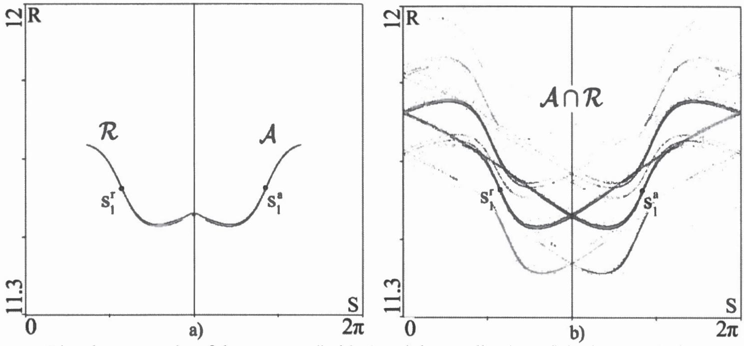

Figure 1. The phase portraits of the attractor (in blue) and the repeller (in red) in the model of two point vortices perturbed by an acoustic wave and a shear flow. (a) Henon-like attractor is separated from the Henon-like repeller. (b) Mixed dynamics after the merger of the Henon-lie attractor with the Henon-lie repeller.

As an example of the systems demonstrating such a phenomenon we consider:

1. Chirikov standard map under a reversible perturbation breaking conservativity,
2. Nonholonimic model of Suslov top [2].
3. The model of two-point vortices perturbed by an acoustic wave and a shear flow.

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References

[1] S.V. Gonchenko, D.V. Turaev. Proceedings of the Steklov Institute of Mathematics, 297, 1, 116-137 (2017).

[2] A.O. Kazakov. Radiophysics and Quantum Electronics, 61(8-9), 650-658 (2019).

Can we use quantum states to store classical Big Data?

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The mere storage of Big Data is a great challenge nowadays, motivating additional manipulations tools for increasing the efficiency of accessing the data. The dynamical growth of Big Data databases complicate this challenge even further.

Current trends, both in the fields of computational quantum physics and machine learning, are pointing to the use of methods from Deep Learning and Big Data analysis to compactify descriptions of complex many-body quantum states. We address the opposite perspective: Is it possible to use complex quantum states as to storage drive for multidimensional classical data? More practically, how can we encode a stream of classical data obtained from multi-variable chaotic dynamical systems into a multi-qubit quantum states?

Chimera and solitary states in 3D oscillator networks with inertia

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We report the appearance of chimera and solitary states in 2D- and 3D- Kuramoto model with periodic boundary conditions.
For the 3D case we found a variety of different patterns such as scroll wave torus, Hopf link, trefoil chimeras; sphere, balls etc. with coherent inner part. Some of them are novel and do not exist in the model without inertia [1-2]. We also report the appearance of different types of solitary states [3] and obtain their stability regions in the parameter space.
Scroll wave tori, Hopf links, trefoils with coherent and incoherent inner part in "solitary noise" surrounding are also exist in the considered system with inertia but, in contrast to the pure phase equations, they can be fixed in oscillatory space.
Stability regions in the parameter space for all considered chimeras are obtained and different scenarios for chimera destructions are considered.

References

[1] Yu.Maistrenko, O.Sudakov, O.Osiv, V.Maistrenko, New Journal of Physics, **17**, 073037, 2015.
[2] V.Maistrenko, O.Sudakov, O.Osiv, Yu.Maistrenko, The European Physical Journal Special Topics , **226**, Issue 9, pp 1867–1881, 2017.
[3] P.Jaros, S.Brezetsky, R.Levchenko, D.Dudkowski, T.Kapitaniak, Yu.Maistrenko, CHAOS **28**, 011103, 2018.

