Novel targets and spectroscopic results for nanofusion experiments

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I present new developments in nanofusion, including recent results on crater analysis upon laser matter interaction, proton energy distribution based on Thomson parabola measurements and the hunt for detecting remnant alpha particles from the $p+^{11}B$ fusion reaction.

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Odtis vezanih elektronskih parov v kotno ločljivi dvo-elektronski koincidenčni fotoemisiji

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Analizirali smo eno-elektronsko spektralno funkcijo v Hubbard Holsteinovem modelu pri majhnem dopiranju z uporabo renormalizacijske grupe in variacijskih metod točne diagonalizacije. Spreminjanje elektronsko-fononske sklopitve in Coulombskega odboja pokaže razliko med tekočino polaronov in bipolaronov: pri polaronski tekočini spektralna gostota sega do Fermijeve energije, pri bipolaronih pa se pojavi vrzel, določena z energijo vezave bipolarona. To nakazuje, da bi kotno ločljiva fotoemisijska spektroskopija lahko razkrila tekočine predoblikovanih elektronskih parov. Pokazali smo tudi, da bipolaronsko tekočino dobro opiše model bozonov s trdo sredico [1]. Izračunali smo tudi spektralno gostoto dvoelektronske koincidenčne fotoemisije na podlagi istega modela. Spektralna gostota se izkaže kot dober približek intenzitete 2e-ARPES procesov. Signal iz istega para je šibkejši, a ločen pri nižjih energijah ter ima značilno momentno odvisnost z drugačno simetrijo kot signal iz različnih parov. Te značilnosti so posledica ohranitve energije in momenta in zato splošne za vse modele z elektronsko bozonsko sklopitvijo. Njihova eksperimentalna potrditev bi dokazala obstoj parov ter omogočila razlikovanje med koherentnimi (superprevodnimi) in nekoherentnimi stanji [2].

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Signature of preformed pairs in angle-resolved two-electron coincidence photoemission

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We use density matrix renormalization group (DMRG) and variational exact diagonalization (VED) to compute the single-electron removal spectral weight of the Hubbard–Holstein model at low electron densities. By tuning electron–phonon coupling and Hubbard repulsion, we distinguish between polaron and bipolaron liquids: the former shows spectral weight up to the Fermi energy, as expected for a metal, while the latter exhibits a gap set by the bipolaron binding energy, despite also being metallic. This suggests that angle-resolved photoemission spectroscopy could identify liquids of preformed pairs. We further show that the bipolaron liquid can be approximated by a gas of hard-core bosons in momentum space [1]. For the two-electron coincidence removal spectrum, calculated with VED from the two-electron ground state, the intensity provides a proxy for 2e-ARPES. The weaker signal from two electrons emitted from the same pair is separated in energy (lower binding energy) and shows distinct momentum symmetry compared to electrons from different pairs. These fingerprints arise from energy and momentum conservation, making them generic to electron–boson models with pairing. Their observation would confirm the existence of pairs and allow one to distinguish coherent (superconducting) from incoherent ones [2].

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Singularity analysis of chaos in nonlinear dynamical systems

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In the early years of the 20th century, the French Mathematician Paul Painlevé and coworkers identified 50 ordinary differential equations (ODEs) of 2nd order as "solvable," because their solutions have only poles, as movable (initial condition dependent) singularities and are hence single-valued in the complex t-plane (t being the independent variable). Some 40 years ago, this approach of "singularity analysis" was extended to differential equations which possess solutions that are infinitely sheeted in the time domain and chaotic in the sense of Mel'nikov. In this talk, I will review, in a pedagogical way, some work I had done in the 1980's and 90's in a direction which led to several interesting results of what I would call *singularity analysis of chaotic dynamical systems in complex time.*

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Entanglement on the attosecond scale

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Exploration of multi-electron dynamics driven by strong and ultrashort high-frequency laser pulses has come into reach with the advent of novel light sources such as HHG and XFEL sources. In this nonlinear response regime photon-atom interactions display novel features qualitatively fundamentally different from those in the standard perturbative regime of Einstein's photoelectric effect. These features include the suppression of ionization by atomic stabilization [1,2,3], Autler-Townes splittings [5,6] and inter-electronic coherence transfer and entanglement [6,7]. By fully ab-initio simulations for helium in a strong XUV field we could demonstrate that inter-electronic coherence and orbital entanglement can be controlled on the ultrashort attosecond time scale. We predict their observability through the atomic time delay of photoemission.

* Work in collaboration with Wei-Chao Jiang, Yong-Kang Fang, Stefan Donsa, Iva Brezinova, and Ling-You Peng.

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Classical statistical properties of the quantum electrodynamical Fermi model

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The inability of classical physics to account for the experimentally observed fre- quency spectrum of blackbody radiation is at the origin of the quantum theory. In spite of desperate attempts, the falloff of the blackbody curve at high frequencies could not be explained by classical mechanics.

Here we discuss the properties of the black- body spectrum by direct numerical solution of the classical equations of motion of a system which is a generalization of a model introduced by Fermi in 1932. More precisely, we consider the classical radiation field generated by an electron interacting with N neutral particles inside a cubic box and we numerically integrate the coupled Newton Maxwell equations. Therefore our approach does not rely on any statistical assumption.

The model we consider is chaotic and exponentially unstable. Here we discuss its classical statistical properties at the light of the predictions of classical thermodynamics, i.e. the Stefan-Boltzmann law and the Wien law.

The present work is a preliminary step before addressing ergodicity in quantum field theories. This will require a nontrivial extension of concepts and tools recently developed for the investigation of thermalization and localization in many-body quantum systems.

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Finite-time classical-quantum correspondence in mixed systems

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I will briefly introduce the correspondence between finite-time dynamical behavior and quantum properties on the energy shell at finite energies, and present their corresponding relationships. I will then explore how, within pseudo-integrable systems, the finite-time classical dynamics can be used to understand the spectral statistics of energy levels at different energies. We expect these findings to extend to mixed systems as well, and we present supporting numerical results to advance our understanding of spectral statistics in such systems.

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String Theory, Geometry and Quantum Field Theory

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In the past decades, String Theory has emerged as the prime candidate for the unification of particle physics with quantum gravity. It has shed light on important fundamental questions of theoretical physics, such as the microscopic structure of black holes and the geometric origin of particle physics. We focus on the important geometric role that branes, extended objects in String Theory play in deriving the Standard Model of particle physics. We further highlight developments in deriving particle physics from F-theory, a geometric domain of String Theory at finite string coupling, and systematic exploration of the landscape of the (quadrillion) Standard Models with three families of quarks and leptons. Time permitting, we also point out recent insights into the geometric origin of higher symmetry structures for quantum field theories derived from String Theory.

