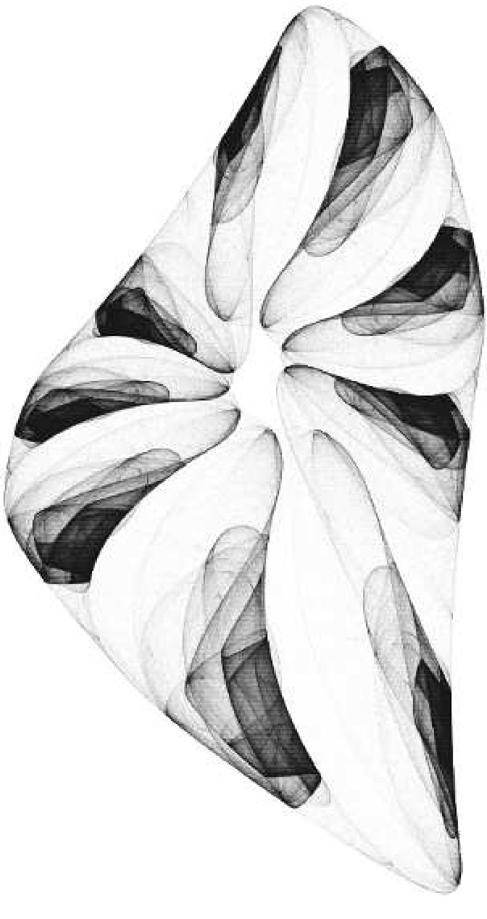
10th Workshop on Quantum Chaos and Localisation Phenomena

27–28 May 2021, Warsaw, Poland

organised by Institute of Physics of the Polish Academy of Sciences,
Center for Theoretical Physics of the Polish Academy of Sciences,
and Pro Physica Foundation

On-line conference



Ministry of Education and Science

Patronage of Polish Physical Society

Organising Committee

Afshin Akhshani (IP PAS)
Szymon Bauch (IP PAS)
Małgorzata Białous (IP PAS)
Omer Farooq (IP PAS)
Marek Kuś (CTP PAS)
Michał Ławniczak (IP PAS)
Paweł Masiak (IP PAS)
Adam Sawicki (CTP PAS)
Leszek Sirko – chairman (IP PAS)
Jerzy Wrochna (IP PAS)

Objectives

- To assess achievements and to formulate directions of new research on quantum chaos and localisation
- To bring together prominent experimental and theoretical physicists who share a common interest in quantum chaos and localisation phenomena

Scope

Presentations will focus on the following topics:

- Quantum chaos and nonlinear classical systems
- Quantum and microwave billiards
- Quantum and microwave graphs
- Atoms in strong electromagnetic fields – experiment and theory
- Chaos vs. coherent effects in multiple scattering
- Anderson localisation
- Random lasers
- Quantum chaos and quantum computing
- Entanglement and noise

Generalization of Wigner time delay to sub-unitary scattering systems

Steven Anlage[1], **Lei Chen**[2], **Tsampikos Kottos**[3], **Yan Fyodorov**[4]

[1] *Physics Department, University of Maryland, 4150 Campus Dr., College Park, MD 20742-4111, USA*

[2] *Department of Electrical and Computer Engineering, University of Maryland, 4150 Campus Dr., College Park, MD 20742-4111, USA*

[3] *Department of Physics, Wesleyan University, Exley Science Tower, 265 Church Street, Middletown CT-06459, USA*

[4] *Department of Mathematics, Faculty of Natural and Mathematical Sciences, King's College London, Strand, London WC2R, United Kingdom*

We introduce a complex generalization of Wigner time delay τ for sub-unitary scattering systems. Theoretical expressions for complex time delay as a function of excitation energy, uniform and non-uniform loss, and coupling, are given. We find very good agreement between theory and experimental data taken on microwave graphs containing an electronically variable lumped-loss element. We find that time delay and the determinant of the scattering matrix share a common feature in that the resonant behavior in $\mathrm{Re}[\tau]$ and $\mathrm{Im}[\tau]$ serves as a reliable indicator of the condition for Coherent Perfect Absorption (CPA). This work opens a new window on time delay in lossy systems and provides a means to identify the poles and zeros of the scattering matrix from experimental data. The results also enable a new approach to achieving CPA at an arbitrary energy/frequency in complex scattering systems. We also investigate the statistical properties of the complex time delay as a function of uniform attenuation, utilizing both theory and experiments on microwave graphs.

This work is supported by AFOSR COE Grant No. FA9550-15-1-0171, NSF/DMR 2004386, and ONR Grants N000141912481 and N000141912480.

Dissipative quantum chaos in Floquet systems

Sergey Denisov[1], **Juzar Thingna**[2], **Peter Hänggi**[3]

[1] *Department of Computer Science, Oslo Metropolitan University, Pilestredet 35 PS245, 0166 Oslo, Norway*

[2] *Center for Theoretical Physics of Complex Systems (PCS), Institute for Basic Science (IBS) , Expo-ro 55, Yuseong-gu, Daejeon 34126, South Korea*

[3] *Institut für Physik, Universität Augsburg, Universitätsstr. 1, D-86135 Augsburg, Germany*

Dissipative Quantum Chaos is an emerging theory with the agenda to relate open quantum and classical dissipative systems and eventually provide us with a tool to determine whether the evolution of an open system is “chaotic” or “regular”. Spectral properties of generators of quantum Markovian evolution are important in this respect. So far the emphasis was put on generators of the Gorini-Kossakowski-Sudarshan – Lindblad (GKS-L) form. Universal features were fund and some new concept, like Complex Spacing Ration, were developed by using the GKS-L framework. However, stationary GKS-L generators do not provide a straightforward way to semiclassical chaotic regime; therefore it is hard to relate open quantum and dissipative classical system with chaotic dynamics. In this talk I address another type of generator, the so-called Redfield generators, which emerge in the Floquet-Markov theory and allows for a semiclassical transition. I use a driven Duffing oscillator as a model to illustrate spectral properties of Redfield generators.