Homodyne measure of nonclassicality for single-mode quantum states of light in the presence of decoherence

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An arbitrary quantum state of light is said to be nonclassical if the Glauber-Sudarshan P-function of the state is highly singular or takes negative values somewhere in the phase space. In this work, the optical tomogram of the state[1] is used to quantify the nonclassicality associated with the single-mode electromagnetic field. A simple and easily computable measure of the degree of nonclassicality for the single-mode state of the electromagnetic field has been introduced. The proposed measure is based on the standard deviation in the measurement of the homodyne rotated quadrature operator. It can be considered as an effective area spanned by the optical tomogram of the state on the optical tomographic plane. It is found that if the nonclassical area spanned by a pure single-mode quantum state of light is nonzero, the state is strictly a nonclassical state. The nonclassical area is zero for the pure single-mode classical states. The nonzero value of the nonclassical area for a given pure single-mode quantum state is a necessary and sufficient condition to say that the state is nonclassical. The nonclassical area projected on the optical tomographic plane by the optical tomogram of the various nonclassical states has been evaluated[2]. The nonclassical area associated with an arbitrary quantum state of light increases with an increase in the strength of any nonclassicality inducing operations acting on the state. The robustness of the nonclassical area measure has been studied by analyzing the nonclassical area of the states in the presence of environment-induced decoherence. The zero-temperature master equation under Born-Markov approximation is used to obtain the time evolved density matrix of an initial nonclassical state and is further used to calculate the optical tomogram of the states in the presence of decoherence. The variation of the nonclassical area of the states is studied as a function of time and found that the nonclassical area measure is robust against decoherence. Nonclassical area projected by the optical tomogram of a quantum state of light may be experimentally tractable using the balanced homodyne detection of the quadrature operator of the field avoiding the reconstruction of density matrix or the quasiprobability distribution of the state.

References

[1] A. I. Lvovsky and M. G. Reymer, Rev. Mod. Phys. **81**, 299 (2009).
[2] M. Rohith, arXiv preprint, arXiv:1802.10050 (2018)

Extreme events and chimera in Josephson junction array

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We study the dynamics of Josephson junction array under common mean field interactions. The governing equations of current and voltage across the junctions resembles simple pendulum motion and quite similar to second order phase model, but with an amplitude. We consider scenarios with both attractive and repulsive mean field interactions in both homogeneous and heterogeneous parametric conditions. For attractive coupling and identical junctions we observe a transition from coherent libration to coherent rotation via chimera and cluster states. We introduce new measures to distinguish different collective states. For the second case we observe rare and recurrent large spiking events in a heterogeneous network of superconducting Josephson junctions (JJ) connected through a resistive load and driven by a radio-frequency (rf) current in addition to a constant bias. The intermittent large spiking events show characteristic features of extreme events (EE) since they are larger than a statistically defined significant height. Under the influence of repulsive interactions and an impact of heterogeneity of damping parameters, the network splits into three sub-groups of junctions, one in incoherent rotational, another in coherent librational motion and a third sub-group originating EE. We are able to scan the whole population of junctions with their distinctive individual dynamical features either in EE mode or non-EE mode in parameter space. EE migrates spatially from one to another sub-group of junctions depending upon the repulsive strength and the damping parameter. For a weak repulsive coupling, all the junctions originate frequent large spiking events, in rotational motion when the average inter-spike-interval (ISI) is small, but it increases exponentially with repulsive interaction; it largely deviates from its exponential growth at a break point where EE triggers in a sub-group of junctions. The probability density of inter-event-intervals (IEI) in the subgroup exhibits a Poisson distribution. EE originates via instability of in-phase synchronization.

References

[1] *Extreme events in a network of heterogeneous Josephson junctions,* Arnob Ray, Arindam Mishra, Dibakar Ghosh, Tomasz Kapitaniak, Syamal K. Dana and ChittaranjanHens (Submitted).

[2] *Coherent libration to coherent rotational dynamics via chimeralike states and clustering in a Josephson junction array,* Arindam Mishra, SumanSaha, Chittaranjan Hens, Prodyot K Roy, Mridul Bose, Patrick Louodop, Hilda A Cerdeira, Syamal K Dana. Phys. Rev. E **95**, 010201(R) (2017).