Ruelle-Pollicottove resonance iz trunkirane dinamike operatorjev v difuzivnih diskretnih mnogodelčnih sistemih

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Korelacijske funkcije lokalnih opazljivk karakterizirajo dinamiko fizikalnih sistemov. V primeru močno kaotičnih sistemov brez ohranitvenih zakonov pričakujemo, da pojemajo eksponentno v času za poljubno fizikalno opazljivko, pri čemer najpočasnejši hitrosti razpadanja pravimo Ruelle-Pollicottova resonanca. Ruelle-Pollicottove resonance so bile v preteklosti študirane predvsem v klasičnih in semiklasičnih sistemih, nedavno pa so zanimive v kontekstu mnogodelčnih kvantnih sistemov, še posebej v kvantnih vezjih – poenostavljenih modelih generične mnogodelčne kvantne dinamike.

V našem delu numerično določimo Ruelle-Pollicottove resonance kvantnih vezij, ki ustrezajo vodilni lastni vrednosti trunkiranega propagatorja opazljivk. Ta metoda je bila v preteklosti uporabljena za določitev relaksacijskega časa sistemov brez ohranitvenih zakonov, mi pa pokažemo [1], da se lahko uporabi za izluščenje fenomenoloških transportnih konstant v sistemih z U(1) ohranjeno količino. Zaradi subeksponentnega pojemanja korelacijskih funkcij s transportom povezanih opazljivk v takšnih sistemih ima spekter trunkiranega propagatorja kontinuue lastnih vrednosti. Vodilni kontinuum pri difuzivnih kubitnih vezjih z ohranjeno magnetizacijo ima Gaussovsko kvazi-momentno odvisnost in je odgovoren za difuzivni transport magnetizacije, kar nam omogoča numerično ekstrakcijo spinske difuzijske konstante. Pričakujemo, da predstavljeni zaključki veljajo za generične sisteme z natanko eno U(1) ohranjeno količino.

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Ruelle-Pollicott resonances from truncated operator dynamics in diffusive discrete many-body systems

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Correlation functions of local observables characterize the dynamics of physical systems. For strongly chaotic systems without conservation laws, they are expected to decay exponentially with time for any physical observable, the slowest decay rate being the Ruelle-Pollicott resonance. While Ruelle-Pollicott resonances have previously been studied mainly for classical or semiclassical systems, interest has recently shifted to many-body quantum systems, in particular to quantum circuits – toy models of generic many-body quantum dynamics.

In our work, we numerically calculate the Ruelle-Pollicott resonances of quantum circuits, which correspond to the leading eigenvalues of the truncated propagator of observables. While this method is known to predict the relaxation time of systems without conservation laws, we show [1] it also gives access to phenomenological transport constants in systems with a U(1) conserved quantity. Due to the non-exponential decay of correlation functions of transport-related observables in such systems, the spectrum of the truncated propagator contains continuums of eigenvalues. For diffusive magnetization-conserving qubit circuits, the leading continuum has a Gaussian quasi-momentum dependence and governs the diffusive transport of magnetization, allowing the numerical extraction of the spin diffusion constant. The presented conclusions are expected to hold for generic systems with exactly one U(1) conserved quantity.

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Resonance chains in planetary systems

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In the Jupiter-system with its numerous moons there are four of them even visible without a telescope. The three innermost ones namely Io (P=1.77d) Europa (P=3.55d) and Ganymede(P=7.15) are caught in a special 1:2:4 Mean Motion Resonance! This so called Laplace Resonance was and is a permanent topic for research in Celestial Mechanics. In our study we tackle the problem from the analytical side but also from the numerical side with extensive numerical integrations. Our interest was to find out the necessary masses of the three bodies to fulfill the requirements of stability for hundreds of thousand years. This question is of special interest because out of the thousands of planetary system several hundred host three and more planets where some of them are situated in these resonance chains.

Od Hopfove do ničelno-Hopfove bifurkacije: dinamika in integrabilnost tridimenzionalnega memristivnega vezja

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Obravnavamo tridimenzionalni nelinearni model električnega vezja, ki vključuje *memristor*, element s spominsko odvisno prevodnostjo. Sistem izkazuje bogato dinamiko, ki jo analiziramo s pomočjo redukcije na centralni mnogoterosti, povprečenja in Lyapunovovih funkcij. Dokažemo globalno asimptotsko stabilnost ravnovesja v določenih parametričnih območjih ter pojav superkritične Hopfove in ničelno-Hopfove bifurkacije, pri čemer nastane stabilen limitni cikel. Poleg tega identificiramo več tipov integralov gibanja (racionalni, polinomski, Liouvillov), ki omogočajo invariantno razslojevanje faznega prostora. Rezultati kažejo, da se iz šibkega fokusa lahko odcepita največ dva limitna cikla ter razkrivajo povezavo med integrabilnostjo in oscilacijami v memristivnih vezjih.

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From Hopf to Zero-Hopf: Dynamics and Integrability in a Three-Dimensional Memristive Circuit

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We investigate a three-dimensional nonlinear circuit model including a memristive element and reveal its rich dynamical structure. The analysis combines center-manifold reduction, averaging theory, and Lyapunov functions to describe the emergence of periodic orbits through Hopf and zero-Hopf bifurcations. We prove global asymptotic stability of the origin for certain parameter domains and show that the equilibrium can lose stability via a supercritical Hopf bifurcation, producing a single stable limit cycle. Furthermore, several types of first integrals (Liouvillian, rational, and polynomial) are identified, allowing the foliation of the phase space by invariant surfaces. The results demonstrate that at most two limit cycles may bifurcate from a weak focus, providing new insights into the interplay between integrability and oscillations in memristive circuit systems.