Microwave photonic crystals, graphene- and honome-billiards with threefold symmetry: a comparison with nonrelativistic and relativistic quantum billiards

Weihua Zhang, Barbara Dietz

Theoretical Lanzhou Center for Theoretical Physics and the Gansu Provisional Key Laboratory of Theoretical Physics, Lanzhou University, 222 South Tianshui Road, Lanzhou, Gansu 730000, China

It was demonstrated recently [1] that the properties of the resonance frequencies and electric field strength distributions of rectangular microwave photonic crystals obtained in superconducting measurements with flat resonators containing metallic cylinders arranged on a triangular grid [2], are well described by the tight binding model of a finite-size honeycomb-kagome lattice of corresponding shape. They are referred to as Dirac and honome billiards, respectively. We investigate properties related to the band structure of a Dirac billiard with a threefold symmetric shape and compare them to those of the corresponding graphene and honome billiards and relativistic neutrino billiards. Generally, the eigenstates of threefold-symmetric systems can be classified according to their behavior under rotation by $2\pi/3$ into singlets, that are rotationally invariant, and pairs of doublets. We reveal for the latter in graphene and honome billiards in momentum space a selective excitation of the two inequivalent Dirac points. For the understanding of the symmetry related features, we extend known results for nonrelativistic quantum billiards and the associated semiclassical approach [3,4] to relativistic neutrino billiards.

This work was supported by NNSF of China under Grant No. 11775100 and No. 12047501.

[1] W. Maimaiti, B. Dietz and A. Andreanov, *Phys. Rev. B* **102**, 214301 (2020).
[2] B. Dietz, T. Klaus, M. Miski-Oglu, and A. Richter, *Phys. Rev. B* **91**, 035411 (2015).
[3] J. M. Robbins, *Phys. Rev. A* **40**, 2128 (1989).
[4] C. H. Joyner, S. Müller, and M. Sieber, *J. Phys. A* **45**, 205102 (2012).

Quantum chaos and quantum measurement – entropy production vs. unitary quantum dynamics

Thomas Dittrich[1], **Frank Grossmann**[2], **Walter Strunz**[2],
Carlos Leonardo Viviescas Ramirez[1], **Oscar Rodriguez Bejarano**[3]

[1] *Departamento de Fisica, Universidad Nacional de Colombia, Ciudad Universitaria, Cra. 30 No. 45-03, 111321 Bogota D.C., Colombia*

[2] *Technische Universität Dresden, Faculty of Physics, Institute of Theoretical Physics, 01062 Dresden, Germany*

[3] *Departamento de Química, Universidad Nacional de Colombia, Ciudad Universitaria, Cra. 30 No. 45-03, 111321 Bogota D.C., Colombia*

Quantum chaos and quantum measurement have one constitutive feature in common: they capture information at the smallest scales to lift it to macroscopic observability. Fundamental bounds of the information content of closed quantum system with finite-dimensional Hilbert space their entropy production is exhausted in a finite time. Only in open systems where fresh entropy infiltrates from the environment, quantum dynamics (partially) recovers chaotic entropy production.

Also in quantum measurements, a macroscopic apparatus observes a quantum system. Typically, notably in spin measurement, their results involve a component of randomness. The analogy with quantum chaos suggests that random outcomes of quantum measurements could, in a similar manner, reveal the entropy generated through the coupling to a macroscopic environment. Decoherence is required anyway to explain a crucial feature of quantum measurement, the collapse of the wavepacket. However, the subsequent step from a set of probabilities to definite individual measurement outcomes (the "second collapse") still evades a proper understanding in microscopic terms and remains shrouded in concepts such as "quantum randomness". Could this process be explained by the back action of the macroscopic apparatus on the measured system?

To explore this hypothesis in the case of spin measurements, we adopt the model of the measurement process proposed by Zurek and others, combined with a unitary approach to decoherence with heat baths comprising only a finite number N of modes, used in quantum chemistry and quantum optics. We expect the dynamics of the measured spin for growing N to exhibit a scenario of increasingly irregular collapses and revivals: episodes of significant spin polarization of increasing length alternating with spin flips, determined by the initial condition of the apparatus. Preliminary analytical and numerical results confirm our expectation. Complementing the quantum model, an analogous classical system is presented: a particle, launched from the top of the barrier of a symmetric double-well potential, will fall into either well, depending on random impacts by ambient degrees of freedom.

Eigenfunction non-orthogonality in a single-channel chaotic scattering: non-perturbative RMT results

Yan Fyodorov, Mohammed Osman

King's College London, Strand, London, WC2R 2LS, UK

I will discuss distribution of diagonal non-orthogonality factors (also known as the Petermann factors, or eigenvalue condition numbers) characterizing eigenmodes in a single-channel wave-chaotic cavity. The results are obtained within RMT framework for the effective Hamiltonian formalism for an arbitrary strength of coupling to continuum.

The trace formula for quantum graphs with piecewise constant potentials and multi-mode quantum graphs

Sven Gnutzmann[1], **Uzy Smilansky**[2]

[1] *School of Mathematical Sciences, University of Nottingham, Nottingham, University Park, NG7 2RD, UK*

[2] *Department of Physics of Complex Systems, The Weizmann Institute of Science, Rehovot, 76100 IL, Israel*

It is well known that one may define a unitary quantum map for quantum graphs with free particle movement on all edges. This is a key ingredient in the derivation of the trace formula by Kottos and Smilansky. We will generalise this quantum map to the case of piecewise constant potentials. Due to the appearance of evanescent modes this is in general not a unitary map. We will show that there is however a reduced unitary map that only acts on the edges where the modes are propagating. We will use this to derive a trace formula and discuss some examples. The same technique may be applied to multi-mode quantum graphs which may be considered as a special case.