[3] *Multicluster oscillation death and chimeralike states in globally coupled Josephson Junctions,* Arindam Mishra, SumanSaha, Prodyot K Roy, Tomasz Kapitaniak, Syamal K Dana, Chaos **27**, 023110 (2017).

Rate of decoherence and entanglement growth in coupled kicked rotors

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The classical-quantum correspondence of the coupled kicked rotors is investigated. They form an interacting system wherein one rotor acting as an environment to the other. This leads to the emergence of decoherence and gives rise to a classical-like behavior for large times. However, this behavior is preceded by an intermediate dynamical localization. This dynamics correspond to an initial exponential decay of coherence followed by a power-law. We argue that the observed crossover can be attributed to the two distinct rates of entanglement entropy growth between the rotors.

Specific type of chaotic attractors with additional zero Lyapunov exponent in spectrum in flows

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Chaos is a typical attribute of nonlinear dynamical systems in various fields of science and technology [1-2]. One of the conventional indicator of chaotic dynamics is the largest Lyapunov exponent. Chaos is implemented in a situation when the spectrum of Lyapunov exponents have one positive, one zero and at least one negative exponents for a flow. In this work, we consider a somewhat different situation, when the spectrum of Lyapunov exponents of chaotic attractor contains an additional zero Lyapunov exponent, it means it includes one positive, two zero and several negative exponents [3].

As part of the work, examples of flow systems will be presented in which this type of chaotic dynamics is observed: modified Anishchenko-Astakhov generator, non-autonomous Rössler system, and coupled generators of quasi-periodic oscillations. A universal scenario such chaotic attractors occurrence associated with torus-doubling bifurcations and homoclinc bifurcation of unstable torus will be discussed.

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References

[1] E. Mosekilde, Y. Maistrenko, D. Postnov. Chaotic synchronization: applications to living systems (Vol. 42). World Scientific. (2002)

[2] S.H. Strogatz. Nonlinear dynamics and chaos: with applications to physics, biology, chemistry, and engineering. CRC Press. (2018)

[3] A.P. Kuznetsov, S.P. Kuznetsov, N.A. Shchegoleva, N.V. Stankevich, Physica D **398**, 1-12 (2019)

Periodic projections in quantum spin chains

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Periodically driven quantum spin chains are an important class of models in many-body quantum physics, which generically (with noteworthy exceptions like many-body localization or integrable points) exhibit many-body quantum chaos, ergodicity and fast equilibration to a stroboscopic ensemble. Here, we investigate a class of systems where a driven, disordered spin chain is opened by the addition of a periodic projection at one end of the chain, in analogy with chaotic classical or quantum maps with escape. The evolution operator over one period then becomes subunitary with a complex spectrum inside the unit circle. This class of systems exhibits several interesting properties, which we demonstrate by studying its level statistics, entanglement dynamics and spectral features like exceptional points which are unique to non-normal matrices. This class of systems may also be experimentally realized in a set-up where certain configurations of the spin chain can be post-selected after a measurement.

Homoclinic tangle and supratransmission threshold in discrete nonlinear lattice

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Supratransmission is a nonlinear phenomenon that has been extensively studied analytically numerically and experimentally to date in a wide variety of physical systems. In nonlinear gap transmission process, the knowledge of the amplitude threshold is very important. Using the continuous approximation to find it, there are discrepancies between analytical and numerical threshold in the strongly discrete aspect of the lattice and for large driven frequencies [1,2]. Using symmetric properties of the reversible planar maps, we construct stable and unstable manifold, homoclinic tangle and derive gap transmission threshold [3,4] which matches very well with the cubic and cubic-quintic DNLS equation.