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Thermalization Universality Classes

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Thermalization of closed many body systems is at the heart of fundamental quantum concepts like many body localization, eigenstate thermalization hypothesis, and quantum computers since several decades. More recently it also entered the world of classical many body systems through light propagation in nonlinear photonic multimode waveguides and waveguide networks, relating to such observations as e.g. spatial beam self cleaning.
I will introduce concepts of quantifying thermalization, which are tied up to measuring time scales (aka length scales in photonic wave guide applications). The paradoxical upshot is that easy to measure scales are footing on the concept of ergodicity and may quickly lead to ambiguous non-universal assessments [1-4]. On the other side stands the universal and unambiguous concept of Lyapunov time scales, which are however much harder to be measured experimentally, but can be easily computed [5-9].
I will present results which show that Lyapunov spectra scale in distinct different ways for different classes of systems, depending on the type of weak coupling network between modes of a decoupled limit [5-9]. These results establish for the first time the existence of different thermalization universality classes in many body physics.

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Prehodi staranja in robustnost v heterogenih omrežjih ekscitabilnih oscilatorjev

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Koncept dinamične robustnosti v omrežjih oscilatorjev obravnava sposobnost sklopljenih sistemov, da ohranjajo kolektivno ritmično aktivnost kljub delni izgubi aktivnih elementov ali zunanjim motnjam. Ena ključnih manifestacij tega pojava je t. i. prehod staranja (aging transition), ki sta ga prvotno opisala Daido in Nakanishi v sistemu globalno sklopljenih oscilatorjev z limitnim ciklom, v katerem se je delež neaktivnih oscilatorjev postopno povečeval [1]. Ta prehod pomeni kolektivni premik iz oscilatornega v stacionarno stanje, ko število neaktivnih enot preseže kritično vrednost, kar ponuja uporaben okvir za preučevanje odpornosti oscilatornih omrežij. Medtem ko se je večina zgodnejših raziskav osredotočala zgolj na oscilatorje z limitnim ciklom, so kasnejše študije ta koncept razširile tudi na populacije vzburljivih enot [2,3]. Zaradi bolj zapletene dinamike teh elementov lahko taki sistemi kažejo bogato in neintuivno obnašanje, vključno z abruptnimi in histereznimi prehodi v globalno neaktivno stanje. V tem prispevku predstavljamo sistematično analizo robustnosti omrežij ekscitabilnih oscilatorjev FitzHugh–Nagumo in karakteriziramo pojav prehoda staranja. Primerjamo homogene in heterogene populacije pri različnih shemah sklopitve – od globalno sklopljenih sistemov do kompleksnih omrežnih topologij – ter analiziramo, kako strukturne in dinamične heterogenosti vplivajo na kolektivno stabilnost oscilatornega stanja. Nadalje naslovimo tudi dejstvo, da oscilatorna dinamika posameznih enot v realnih sistemih pogosto presega napovedi preprostih modelov z limitnim ciklom ali ekscitabilnih oscilatorjev. Mnogi naravni sistemi izkazujejo multimodalno aktivnost, za katero so značilne medsebojno odvisne oscilacije na različnih časovnih skalah. V tem kontekstu smo dodatno raziskali prehod staranja v dvoplastnih omrežnih modelih, ki vključujejo dva sklopljena oscilatorna podsistema – enega počasnega in enega hitrega. Naši rezultati razkrivajo, da se lahko prehod staranja v takih hierarhičnih omrežjih bistveno spremeni, saj interakcije med počasno in hitro plastjo vodijo do novih dinamičnih režimov in razširjenih območij delne sinhronije [4]. Naše ugotovitve ne pojasnjujejo le, kako medsebojno delovanje omrežne strukture, heterogenosti oscilatorjev in kompleksnosti interakcij skupaj oblikujejo prehod staranja, temveč tudi prispevajo k boljšemu razumevanju motenj

v delovanju realnih bioloških omrežij, ki so posledica bolezenskih stanj, kot sta sladkorna bolezen in različne nevrodegenerativne motnje.

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Aging transitions and resilience in heterogeneous networks of excitable oscillators

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The concept of dynamic robustness in oscillator networks addresses the capacity of coupled systems to sustain collective rhythmic activity despite partial loss of active elements or external perturbations. One of the key manifestations of this phenomenon is the aging transition, originally reported by Daido and Nakanishi for a system of globally coupled limit-cycle oscillators in which the fraction of inactive oscillators was progressively increased [1]. This transition marks a collective shift from an oscillatory to a stationary state as the number of inactive units crosses a critical threshold, thus providing a useful framework for studying the resilience of oscillatory networks. While the majority of earlier works focused solely on limit-cycle oscillators, subsequent research has extended this concept to populations of excitable units [2,3]. Due to the more intricate dynamics of excitable elements, such systems can exhibit rich and nonintuitive behavior, including abrupt and hysteretic transitions to a globally inactive state under specific coupling configurations. In this contribution, we present a systematic analysis of the robustness of FitzHugh–Nagumo oscillator networks and characterize the emergence of aging transitions. We compare homogeneous and heterogeneous populations under multiple coupling schemes—ranging from globally coupled systems to complex network topologies—and identify how structural and dynamical heterogeneities affect the collective stability of the oscillatory state. Moreover, the oscillatory dynamics of individual units within real-world systems often surpass the predictions of simple limit-cycle or excitable models. Many natural systems display multimodal activity, characterized by interdependent oscillations on different time scales. Motivated by this, we further explore the aging transition in a two-layered network model consisting of two coupled oscillatory subsystems—one slow and the other fast—interacting through interlayer coupling. Our results reveal that the aging transition can be markedly altered in such multilayered networks, where cross-scale interactions between slow and fast layers give rise to novel dynamical regimes and extended regions of partial synchrony [4]. Overall, our findings not only elucidate how the interplay between network structure, os-

cillator heterogeneity, and interaction complexity collectively shapes the aging transition, but also contribute to a deeper understanding of abnormalities in biological network dynamics observed in pathological conditions such as diabetes and various neurodegenerative disorders.

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Spektri perturbacij črnih lukenj in spektralna dualnostna zveza

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Perturbacije črnih lukenj povzročijo nihanja prostor-časa, znana kot gravitacijski valovi. V opazovalni astronomiji lahko danes spektre teh valov merimo z interferometričnimi eksperimenti, kot sta LIGO in VIRGO. V našem približno asimptotsko ravnem vesolju so spektri kvazinormalnih načinov v dveh obstoječih kanalih perturbacij črnih lukenj—vzdolžnem in prečnem—povezani s tako imenovano *izospektralnostjo*. Na tem predavanju bom predstavil novo, rigorozno in univerzalno *spektralno dualnostno zvezo*, ki povezuje spektre kvazinormalnih načinov črnih lukenj v prostorih z negativno kozmološko konstanto. S pomočjo AdS/CFT korespondence ta gravitacijska zveza implicira vrsto netrivialnih omejitev za spektre kvantnih teorij polja, ki izkazujejo S-dualnost (ali dualnost delcev in vrtincev), ter za konformne teorije polja z dvojnoslednimi deformacijami.