Non-stationarity and generic features in complex systems

Thomas Guhr

Faculty of Physics, University of Duisburg-Essen, Lotharstrasse 1, 47057 Duisburg, Germany

Non-stationarity, i.e. the seemingly erratic change of important properties, is a characteristic feature of most complex systems. Equilibrium methods as in standard statistical mechanics do not apply, and new approaches are called for. We present two complementary approaches: first, an analysis that identifies different operational states of complex systems and, second, a random matrix model explaining the heavy tails of multivariate amplitude distributions, i.e. the emergence of certain generic features. We illustrate our findings with examples from finance.

Coupled cat maps as a toy model of many body quantum chaos

Boris Gutkin

Faculty of Science, Holon Institute of Technology, 52 Golomb Street, Holon 5810201, Israel

For decades, Arnold's cat map served as a paradigm in classical and quantum chaos studies. I will discuss a natural extension of this model to many-body setting – a chain of cat maps linearly coupled by a nearest neighbor interaction. Despite of fully chaotic dynamics, the model turns out to be amenable to analytical treatment due to the duality between its spatial and temporal dynamics. In particular, I will provide an explicit formula for correlations between local operators in sufficiently long chains.

Quantization of states in complex soft-wall quantum billiards

Liang Huang

Lanzhou Center for Theoretical Physics, School of Physical Science and Technology, 222 South Tianshui Road, Lanzhou, Gansu 730000, China

Semiclassical quantization yields the exact eigenenergy spectrum for harmonic oscillators. How well it works for general confinements with complex potentials that the classical dynamics varies drastically with energy? In this talk we will show an example of semiclassical quantization of a complicated confinement potential. Despite the complexity in the classical dynamics, the semiclassical quantization works well for the scarring patterns around periodic orbits in this system even for low energy eigenstates. Particularly, unlike the hard-wall confinement of the two-dimensional electron gas where the recurrent scarring patterns are equally spaced in square root of E, a general feature of the soft-wall confinement is that the recurrent scarring patterns are equally spaced in E, which has been identified previously as a signature for relativistic billiards with hard-wall confinements. The underlying mechanism here is the similarity of the potential profile that the particle felt and that for a harmonic oscillator. These results could be exploited in understanding the measurements of the density of states and transport properties in two dimensional electron gas systems with random long-range impurities.

Microwave studies of the three chiral ensembles in chains of coupled dielectric resonators

Martin Richter[1], **Aimati Rehemanjiang**[2], **Ulrich Kuhl**[3], **Hans-Jürgen Stöckmann**[2]

[1] *School of Mathematical Sciences, University of Nottingham, Nottingham NG7 2RD, United Kingdom*

[2] *Fachbereich Physik der Philipps-Universität Marburg, D-35032 Marburg, Germany*

[3] *Université Côte d'Azur, CNRS, Institut de Physique de Nice (InPhyNi), Ave. Joseph Vallot, 06108 Nice, France*

Following a recently published work on chiral random matrix ensembles and their experimental realizations (Phys. Rev. Lett. 124, 116801 (2020)), the present work describes in more detail the obtained results and setup. The work will establish in detail the link between Random Matrix Theory (RMT) for systems with a chiral symmetry and how to create them with a finite set of microwave resonators. The finite systems from the experimental setup are compared to analytical results for finite-size systems.

On isospectral metric graphs

Pavel Kurasov, Jacob Muller

Institute of Mathematics, Stockholm University, Kräftriket hus 6, 106 91 Stockholm, Sweden

Isospectral standard Laplacians on metric graphs are studied. Different mechanisms behind isospectrality will be discussed.

Graphs with preferred-orientation coupling and their spectral properties

Jiří Lipovský[1], **Pavel Exner**[2]

[1] *Faculty of Science, Department of Physics, University of Hradec Králové, Rokitanského 62/26, 500 03 Hradec Králové, Czech Republic*

[2] *Department of Theoretical Physics, Nuclear Physics Institute, Academy of Sciences, Hlavni 130, 25068 Řež near Prague, Czech Republic*

We investigate quantum graphs with the preferred-orientation coupling conditions suggested by Exner and Tater [1]. In particular, we are interested in the high-energy limit of their spectra. These coupling conditions violate the time-reversal symmetry, for a particular energy, the particle approaching the vertex from a given edge leaves it through the neighbouring edge (for instance, to the left of the incoming edge) and this property is cyclical. It was previously shown that the vertex scattering matrix depends on the degree of the vertex; for an odd-degree vertex, the scattering matrix converges in the high-energy limit to the identity matrix, while even-degree vertices behave differently. This behaviour affects the transport properties of these graphs.

We study two models. The first one is a finite graph consisting of edges of Platonic solids. We find that the asymptotical distribution of the eigenvalues for the octahedron graph (having vertices with even degrees) is different from the other Platonic solids (having vertices with odd degrees), for which the eigenvalues approach the spectrum of the Neumann Laplacian on an interval. The second model consists of two types of infinite lattices. For one of them, the transport at high energies is possible in the middle of the strip and is suppressed at the edges. For the other one, the transport is possible at the edge of the strip only.

[1] P. Exner, M. Tater, "Quantum graphs with vertices of a preferred orientation", *Phys. Lett. A* **382**, 283–287 (2018).

[2] P. Exner, J. Lipovský, "Spectral asymptotics of the Laplacian on Platonic solids graphs", *J. Math. Phys.* **60**, 122101 (2019).

[3] P. Exner, J. Lipovský, "Topological bulk-edge effects in quantum graph transport", *Phys. Lett. A* **384**, 126390 (2020).