References

[1] F. Geniet, J. Leon, Phys. Rev. Lett. **89**, 134102 (2002)

[2] R. Khomeriki, Phys. Rev. Lett. **92**, 063905 (2004)

[3] A. B. Togueu Motcheyo, J.D. Tchinang Tchameu, M. Siewe Siewe, C. Tchawoua, Commun. Nonlinear Sci. Numer. Simul. **50**, 29 (2017)

[4] A. B. Togueu Motcheyo, M. Kimura, Y. Doi , C. Tchawoua, Nonlinear Dyn **95**, 2461 (2019)

Chaotic transitions in model open quantum systems

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Recent successes in technology have brought open quantum systems to the forefront of research. It is known that beside "simple" completely thermalized state, these systems can be driven to complex regimes. Understanding such, in particular, the dissipative chaos is therefore a timely challenge. We consider two nonlinear mean-field models for an open quantum dimer and an open quantum resonator with a periodic modulation. Their dynamics is systematically investigated on the parameter plane “interaction strength - driving amplitude” and “driving period – driving amplitude” respectively. The constructed two-dimensional maps of dynamic regimes give a detailed picture of the transition to and structure of chaotic regimes. The obtained results are of interest for experimental studies, primarily for quantum electrodynamic and optical systems.

References

[1] H. Walther, B.T.H. Varcoe, B.G. Englert, Th. Becker, Rep. Prog. Phys. **69**, 1325 (2006)

[2] M. Aspelmeyer, T.J. Kippenberg, F. Marquardt, Rev. Mod. Phys. **86**, 1391 (2014)

[3] J.Q. You, F. Nori, Nature **474**, 589 (2011)

Quasiperiodicity, chaos and the loss of symmetry in two quorum sensing coupled identical ring oscillators

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We study the dynamical regimes demonstrated by a pair of identical 3-element ring oscillators (reduced version of synthetic 3-gene genetic Repressilator) coupled using the design of the 'quorum sensing (QS)' process natural for interbacterial communications. In this work QS is implemented as an additional network incorporating elements of the ring as both the source and the activation target of the fast diffusion QS signal. This version of indirect nonlinear coupling, in cooperation with the reasonable extension of the parameters which control properties of the isolated oscillators, exhibits the formation of a very rich array of attractors. Using a parameter-space defined by the individual oscillator amplitude and the coupling strength, we found the extended area of parameter-space where the identical oscillators demonstrate quasiperiodicity, which evolves to chaos via the period doubling bifurcation of different resonant limit cycles. The symmetric chaos extends over large parameter areas up to its loss of stability, followed by a system transition to an unexpected mode: an inhomogeneous limit cycle with a winding number of 1:2. In turn, after long evolution across the parameter-space, this cycle demonstrates a period doubling cascade which restores the symmetry of dynamics by formation of symmetric chaos, which nevertheless preserves the memory of the asymmetric limit cycles in the form of stochastic alternating "polarization" of the time series. All stable attractors coexist with some others, forming remarkable and complex multistability including the coexistence of torus and limit cycles, chaos and regular attractors, symmetric and asymmetric regimes. We traced the paths and bifurcations leading to all areas of chaos, and presented a detailed map of all transformations of the dynamics.

References

[1] Edward H. Hellen, Evgeny Volkov, Commun Nonlinear Sci Numer Simulat 62, 462–479 (2018)

Is there Lindbladian?: a computer-aided search

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The existence of a generator of time-continuous Markovian evolution, so-called Lindbladian, which after fixed time results in a given completely-positive quantum map is an open challenging problem.
Mathematically, this problem can be posed as the problem of solving a system of linear matrix inequalities (LMIs) with Hermitian matrices and integer coefficients [1]. We discuss the construction of a computationally efficient algorithm that allows us to give an answer about the existence (or nonexistence) of Lindbladian in an acceptable time. We propose an iterative method, verified for the absence of an integer solution.

References

[1] A. Schnell, A. Eckardt, S. Denisov, arXiv preprint arXiv:1809.11121 (2018)