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Spectra of black hole perturbations and the spectral duality relation

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Perturbations of black holes generate fluctuations in spacetime known as gravitational waves. In observational astronomy, the spectra of these waves can now be measured through interferometric experiments such as LIGO and VIRGO. In our approximately asymptotically flat universe, the spectra of quasinormal modes in the two existing channels of black hole perturbations—longitudinal and transverse—are related by the so-called *isospectrality* property. In this talk, I will present a new, rigorous, and universal *spectral duality relation* that connects the quasinormal mode spectra of black holes in spacetimes with a negative cosmological constant. Through the AdS/CFT correspondence, this gravitational relation implies a series of nontrivial constraints on the spectra of quantum field theories exhibiting S-duality (or particle–vortex duality), as well as on conformal field theories with double-trace deformations.

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Crows and Traffic Jams

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The guiding principle of statistical physics is to find universal laws for systems with very many degrees of freedom. While a wealth of results is available for physics systems in equilibrium, less is known for nonstationary systems and/or complex systems beyond traditional physics. Here, the focus is on motorway traffic. Based on large–scale data analyses, I will present three new results:
(1) antipersistence and a certain universality in traffic jams
(2) measurement of response functions to study the spreading of traffic jams
(3) robust scaling for the distributions of traveled distances in motorway networks of many countries
What is the role played by the crows? — I will tell you in my talk.

Chaotic billiard lasers

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Chaotic billiard lasers contain two different kinds of nonlinearities separately studied in the research fields of quantum/wave chaos and laser dynamics: nonseparable wave equations with chaotic wave functions due to the deformation of the billiard shape and nonlinear dynamics due to the interaction among lasing modes through the lasing medium. I will explain that the synergistic effect of these two nonlinearities has given rise to a number of interesting phenomena in chaotic billiard lasers.

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Relativistic Quantum Chaos

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Classical-quantum correspondence has been an intriguing issue ever since the beginning of quantum theory. The search for signatures of classically nonintegrable dynamics in quantum systems constitutes the rich and dynamically evolving field of quantum chaos. In this talk, I shall present our efforts, along with many others, to extend the understanding of these features into relativistic quantum systems. I shall mostly focus on the scarring phenomena, discussing the new features due to the relativistic energy-momentum relation, and the new phases in the quantization condition emerging in relativistic quantum systems due to spin and mass. I shall also explain the consequences of these effects for time-reversal symmetry.

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Valčna analiza kot orodje za raziskovanje večskalne dinamike in funkcionalne povezanosti v bioloških sistemih

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Valčna analiza se vedno bolj uveljavlja kot nepogrešljivo orodje pri obdelavi biomedicinskih signalov, saj ponuja zanesljiv okvir za analizo kompleksnih, nestacionarnih signalov, kot so denimo elektroencefalogrami, elektromiogrami, elektrokardiogrami ali laserski dopplerski signali mikrocirkulacije [1,2,3,4]. Za razliko od klasične Fourierjeve analize, ki signale razčleni zgolj na njihove frekvenčne komponente, valčna analiza omogoča hkratno časovno-frekvenčno razčlenitev, kar omogoča zanesljivo zaznavanje prehodnih pojavov in subtilnih variacij, ki so pogosto značilne za fiziološke procese [4,5,6,7].

Predavanje se bo začelo s pregledom temeljnih načel valčne analize, s poudarkom na tem, kako ta pristop razčleni biomedicinske signale v časovnem in frekvenčnem območju ter s tem omogoča zaznavanje in karakterizacijo prehodnih ter večskalnih pojavov v različnih fizioloških sistemih – značilnosti, ki jih s tradicionalnimi spektralnimi metodami pogosto ni mogoče zanesljivo zajeti. Na podlagi teh izhodišč bomo v nadaljevanju obravnavali oscilatorno aktivnost v kompleksnih bioloških sistemih, ki je pogosto modulirana s sovisnimi podsistemi, kar vodi do nastanka multimodalne dinamike. Prepleteni oscilatorni vzorci, ki delujejo na različnih frekvencah, nosijo specifičen funkcionalni pomen in odražajo večplastno organiziranost procesov. Poleg tega oscilatorno obnašanje običajno izhaja tudi iz interakcij med gradniki sistema, ki so funkcionalno ali fizično povezani ter tvorijo kompleksna omrežja dinamične soodvisnosti. Valčna analiza predstavlja učinkovito orodje za preučevanje takšnih sistemov, saj hkrati zajema časovne in spektralne značilnosti ter s tem omogoča razločevanje procesov, ki delujejo na različnih časovnih skalah. Poleg tega je mogoče valčno analizo razširiti tudi na izgradnjo funkcionalnih omrežij, kar omogoča dodaten vpogled v komunikacijo znotraj kompleksnih skupkov medsebojno delujočih enot [8].

V zaključku predavanja bomo kot modelni sistem obravnavali večcelično dinamiko kalcijevih oscilacij v celicah β trebušne slinavke, kjer se celična aktivnost odvija na več časovnih skalah in izhaja iz medcelične sklopitve [9]. Pokazali bomo, kako lahko s pomočjo valčne analize izločimo časovne in frekvenčne kazalce sinhronosti ter zgradimo mreže funkcionalne

povezanosti, ki razkrivajo vzorce usklajenosti in komunikacije znotraj populacij celic β. Predstavljeni metodološki koncept tako povezuje dinamiko posameznih celic z organizacijo na ravni mreže in ponuja vsestranski pristop za raziskovanje kompleksnih bioloških oscilacij.

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Wavelet-Based Approaches for Multiscale Analysis and Functional Connectivity in Complex Biological Systems

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Wavelet analysis has become an increasingly powerful tool in biomedical signal processing, offering a robust framework for analyzing complex, non-stationary signals such as electroencephalograms, electromyograms, electrocardiograms, or laser Doppler microcirculatory signals [1,2,3,4]. Unlike classical Fourier analysis, which represents signals solely in terms of frequency content, wavelet analysis enables simultaneous time–frequency decomposition, allowing the identification of transient phenomena and subtle variations characteristic of physiological processes [4,5,6,7].