Euler characteristic of graphs and Fermi golden rule

Michał Ławniczak[1], **Pavel Kurasov**[2], **Jiří Lipovský**[3], **Szymon Bauch**[1], **Małgorzata Białous**[1], **Afshin Akhshani**[1], **Leszek Sirko**[1]

[1] *Institute of Physics, Polish Academy of Sciences, Aleja Lotników 32/46, 02-668 Warsaw, Poland*

[2] *Department of Mathematics, Stockholm University, S-106 91 Stockholm, Sweden*

[3] *Department of Physics, University of Hradec Králové, Rokitanského 62, 500 03 Hradec Králové, Czech Republic*

We present theoretical, experimental and numerical studies of the Euler characteristic χ for simple quantum graphs simulated experimentally by microwave networks [1]. The Euler characteristic χ is defined as a difference between the number of graph vertices $|V|$ and the number of its edges $|E|$. It also defines the Betti number $\beta = 1-\chi$ of independent cycles in a graph. Thus, together with the total graph length L the Euler characteristic χ is the most important topological and geometrical characteristic of graphs. We show theoretically and confirm experimentally that the Euler characteristic can be determined from a finite sequence of the lowest eigenenergies $\lambda_1, \ldots, \lambda_N$ of a quantum graph, without the need for a visual inspection of the system. Thus, from a graph spectrum one can find out what is the number of its vertices and edges, provided that the graph is fully connected, or that the graph is planar ($\beta \leq 3$).

We also present the experimental results of a Fermi golden rule study in the case of two- and five-edge quantum graphs simulated by microwave networks. A Fermi golden rule gives rates of decay of states obtained by perturbing embedded eigenvalues of graphs [2].

This work was supported in part by the National Science Centre, Poland, Grant Nos. 2016/23/B/ST2/03979 and 2018/30/Q/ST2/00324, the Swedish Research Council (Grant No. D0497301), and the Center for Interdisciplinary Research (ZiF) in Bielefeld in the framework of the cooperation group on "Discrete and continuous models in the theory of networks". J. L. was supported by the research programme "Mathematical Physics and Differential Geometry" of the Faculty of Science of the University of Hradec Králové.

[1] M. Ławniczak, P. Kurasov, S. Bauch, M. Białous, V. Yunko, and L. Sirko, *Phys. Rev. E* **101**, 053320 (2020).

[2] M. Ławniczak, J. Lipovský, M. Białous, and L. Sirko, *Phys. Rev. E* **103**, 032208 (2021).

Emulating π orbitals in aromatic molecules using elastic waves: borazine

Rafael Méndez

Instituto de Ciencias Físicas, Universidad Nacional Autónoma de México, Apartado Postal 48-3, 62210 Cuernavaca, Morelos, Mexico

Mechanical waves have emerged as a paradigm of condensed matter physics since with them many effects of the latter can be emulated. Molecular π orbitals are of great interest in this area since they play a key role in electronic transport in 2D materials and aromatic molecules as benzene and borazine. Molecular π orbitals are of great interest in this area because they play a key role in the electronic transport of 2D materials and aromatic molecules such as benzene and borazine. In this work we show the design, construction and characterization of a mechanical structure, the artificial mechanical borazine, which emulates the π orbitals of the borazine. The structure consists of hexagonal resonators, which act as artificial mechanical atoms coupled to each other through finite phononic crystals that act as artificial sigma bonds. When the resonant frequency of an artificial atom falls within the gap of the phononic crystal, the vibrations are trapped in it and interact weakly with neighboring atoms through evanescent Bloch waves. In this case, a tight-binding regime for mechanical waves emerge. Here these ideas are applied to emulate the π orbitals of borazine. The design relies on extensive finite element numerical simulations. The experimental results show an excellent agreement with both, the tight-binding formalism and with the numerical results.

This work was supported by DGAPA-UNAM and CONACYT through projects PAPIIT-IN111021, and CB/284096, respectively.

Simple approach to multiple scattering of waves from nontrivial media

Arkadiusz Orłowski, Marian Rusek

Institute of Technical Informatics, Warsaw University of Life Sciences, Nowoursynowska Str. 159/building 34, 02-776 Warsaw, Poland

Many interesting, subtle, and nontrivial effects can be observed when classical or quantum waves undergo multiple scattering. Depending on the size and structure of scattering media a plethora of phenomena can manifest themselves, including, but not restricted to, proximity resonances, coherent backscattering, strong (Anderson) localization, and others. Theoretical approaches to such effects are often marred by inadequate descriptions of the scattering objects and too crude approximations made at the wave propagation level. Here some results concerning coherence effects in multiple scattering are presented within a computational model that is extremely simple (although still realistic enough) at the level of the scattering medium description but which is exact at the wave propagation level. It is surprising how far one can go by modeling a scattering medium by discrete point-like dipoles and making no approximations to the wave propagation, thus describing scattering events in full generality within a given model. Apart from looking at the known examples from a different perspective, some new results for both scalar and vector waves are given.

Exactly solved models of chaotic many-body dynamics

Tomaž Prosen

Department of Physics, University of Ljubljana, Jadranska 19, SL-1000 Ljubljana, Slovenia

One should be amazed with an unreasonable effectiveness of random matrix theory to describe spectral fluctuations in simple non-integrable many-body systems, say one dimensional spin 1/2 chains with local interactions. I will discuss a class of Floquet (periodically driven) quantum spin chains – specifically, dual unitary Floquet circuits – where the random matrix result for the spectral form factor can be derived or even rigorously proven. Several other nontrivial exactly solvable features of the presented models, such as dynamical correlations or entanglement dynamics, will be discussed.

Quantum searching on Markov chains

Gregor Tanner[1], **Iain Foulger**[1], **Sven Gnutzmann**[1], **Birgit Hein**[1], **Nark-Nyul Choi**[2], **Min-ho Lee**[2]

[1] *School of Mathematical Sciences, University of Nottingham, Nottingham, University Park, NG7 2RD, UK*

[2] *Kumoh National Institute of Technology, 61 Daehak-ro (yangho-dong), Gumi, Gyeongbuk, 39177 Korea*

I will give an introduction into the quantum search algorithms on Markov chains introduced by Szegedy about 15 years ago and highlight some recent developments culminating in a proof by Apers *et al.* published as a preprint in 2019 showing that a quantum search can find a set of marked vertices quadratically faster (in units of the hitting time) for any reversible Markov chain. I will make some speculations about the underlying mechanisms for the search to work and critically discuss the use of the hitting time as a measure for the search time.

Does longitudinal light prevent Anderson localization?

Bart van Tiggelen, Sergey Skipetrov

LPMMC, University Grenoble Alpes and CNRS, 38000 Grenoble, France

Recent numerical simulations demonstrated the absence of an Anderson transition when light propagates in a dense medium filled with electric dipoles. We present a transport theory in which longitudinal waves induce a novel transport channel. The mixing of this channel with the usual transverse channel imposes a minimum conductivity.

https://arxiv.org/abs/2012.11210.

Many-body localization without disorder

Jakub Zakrzewski

Institute of Theoretical Physics, Jagiellonian University, Profesora Stanisława Łojasiewicza 11, 30-348 Cracow, Poland

I will discuss aspects of nonergodic dynamics for spin chains (or their implementations as cold atoms in optical lattices) in disorder-free models: lattice with a constant tilt and/or strong (un-)harmonic binding.

Random generators of Markovian evolution: a quantum-classical transition by superdecoherence

Karol Życzkowski[1,2], **Wojciech Tarnowski**[1], **Sergey Denisov**[3], **Tatyana Laptyeva**[4], **Igor Yusipov**[4], **Dariusz Chruściński**[2,5]

[1] *Institute of Theoretical Physics, Jagiellonian University, ul. Łojasiewicza 11, 30-348 Kraków, Poland*

[2] *Center for Theoretical Physics PAS, Al. Lotników 32/46, 02-668 Warsaw, Poland*

[3] *Department of Computer Science, Oslo Metropolitan University, Pilestredet 52, 0166 Oslo, Norway*

[4] *Mathematical Center, Lobachevsky University, 603950 Nizhni Novgorod, Russia*

[5] *Institute of Physics, Faculty of Physics, Astronomy and Informatics, Nicolaus Copernicus University, 87-100 Toruń, Poland*

Continuous-time Markovian evolution appears to be manifestly different in classical and quantum worlds. We consider ensembles of random generators of N-dimensional Markovian evolution, quantum and classical ones, and evaluate their universal spectral properties [1]. It is shown, how the two types of generators can be related by superdecoherence. In analogy with the mechanism of decoherence, which transforms a quantum state into a classical one, superdecoherence can be used to transform a Lindblad operator (generator of quantum evolution) into a Kolmogorov operator (generator of classical evolution). By gradually increasing strength of superdecoherence, we observe a sharp quantum-to-classical transition.

[1] arXiv:2105.02369.

Investigations of the enhancement factor in an open wave chaotic system with time-reversal-invariance violation

Małgorzata Białous[1], **Barbara Dietz**[2], **Leszek Sirko**[1]

[1] *Institute of Physics, Polish Academy of Sciences, Aleja Lotników 32/46, 02-668 Warszawa, Poland*

[2] *Lanzhou Center for Theoretical Physics and the Gansu Provincial Key Laboratory of Theoretical Physics, Lanzhou University, Lanzhou, 730000 Gansu, China*

We show experimentally and confirm theoretically that above a certain size of time-reversal T-invariance violation the increase of the openness of a wave chaotic system can lead to an increase of the elastic enhancement factor. In the experiment a quantum billiard with partially violated time-reversal invariance, characterized by the T-invariance violation parameter $\zeta \in [0,1]$ is simulated with a flat quarter-bow-tie microwave cavity which contains two cylindrical ferrites that are magnetized by an external magnetic field. The elastic enhancement factor $F_M(\eta,\gamma,\zeta)$ is investigated as a function of internal absorption γ and openness η. In these investigations we focus on the frequency range of strongest T-invariance violation where the increase of the number of open channels causes a boost of the elastic enhancement factor $F_M(\eta,\gamma,\zeta)$ instead of the expected lowering [1,2].

This work was supported in part by the National Science Center, Poland, Grant No. UMO-2018/30/Q/ST2/00324. B.D. thanks the National Natural Science Foundation of China for financial support through Grants No. 11775100, No. 11961131009, and No. 12047501. Supported by the 111 Project under Grant No. B20063.

[1] M. Białous, B. Dietz, and L. Sirko, *Phys. Rev. E* **102**, 042206 (2020).
[2] M. Białous, B. Dietz, and L. Sirko, *Acta Phys. Pol. A* **139**, 462 (2021).

Experimental demonstration of complex Wigner time delay in sub-unitary scattering systems

Lei Chen[1], **Steven Anlage**[2], **Yan Fyodorov**[3]

[1] *Department of Electrical and Computer Engineering, University of Maryland, 4150 Campus Dr., College Park, MD 20742-4111, USA*

[2] *Physics Department, University of Maryland, 4150 Campus Dr., College Park, MD 20742-4111, USA*

[3] *Department. of Mathematics, Faculty of Natural and Mathematical Sciences, King's College London, Strand, London WC2R, United Kingdom*

Wigner time delay has been appealing to physicists for its intuitive insights into the scattering properties of the complex scattering region. Here we develop a complex generation of Wigner time delay in the sub-unitary scattering systems. By including both lumped and uniform loss and coupling effects into the Scattering matrix, we model the complex time delay using the S-matrix zeros and poles, and establish connections between the time delay and Coherent Perfect Absorption (CPA). We demonstrate the idea of complex time delay in the sub-unitary scattering systems using a microwave graph experiment, and provide effective methods for manipulating zeros and poles of the S-matrix. We also further investigate the statistical properties of the complex time delay as a function of uniform attenuation, utilizing both Random Matrix Theory (RMT) simulations and experiments on microwave graphs.