The talk will begin with a concise overview of the fundamental principles of wavelet analysis, focusing on how this approach decomposes biomedical signals into their time–frequency representations and facilitates the detection and characterization of transient or multi-scale events across different physiological systems—features often inaccessible with traditional spectral tools.

Building on this foundation, we will address how oscillatory activity in complex biological systems is often modulated by multiple intertwined subsystems, giving rise to multimodal dynamics. These superimposed rhythms, operating at distinct frequencies, each carry specific functional significance and reflect the hierarchical organization of underlying processes. Moreover, oscillatory behavior typically arises from interactions among components that are functionally or physically coupled, forming intricate networks of dynamical interdependence. Wavelet analysis provides an effective framework for studying such systems, as it captures both temporal and spectral characteristics, disentangling processes that operate on different timescales. In addition, wavelet-based approaches can be extended toward constructing functional networks, offering valuable insight into communication within complex ensembles of interacting units [8].

To illustrate these concepts, the talk will finally focus on multicellular calcium dynamics in pancreatic β-cells as a model system, where activity unfolds over multiple temporal scales and emerges from intercellular coupling [9]. We will demonstrate how wavelet analysis can be employed to extract time- and frequency-resolved measures of synchrony and to

construct functional connectivity networks that reveal patterns of coordination and communication across β-cell ensembles. This methodological framework thus bridges single-cell dynamics with network-level organization, offering a versatile approach for probing complex biological oscillations.

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A Microwave Study on Fisher Information Flow

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Information is created when a system is changed. This information can be detected by waves, in our case by electromagnetic waves, created and measured far from the creation point. I will shortly introduce Fisher information and then show how the information transport can be visualized using the Fisher information flow, similar to the Poynting vector showing the energy flow. The main focus of the talk will be on the experimental realization in a microwave waveguide supporting 4 transporting modes [1,2].

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Vmesne spektralne statistike racionalnih trikotniških kvantnih biljardov

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Trikotni biljard, katerega koti so racionalni večkratniki π, je eden najpreprostejših primerov psevdointegrabilnih modelov z zanimivimi klasičnimi in kvantnimi lastnostmi. Predstavil bom obsežno numerično študijo spektralne statistike osmih kvantiziranih racionalnih trikotnikov, od katerih šest pripada družini pravokotnih Veechovih trikotnikov, dva pa sta topokotna racionalna trikotnika. Za vsak trikotnik so bili izračunani veliki spektralni vzorci do milijona energijskih ravni, kar omogoča določitev njihove spektralne statistike z veliko natančnostjo. Pokazal bom, da so statistike vmesnega tipa in imajo nekatere lastnosti kaotičnih sistemov, kot je odboj ravni, in nekatere lastnosti integrabilnih sistemov, kot so eksponentni repi porazdelitev razmikov ravni. Druga značilnost vmesne spektralne statistike je končna vrednost spektralne stisljivosti. Podrobno bomo analizirali statistike kratkega dosega, kot so porazdelitve razmikov med ravnmi, in statistike dolgega dosega, kot so varianca števila nivojev in spektralni oblikovni faktorji. Pokazal bom, da se numeričnimi podatki odlično ujemajo z modelom gama porazdelitev.

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Intermediate spectral statistics of rational triangular quantum billiards

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Triangular billiards whose angles are rational multiples of π are one of the simplest examples of pseudo-integrable models with intriguing classical and quantum properties. I shall present an extensive numerical study of spectral statistics of eight quantized rational triangles, six belonging to the family of right-angled Veech triangles and two obtuse rational triangles. Large spectral samples of up to one million energy levels were calculated for each triangle, which permits to determine their spectral statistics with great accuracy. I will demonstrate that they are of the intermediate type, sharing some features with chaotic systems, like level repulsion and some with integrable systems, like exponential tails of the level spacing distributions. Another distinctive feature of intermediate spectral statistics is a finite value of the level compressibility. The short range statistics such as the level spacing distributions, and long-range statistics such as the number variance and spectral form factors will be analyzed in detail. I will show that there is excellent agreement between the numerical data and the model of gamma distributions.

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From Complex Systems and AI to Emerging Technologies

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Permanently increasing sets of data (Big Data) in machine learning are not sufficient to provide reliable and accurate artificial intelligence. What is needed are AI-methods based and regulated by models of physical sciences. That is especially true for the safety relevant complex infrastructure which is explored in engineering (e.g., bridges, transport, traffic). Therefore, since many years, my research is dedicated to the foundations of complex systems and intelligent technologies. However, digitalisation requires a huge amount of energy. Therefore, classic digitalisation and artificial intelligence are examined together with future technologies such as neuromorphic computing (based on the energy-saving mode of natural brains with analog computing) as well as quantum computers and quantum technology. Digital and analogue technologies must then be integrated in a 'hybrid' IT and AI so that this innovation portfolio, together with the energy issue, is also geared towards a sustainable future of mankind.

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Integrabilnost družine štiridimenzionalnih kvadratnih sistemov

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Preučujemo lokalno integrabilnost družine štiridimenzionalnih kvadratnih sistemov z resonanco $(1 : -1 : 2 : -2)$. V članku raziskujemo formalne in analitične prve integrale z uporabo teorije Poincaré-Dulacovih normalnih form. Natančneje, analiziramo pogoje za integrabilnost družine štiridimenzionalnih polinomskih sistemov ter podamo potrebne pogoje za obstoj prvih integralov v tej družini. Poleg tega pokažemo, da so nekateri izmed teh pogojev tudi zadostni. Naš pristop temelji na izračunih normalnih form do osmega reda, s katerimi sistematično določimo pogoje integrabilnosti. Za dokaz zadostnosti uporabimo metode, kot so Darbouxova teorija, tehnike linearizacije in teorija inverznih Jakobijevih multiplikatorjev.

To je skupno delo z Xinhaojem Hujem, Valerijem Romanovskijem in Yilei Tangovo.

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Integrability of a family of four dimensional quadratic systems

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We study the local integrability of a family of four-dimensional quadratic systems with $(1 : -1 : 2 : -2)$ resonance and explore formal and analytic first integrals using Poincaré-Dulac normal forms. Specifically, we analyze the integrability conditions for a family of four-dimensional polynomial systems and establish necessary conditions for the existence of first integrals in the family. Furthermore, we demonstrate that certain conditions are also sufficient. Our approach uses normal form computations up to order eight to determine integrability conditions. To prove the sufficiency, we use methods such as Darboux theory, linearizability techniques and the theory of the inverse Jacobian multipliers.