Eigenfunction and eigenmode-spacing statistics in chaotic photonic crystal graphs

Shukai Ma, Steven M. Anlage, Thomas Antosen, Edward Ott

Physics Department, University of Maryland, College Park, MD 20742-4111, USA

The properties of chaotic systems have been studied extensively in different dimensionalities. Common statistical tests include the eigenmode-spacing and eigenfunction analysis. However, the experimental studies of chaotic graph eigenfunctions are generally confined to just the wavefunction values at the nodes, because 1D graphs are usually constructed with coaxial cables. In the meantime, recent studies reveal that the chaotic graphs face challenges from trapped modes, which may be better analyzed and understood with eigenfunction analysis tools. Here, we propose photonic crystal (PC) arrays as an alternative physical system for chaotic graph studies. The graph bonds are realized with defect waveguides which can be modeled by the telegrapher's equation for parallel plate waveguides. We have numerically demonstrated an ensemble of such PC-graphs and conducted both eigenfunction amplitude and eigenmode-spacing studies, and these statistical properties are in good agreement with the GOE predictions. Different methods are tested in order to measure the graph eigenfunction profile. Our proposed system can be readily applied to other statistical studies, such as inverse participation ratio, as well as further experimental realizations.

PARTICIPANTS AND AUTHORS

Afshin Akhshani, p. 14

Institute of Physics, Polish Academy of Sciences, Al. Lotnikow 32/46, 02-668 Warsaw, Poland
e-mail: akhshani@ifpan.edu.pl

Steven M. Anlage (invited speaker), p. 1, 23, 24

Physics Department, University of Maryland, 4150 Campus Dr., College Park, MD 20742-4111, USA
e-mail: anlage@umd.edu

Thomas Antonsen (co-author), p. 24

Physics Department, University of Maryland, College Park, MD 20742-4111, USA
e-mail: antonsen@umd.edu

Szymon Bauch, p. 14

Institute of Physics, Polish Academy of Sciences, Al. Lotników 32/46, 02-668 Warsaw, Poland
e-mail: bauch@ifpan.edu.pl

Małgorzata Białous (poster), p. 14, 22

Institute of Physics, Polish Academy of Sciences, Al. Lotników 32/46, 02-668 Warsaw, Poland
e-mail: bialous@ifpan.edu.pl

Lei Chen (poster), p. 1, 23

Department of Electrical and Computer Engineering, University of Maryland, 4150 Campus Dr., College Park, MD 20742-4111, USA
e-mail: LChen95@umd.edu

Nark-Nyul Choi (co-author), p. 18

Kumoh National Institute of Technology, 61 Daehak-ro (yangho-dong), Gumi, Gyeongbuk, 39177 Korea
e-mail: nnchoi@kumoh.ac.kr

Dariusz Chruściński (co-author), p. 21

Institute of Physics, Faculty of Physics, Astronomy and Informatics, Nicolaus Copernicus University, ul. Grudziądzka 5, 87Ð100 Toruń, Poland
e-mail: darch@fizyka.umk.pl

PARTICIPANTS AND AUTHORS

Sergey Denisov (invited speaker), p. 2, 21

Department of Computer Science, Oslo Metropolitan University, Pilestredet 52,
0166 Oslo, Norway
e-mail: Sergiy.Denysov@oslomet.no

Barbara Dietz (invited speaker), p. 3, 22

Theoretical Lanzhou Center for Theoretical Physics and the Gansu Provisional Key Laboratory of Theoretical Physics, Lanzhou University, 222 South Tianshui Road, Lanzhou, Gansu 730000, China
e-mail: dietz@lzu.edu.cn

Thomas Dittrich (invited speaker), p. 4

Departamento de Fisica, Universidad Naional de Colombia, Ciudad Universitaria,
Cra. 30 No. 45-03, 111321 Bogota D.C., Colombia
e-mail: tdittrich@unal.edu.co

Pavel Exner (co-author), p. 13

Department of Theoretical Physics, Nuclear Physics Institute, Academy of Sciences, Hlavni 130, 25068 Rez near Prague, Czech Republic
e-mail: exner@ujf.cas.cz

Omer Farooq

Institute of Physics, Polish Academy of Sciences, Al. Lotnikow 32/46, 02-668 Warsaw, Poland
e-mail: farooq@ifpa.edu.pl

Iain Foulger (co-author), p. 18

School of Mathematical Sciences, University of Nottingham, University Park,
Nottingham NG7 2RD, UK

Yan Fyodorov (invited speaker), p. 1, 6, 23

Dept. of Mathematics, Faculty of Natural and Mathematical Sciences, King's College London, Strand, London WC2R, United Kingdom
e-mail: yan.fyodorov@kcl.ac.uk

Sven Gnutzmann (invited speaker), p. 7, 18

School of Mathematical Sciences, University of Nottingham, University Park,
Nottingham NG7 2RD, UK
e-mail: sven.gnutzmann@nottingham.ac.uk

Frank Grossmann (co-author), p. 4

Technische Universität Dresden, Faculty of Physics, Institute of Theoretical Physics, 01062 Dresden, Germany
e-mail: grossman@physik.tu-dresden.de

Thomas Guhr (invited speaker), p. 8

Faculty of Physics, University of Duisburg-Essen, Lotharstrasse 1, 47057 Duisburg, Germany
e-mail: thomas.guhr@uni-due.de

Boris Gutkin (invited speaker), p. 9

Faculty of Science, Holon Institute of Technology, 52 Golomb Street, Holon 5810201, Israel
e-mail: borisgu@hit.ac.il

Peter Hänggi (co-author), p. 2

Institut für Physik, Universität Augsburg, Universitätsstr. 1, D-86135 Augsburg, Germany
e-mail: Hanggi@Physik.Uni-Augsburg.DE

Birgit Hein (co-author), p. 18

School of Mathematical Sciences, University of Nottingham, University Park, Nottingham NG7 2RD, UK
e-mail: birgit.hein@maths.nottingham.ac.uk

Liang Huang (invited speaker), p. 10

Lanzhou Center for Theoretical Physics, School of Physical Science and Technology, 222 South Tianshui Road, Lanzhou, Gansu 730000, China
e-mail: huangl@lzu.edu.cn

Tsampikos Kottos (co-author), p. 1

Department of Physics, Wesleyan University, Exley Science Tower, 265 Church Street, Middletown CT-06459, USA
e-mail: tkottos@wesleyan.edu

Ulrich Kuhl (invited speaker), p. 11

Institut de Physique de Nice (INPHYNI), CNRS, University Cote d’Azur, Parc Valrose, 06100 Nice, France
e-mail: ulrich.kuhl@univ-cotedazur.fr

PARTICIPANTS AND AUTHORS

Pavel Kurasov (invited speaker), p. 12, 14

Institute of Mathematics, Stockholm University, SE-106 91, Stockholm, Sweden
e-mail: kurasov@math.su.se

Marek Kuś

Center for Theoretical Physics of the Polish Academy of Sciences, Al. Lotników 32/46, 02-668 Warsaw, Poland
e-mail: marek@cft.edu.pl

Tatyana V. Lapteva (co-author), p. 21

Mathematical Center, Lobachevski State University of Nizhni Novgorod, pr. Gagarina 23, Nizhnii Novgorod 603950, Russia
e-mail: ivanchenko.mv@gmail.com

Min-ho Lee (co-author), p. 18

Kumoh National Institute of Technology, 61 Daehak-ro (yangho-dong), Gumi, Gyeongbuk, 39177 Korea
e-mail: minho.lee@kumoh.ac.kr

Jiří Lipovský (invited speaker), p. 13, 14

Department of Physics, Faculty of Science, University of Hradec Králové, Rokitanského 62, 500 03 Hradec Králové, Czech Republic
e-mail: jiri.lipovsky@uhk.cz

Michał Ławniczak (invited speaker), p. 14

Institute of Physics, Polish Academy of Sciences, Al. Lotników 32/46, 02-668 Warsaw, Poland
e-mail: lawni@ifpan.edu.pl

Shukai Ma (poster), p. 24

Department of Physics, University of Maryland, College Park, MD 20742-4111, USA
e-mail: skma@terpmail.umd.edu

Paweł Masiak

Institute of Physics, Polish Academy of Sciences, Al. Lotników 32/46, 02-668 Warsaw, Poland
e-mail: pmasiak@ifpan.edu.pl

PARTICIPANTS AND AUTHORS

Rafael Méndez (invited speaker), p. 15

Instituto de Ciencias Físicas, Universidad Nacional Autonoma de Mexico, Apartado Postal 48-3, 62210 Cuernavaca, Morelos, Mexico
e-mail: mendez@icf.unam.mx

Jacob Muller (co-author), p. 12

Institute of Mathematics, Stockholm University, SE-106 91, Stockholm, Sweden
e-mail: muller@math.su.se

Arkadiusz Orłowski (invited speaker), p. 16

Institute of Technical Informatics, Warsaw University of Life Sciences, Nowoursynowska Str. 159/building 34, 02-776 Warsaw, Poland
e-mail: arkadiusz_orlowski@sggw.edu.pl

Mohammed Osman (co-author), p. 6

Dept. of Mathematics, Faculty of Natural and Mathematical Sciences, King's College London, Strand, London WC2R, United Kingdom
e-mail: mohammed.osman@kcl.ac.uk

Edward Ott (co-author), p. 24

Physics Department, University of Maryland, College Park, MD 20742-4111, USA
e-mail: edott@umd.edu

Tomaž Prosen (invited speaker), p. 17

Department of Physics, University of Ljubljana, Jadranska 19, SL-1000 Ljubljana, Slovenia
e-mail: tomaz.prosen@fmf.uni-lj.si

Aimati Rehemanjiang (co-author), p. 11

Fachbereich Physik der Philipps-Universität Marburg, D-35032 Marburg, Germany
e-mail: aimaiti@rehemanjiang.de

Martin Richter (co-author), p. 11

School of Mathematical Sciences, University of Nottingham, Nottingham NG7 2RD, United Kingdom
e-mail: Martin.Richter@nottingham.ac.uk

Oscar Rodriguez Bejarano (co-author), p. 4

Departamento de Química, Universidad Naional de Colombia, Ciudad Universitaria, Cra. 30 No. 45-03, 111321 Bogota D.C., Colombia
e-mail: orodriguez@unal.edu.co

Marian Rusek (co-author), p. 16

Institute of Technical Informatics, Warsaw University of Life Sciences, Nowoursynowska Str. 159/building 34, 02-776 Warsaw, Poland
e-mail: marian_rusek@sggw.edu.pl

Adam Sawicki

Center for Theoretical Physics, Polish Academy of Sciences, Al. Lotników 32/46, 02-668 Warsaw, Poland
a.sawicki@cft.edu.pl

Leszek Sirko, p. 14, 22

Institute of Physics, Polish Academy of Sciences, Al. Lotników 32/46, 02-668 Warsaw, Poland
e-mail: sirko@ifpan.edu.pl

Sergey Skipetrov (co-author), p. 19

Laboratoire de Physique et Modélisation des Milieux Condensés UMR 5493, Maison des Magistères CNRS, 25 avenue des Martyrs, BP166, 38042 Grenoble Cedex, France
e-mail: Sergey.Skipetrov@grenoble.cnrs.fr

Uzy Smilansky (co-author), p. 7

Department of Physics of Complex Systems, The Weizmann Institute of Science, Rehovot, 76100 IL, Israel
e-mail: uzy.smilansky@weizmann.ac.il

Hans-Jürgen Stöckmann (co-author), p. 11

Fachbereich Physik der Philipps-Universität Marburg, D-35032 Marburg, Germany
e-mail: stoeckmann@physik.uni-marburg.de

Walter Strunz (co-author), p. 4

Technische Universität Dresden, Faculty of Physics, Institute of Theoretical Physics, 01062 Dresden, Germany
e-mail: walter.strunz@tu-dresden.de