This is a joint work with Xinhao Hu, Valery Romanovski and Yilei Tang.

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Fredholm Solutions in One-Dimensional Quantum Systems

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We obtain an exact, absolutely convergent solution of t he one-dimensional Schrödinger equation for arbitrary potentials, with each term carrying a clear path/ray picture. By the theory of Fredholm integral equations, evaluating $(\mathbb{1} - K)^{-1}$ for the integral operator K should be done via the adjugate–determinant formula rather than by the geometric series $\sum_{n\geq 0} K^n$. For the Bremmer series—which, despite its transparent path picture, is not absolutely convergent—we reorder the terms so that the series becomes absolutely convergent to the correct value while retaining the path picture. The coefficients are sums over pseudo-paths, structures analogous to pseudo-orbits. This framework offers a new perspective on the quantum-classical correspondence.

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Spektralna statistika in lokalizacijske lastnosti C_3-simetričnega biljarda

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Ponovno preučimo spektralno statistiko biljarda z C_3-simetrijo, ki so ga uvedli Dembowski *et al.* [Phys. Rev. E **62**, R4516 (2000)], in ki kaže tako statistiko tipa GOE kot GUE, odvisno od simetrijskega razreda. Z uporabo visokonatančne Beynove metode konturnega integrala za nelinearni Fredholmov problem lastnih vrednosti, ki vključuje vgrajeno ločitev ireducibilnih podprostorov, izračunamo 2×10^5 lastnih vrednosti v vsakem simetrijskem razredu, kar omogoča statistično zanesljive primerjave s teorijo naključnih matrik. Izboljšani spektri jasno pokažejo skladnost med GOE in GUE statistiko ter odpravijo prej opažena odstopanja v dolgosežnih spektralnih korelacijah. Poleg tega analiziramo lokalizacijo lastnih stanj preko porazdelitve lokalizacijskih entropijskih mer, ki sledijo beta porazdelitvi, katere standardni odklon z energijo pada algebrsko, skladno z začetkom kvantne ergodičnosti, kot jo opisuje Schnirelmanov izrek.

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Spectral statistics and Localization properties of a C_3-Symmetric Billiard

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We revisit the spectral statistics of the C_3-symmetric billiard introduced by Dembowski *et al.* [Phys. Rev. E **62**, R4516 (2000)], which exhibits both GOE and GUE statistics depending on the symmetry block. Using the high-precision Beyn's contour-integral method for the nonlinear Fredholm eigenvalue problem with built-in separation of irreducible subspaces, we compute 2×10^5 eigenvalues in each symmetry subspace, enabling statistically meaningful comparisons with random-matrix theory. The improved spectra reveal clear GOE–GUE correspondence and resolve previously observed deviations in long-range spectral correlations. Furthermore, we analyze eigenstate localization through the distribution of entropy measures, which follow a beta distribution whose standard deviation decays algebraically with energy, consistent with the onset of quantum ergodicity as described by Schnirelman's theorem.

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Relativistic Description of Hadron Resonances

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In most theoretical approaches to hadron resonances these states have been described as excited bound states rather than as genuine resonances, taking into account their decay properties explicitly. As a consequence, essential properties, such as the decay widths, have usually not been predicted reliably. Take as an example the nucleon spectrum, where we have only one ground state N, the proton p, with a mass corresponding to a real eigenvalue, whereas all other states in the spectrum, the excitations N^*, are characterised by resonance energies and decay widths (equivalent to complex eigenvalues).

In a quantum Hamiltonian approach describing hadrons as consisting of some fundamental constituents (quarks), a proper description of resonances exceeds a Hermitean theory in a pre-defined Hilbert space. Either one adheres to a non-Hermitean quantum theory or extends the Hilbert space to comprise further degrees of freedom explicitly, i.e. the products of open decay channels. In addition a relativistic theory respecting Poincaré invariance is mandatory for hadrons. Especially Lorentz boost effects must be taken into account in order to arrive at covariant observables such as electromagnetic form factors, axial form factors, and notably decay widths. Concerning the latter, in addition a proper treatment of de-/confinement (hadronization) poses a respectable challenge.

In order to approach these problems on solid theoretical grounds we have resorted to a fully Poincaré-invariant description of hadron resonances by a relativistic multi-channel constituent-quark model based on an extended invariant mass operator. Thereby we aim at a relativistic description of ground and resonant states in a consistent manner.

We have first considered the N-Δ system. Given the experimental fact that the Δ decay width is practically constituted only by the π-N decay channel, it should suffice to consider a coupled-channels invariant mass operator incorporating only N, Δ, and π-N degrees of freedom. I shall present results from such an approach for the N ground state mass, the Δ resonance energy, and the Δ decay width. They are promising for extending corresponding studies to higher excitations such as the N^* Roper resonance, with even more open decay channels, and also the wealth of further hadron excitation spectra.

Primerjava obratovalnih stroškov klasičnih 19 sedežnih letal in 19 sedežnih letal na vodikove gorivne celice

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Prehod v trajnostno letalstvo zahteva inovativne rešitve, ki lahko bistveno zmanjšajo emisije toplogrednih plinov, hkrati pa ostanejo ekonomsko izvedljive. Ena izmed posebej obetavnih možnosti je uporaba 19-sedežnih letal na vodikov pogon, ki združujejo ekološke prednosti z regulativno ugodnostjo: letala z manj kot 19 potniki so namreč izvzeta iz najzahtevnejših postopkov certificiranja, ki veljajo za večja potniška letala. Zaradi tega predstavljajo idealne kandidate za zgodnjo uvedbo vodikovih tehnologij v regionalnem letalstvu. V predavanju bomo najprej predstavili trenutno stanje 19-sedežnih letal, vključno z glavnimi operaterji in sestavo flot, da bi vzpostavili kontekst za prihodnjo integracijo vodika. Nato bomo prikazali primerjalno analizo neposrednih obratovalnih stroškov (DOC) med letali na konvencionalni kerozin in letali z gorivnimi celicami na vodik. Analiza temelji na modelu, ki napoveduje razvoj obratovalnih stroškov v obdobju med letoma 2030 in 2050. Glede na zgodnjo fazo razvoja vodikove tehnologije analiza vključuje tako optimistične kot pesimistične scenarije razvoja ter različne stopnje rasti cen kerozina, s čimer zajame negotovosti prihodnjih razmer. Predstavljen bo tudi študijski primer hrvaškega letalskega prevoznika Trade Air, ki prikazuje, kako bi se letala na vodikov pogon lahko vključila v obstoječe regionalne operacije. Rezultati kažejo, da bi 19-sedežna letala z gorivnimi celicami lahko v naslednjih desetletjih postala konkurenčna in trajnostna alternativa konvencionalnemu letalstvu. V zaključku bomo obravnavali še možne politične instrumente in strateške ukrepe, ki bi lahko pospešili prehod k regionalnemu zračnemu prometu na osnovi vodika.

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Comparative analysis of the operating costs of conventional 19-seat aircraft and 19-seat hydrogen fuel cell aircraft

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The transition to sustainable aviation calls for innovative solutions that can substantially reduce greenhouse gas emissions while remaining economically viable. One particularly promising approach is the use of 19-seat hydrogen-powered aircraft, which combine ecological advantages with a regulatory benefit: aircraft below the 19-passenger threshold are exempt from the most demanding certification procedures required for larger airliners. This makes them ideal candidates for the early implementation of hydrogen technologies in regional aviation. In this talk, we will first outline the current landscape of 19-seat aircraft, including the main operators and fleet composition, to set the context for future hydrogen integration. We will then present a comparative analysis of direct operating costs (DOC) between conventional kerosene-powered and hydrogen fuel cell aircraft, using a model developed to project DOC evolution from 2030 to 2050. Given the early stage of hydrogen technology, the analysis considers both optimistic and pessimistic development scenarios, as well as high and low kerosene price growth rates, to capture future uncertainties. A case study of the Croatian airline Trade Air will be presented, demonstrating how hydrogen aircraft could fit into existing regional operations. The results show that 19-seat hydrogen fuel cell aircraft can become a competitive and sustainable alternative to conventional aviation within the next few decades. The talk will also discuss potential policy instruments and strategic measures that could accelerate the transition toward hydrogen-based regional air transport.

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Točno rešljivi modeli mnogodelčnega kvantnega kaosa

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Razpravljal bom o problemu nepričakovane učinkovitosti teorije naključnih matrik pri opisu spektralnih fluktuacij v mnogodelčcnih kvantnih sistemih na mrežah. Nedavno smo identificirali razred lokalno interagirajočih spinskih sistemov, pri katerem smo lahko dokazali, da se spektralni oblikovni faktor, ki predstavlja splošno dvo-točkovno spektralno statistiko, v termodinamski limiti ujema s cirkularnimi anambli teorije naključnih matrik. V teh sistemih je mogoče tudi analitično izračunati prostorsko-časovne korelacijske funkcije lokalnih opazljivk in nekatere mere dinamične kompleksnosti. Ti tako imenovani dvojno unitarni sistemi vključujejo integrabilne, neergodične, ergodične in – splošno gledano – (maksimalno) kaotične primere. Po uvedbi in diskusiji osnovnih lastnosti takšnih dvojno unitarnih Floquetovih kvantnih vezij bom nakazal, da so korelacijske funkcije teh modelov na splošno perturbativno stabilne glede na kršitev dvojne unitarosti.

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Exactly solved models of many-body quantum chaos

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I will discuss the problem of unreasonable effectiveness of random matrix theory for description of spectral fluctuations in extended quantum lattice systems. A class of locally interacting spin systems has been recently identified where the spectral form factor is proven to match with gaussian or circular ensembles of random matrix theory, and where spatiotemporal correlation functions of local observables as well as some measures of dynamical complexity can be calculated analytically. These, so-called dual unitary systems, include integrable, non-ergodic, ergodic, and generically, (maximally) chaotic cases. After reviewing the basic properties of dual unitary Floquet circuits, I will argue that correlation functions of these models are generally perturbatively stable with respect to breaking dual-unitarity, and describe a simple result within this framework.

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CUDOs and their impact (literal and figurative)

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Where is the meteorite? Just maybe it went into the depth of Earth: we consider compact ultra-dense objects (CUDO) meteors made predominantly of ultra dense matter such as dark matter bound objects, micro black holes, even ultra-superhavy elements. For such exotic impactors each planet or moon is a macroscopic detector accumulating CUDO impact signature over geological time scale. Only a fraction of the CUDO kinetic energy is damaging the entry/exit surface regions since CUDOs high density of gravitating matter assures surface-penetrating puncture – shot into, and even through, a moon or the planet. CUDOs could be the origin of hot-spots (random location shield volcanoes that are fed from depth of Earth across solid crust). If CUDOs are today at rest in the Cosmological frame their relative high speed allows to consider shot through solar bodies. Asteroid belt could harbor captured CUDOs with 31 Polyhymnia a high density (75g/cc!) candidate and the "egg in space" offering another suspect case. In this lecture I will show many fascinating images and recount facts that could all be explained with this hypothesis once we "see" a first CUDO.

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Kvantni kaos v mešanih sistemih: Potenčno pojemanje deleža mešanih stanj v semiklasični limiti II in WKB metoda do vseh redov

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V prvem delu predavanja bom podal novo semiempirično evidenco za veljavnost principa enakomerne semiklasične kondenzacije Wignerjevih funkcij (ali Husimijevih funkcij) (Principle of Uniform Semiclassical Condensation- PUSC): v striktni semiklasični limiti pojenja delež mešanih stanj v mešanih kvantnih hamiltonskih sistemih potenčno, preživijo le bodisi povsem regularna stanja, ali kaotična stanja. Ta evidenca je sedaj trdno podprta v številnih modelskih sistemih: različni biljardi, kvantna brcana vrtavka, kvantni rotor, Dickejev model, 3-delčni FPUT sistem (Henon-Heilesov hamiltonjan), in drugi.

V drugem delu predavanja pa bom predstavil metodo WKB do vseh redov, ki je primerna za reševanje lastnih energij poljubnih enodimenzionalnih potencialov. V članku z Valerijem Romanovskijem 2000 sva uspela rešiti rekurzijsko WKB formulo eksaktno do vseh redov, kar ni trivialno, saj je n-ti člen potenčnega razvoja po $\hbar$ odvisen od vseh prejšnjih redov, in sicer na nelinearen način. Pokazala sva, da vrsta v primeru vseh rešljivih potencialov konvergira, seštevek pa natančno poda eksaktne vrednosti. Ta prelomni rezultat odpira nova ključna vprašanja v okviru WKB teorije.