Gregor Tanner (invited speaker), p. 18
School of Mathematical Sciences, University of Nottingham, University Park, Nottingham NG7 2RD, UK
e-mail: gregor.tanner@nottingham.ac.uk

Wojciech Tarnowski (co-author), p. 21
Institute of Theoretical Physics, Jagiellonian University, ul. Łojasiewicza 11, 30-348 Cracow, Poland
e-mail: rumcajs7777@gmail.com

Juzar Thingna (co-author), p. 2
Center for Theoretical Physics of Complex Systems (PCS), Institute for Basic Science (IBS) , Expo-ro 55, Yuseong-gu, Daejeon 34126, South Korea
e-mail: juzar18@gmail.com

Bart van Tiggelen (invited speaker), p. 19
Laboratoire de Physique et Modélisation des Milieux Condensés UMR 5493, Maison des Magistères CNRS, 25 avenue des Martyrs, BP166, 38042 Grenoble Cedex, France
e-mail: bart.van-tiggelen@grenoble.cnrs.fr

Carlos Leonardo Viviescas Ramirez (co-author), p. 4
Departamento de Fisica, Universidad Naional de Colombia, Ciudad Universitaria, Cra. 30 No. 45-03, 111321 Bogota D.C., Colombia
e-mail: clviviescasr@unal.edu.co

Jerzy Wrochna
Institute of Physics, Polish Academy of Sciences, Al. Lotników 32/46, 02-668 Warsaw, Poland
e-mail: wrochna@ifpan.edu.pl

Igor Yusipov (co-author), p. 21
Mathematical Center, Lobachevski State University of Nizhni Novgorod, pr. Gagarina 23, Nizhnii Novgorod 603950, Russia
e-mail: yusipov.igor@gmail.com

Jakub Zakrzewski (invited speaker), p. 20
Institute of Theoretical Physics, Jagiellonian University, ul. Łojasiewicza 11, 30-348 Cracow, Poland
e-mail: jakub.zakrzewski@uj.edu.pl

Weihua Zhang (co-author), p. 3

Theoretical Lanzhou Center for Theoretical Physics and the Gansu Provisional Key Laboratory of Theoretical Physics, Lanzhou University, 222 South Tianshui Road, Lanzhou, Gansu 730000, China
e-mail: zhangwh18@lzu.edu.cn

Karol Życzkowski (invited speaker), p. 21

Institute of Theoretical Physics, Jagiellonian University, ul. Łojasiewicza 11,
30-348 Kraków, Poland and Center for Theoretical Physics PAS, Al. Lotników 32/46, 02-668 Warsaw, Poland
e-mail: karol.zyczkowski@uj.edu.pl

PROGRAMME (Central European Summer Time, Warsaw)

Thursday, May 27

9:50–10:00	**Leszek Sirko** (Warsaw, Poland) Opening
	INVITED TALKS
10:00–10:30	**Thomas Guhr** (Duisburg, Germany) Non-stationarity and generic features in complex systems
10:30–11:00	**Barbara Dietz** (Lanzhou, China) Microwave photonic crystals, graphene- and honome-billiards withthreefold symmetry: a comparison with nonrelativistic and relativistic quantum billiards
11:00–11:30	**Yan Fyodorov** (London, UK) Eigenfunction non-orthogonality in a single-channel chaotic scattering: non-perturbative RMT results
11:30–12:00	**Karol Życzkowski** (Cracow and Warsaw, Poland) Random generators of Markovian evolution: a quantum-classical transition by superdecoherence
12:00–13:00	coffee break
12:30–13:00	**Bart van Tiggelen** (Grenoble, France) Does longitudinal light prevent Anderson localization?
13:00–13:30	**Jakub Zakrzewski** (Cracow, Poland) Many-body localization without disorder
13:30–14:00	**Arkadiusz Orłowski** (Warsaw, Poland) Simple approach to multiple scattering of waves from nontrivial media
14:00–14:30	**Boris Gutkin** (Holon, Israel) Coupled cat maps as a toy model of many body quantum chaos
14:30–15:30	lunch break
15:30–16:00	**Steven M. Anlage** (College Park, USA) Generalization of Wigner time delay to sub-unitary scattering systems
16:00–16:30	**Ulrich Kuhl** (Nice, France) Microwave studies of the three chiral ensembles in chains of coupled dielectric resonators
16:30–17:00	**Rafael Méndez** (Morelos, Mexico) Emulating π orbitals in aromatic molecules using elastic waves: borazine
17:00–17:30	**Thomas Dittrich** (Bogota, Colombia) Quantum chaos and quantum measurement – entropy production vs. unitary quantum dynamics

PROGRAMME (Central European Summer Time, Warsaw)

Friday, May 28

	INVITED TALKS
10:00–10:30	**Liang Huang** (Lanzhou, China) Quantization of states in complex soft-wall quantum billiards
10:30–11:00	**Gregor Tanner** (Nottingham, UK) Quantum searching on Markov chains
11:00–11:30	**Sven Gnutzmann** (Nottingham, UK) The trace formula for quantum graphs with piecewise constant potentials and multi-mode quantum graphs
11:30–12:00	**Tomaž Prosen** (Ljubljana, Slovenia) Exactly solved models of chaotic many-body dynamics
12:00–13:00	coffee break
12:30–13:00	**Pavel Kurasov** (Stockholm, Sweden) On isospectral metric graphs
13:00–13:30	**Jiři Lipovský** (Hradec Králové, Czechia) Graphs with preferred-orientation coupling and their spectral properties
13:30–14:00	**Sergey Denisov** (Oslo, Norway) Dissipative quantum chaos in Floquet systems
14:00–14:30	**Michał Ławniczak** (Warsaw, Poland) Euler characteristic of graphs and Fermi golden rule
14:30–15:30	lunch break
15:30–17:00	POSTER SESSION and CHAT TIME
17:00–17:10	Closing remarks