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Quantum chaos in mixed-type systems: Power-law decay of the fraction of mixed eigenstates in the semiclassical limit II and WKB method to all orders

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In the first part of my talk I shall present new semiempirical evidence for the validity of the Principle of Uniform Semiclassical Condensation (PUSC) of Wigner (or Husimi) functions: In the strict semiclassical limit the relative fraction of mixed-type states in mixed-type systems decays as a power law, and only purely regular or purely chaotic eigenstates survive. This evidence is now strongly supported in numerous model systems: various billards, quantum kicked top, quantum kicked rotator, Dicke model, 3-particle FPUT system (Henon-Heiles Hamiltonian), and others.

In the second part of my talk I shall present the WKB method to all orders, which is suitable for solving the eigenenergies of arbitrary one-dimensional potentials. In the paper with Valery Romanovski 2000 we have succeeded to exactly solve WKB recursion formula to all orders, which is not trivial, as the n-th term in the $\hbar$ power expansion depends on all the previous terms in a nonlinear way. We have shown that the series converges in all cases of solvable potentials, and its summation yields precisely the exact eigenvalues. This groundbreaking result raises new key questions of the WKB theory.

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Normalne forme sistemov NDE

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Obravnavamo transformacije lokalnih analitičnih oziroma formalnih vektorskih polj v Poincaré-Dulacovo normalno formo ter konvergenco takih transformacij. Najprej omenimo pristop A. D. Bruno k formalni normalizaciji [1] in rezultate o konvergenci ob prisotnosti določenih (poenostavljenih) različic Brunovega "Pogoja A". V nadalje opredelimo obsežno družino sistemov, ki zadoščajo Brunovemu diofantskemu "Pogoju omega" . Nato pokažemo, kako se Brunov pristop naravno razširi v elementaren dokaz izreka o sočasni normalizaciji za abelove Liejeve algebre vektorskih polj, ki jih je podal L. Stolovitch [2]. Obravnavana je tudi povezava med konvergenco in integrabilnostjo.

Predavanje temelji na nedavnem skupnem delu s Sebastianom Walcherjem [3].

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Normal forms of systems of ODEs

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We discuss transformations of local analytic, or formal, vector fields to Poincare-Dulac normal form, and the convergence of such transformations. We first mention A.D. Bruno's approach to formal normalization [1], as well as convergence results in presence of certain (simplified) versions of Bruno's "Condition A", and along the way we also identify a large class of systems that satisfy Bruno's diophantine "Condition omega". We then proceed to show how Bruno's approach naturally extends to an elementary proof of L. Stolovitch's simultaneous normalization theorem for abelian Lie algebras of vector fields [2]. An interconnection of convergence and integrability is also discussed.

The talk is based on the recent joint work with Sebastian Walcher [3].

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Recent developoments on Ultralong-Range Rydberg Molecules

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A review on the most recent activities in Rydberg molecular physics at the center for optical quantum technologies will be provided. I start out with addressing the exotic properties of ultralong-range Rydberg molecules (ULRM). Trilobite and butterfly states can easily be controlled by weak external electric or magnetic fields. I demonstrate that synthetic dimensions based on quantum numbers can be used to design conical intersections and consequently non-adiabatic interaction effects in the spectra of ULRMs. Ultrafast decay processes are a consequence of these intersections. Quenches of external fields then lead to a rich rovibrational quantum dynamics of ULRM and it is shown that the ULRM is a self-diffracting molecule. Very recently high precision spectroscopy of trilobite molecules has been performed and we present the theory experimental collaboration results. Last, but not least, we show the non-adiabatic stabilization of those molecules in a regime where an adiabatic approach would predict a fast decay into highly energetic products.

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Coherence Resonance in Excitable Systems and Networks

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Coherence resonance is a counterintuitive phenomenon in nonlinear stochastic systems. It is associated with the constructive role of noise, which leads to a nonmonotonic dependence of the coherence upon noise intensity, i.e., for intermediate values of noise intensity the oscillations in a nonlinear dynamical system are most regular. It was first discovered by Hermann Haken [1], and later studied in various systems ranging from lasers to the brain [2], using nonlinear Langevin equations. Specifically, I will consider laser dynamics [1], semiconductor superlattices [3], coherence-resonance chimeras in neural networks [4], and a socio-economic model for economic cycle dynamics [5]. Coherence resonance can be controlled by time-delayed feedback [6].

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Origin fate map: a simple and efficient numerical tool for analyzing phase space transport

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Following [1], we introduce and apply the origin fate map (OFM) as a powerful tool for the detailed analysis of phase space transport in reactant–product–type systems. These systems, characterized by well-defined initial (reactant) and final (product) states, allow a comprehensive understanding of the underlying manifold dynamics through the backward and forward integration of initial conditions, which are subsequently classified according to their origin and fate. We demonstrate the method using a two-degrees-of-freedom caldera potential with four exit channels. Our results show that the OFM not only reproduces key features identified by classical manifold theory but also reveals finer details, including intricate lobe structures and dynamically significant transitions associated with lobe formation. Overall, the OFM provides a conceptually simple yet highly effective framework, offering broad applicability for both qualitative visualization and quantitative analysis of complex dynamical systems.

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Microwave studies of complex systems

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A review is given on the microwave studies performed in the Marburg quantum chaos group starting from the very beginning about 1990 up to the shut-down two years ago. This includes tests of random matrix theory in chaotic microwave resonators, studies of microwave equivalents of graphene-like structures, a microwave realization of the Hofstadter butterfly, the emission patterns of distorted dielectric resonators, and the generation of freak waves in a lab-size version of the ocean.

Aerodinamika smučarskega skakalca

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V prispevku predstavimo koncept projektiranja smučarske letalnice, ki zagotavlja varne polete. Varno letenje naj bi bilo smiselno oddaljeno od hrbtišča letalnice, sile na skakalca ob doskoku pa naj bi bile čim manjše. Za odgovor, ali letalnica zadostuje tem zahtevam, smo razvili računalniški model aerodinamike skakalca [1], ki na podlagi Reynoldsovo povprečenih Navier-Stokesovh enačb računa sile vzgona in upora med tremi fazami (vzlet, letenje, pristanek) leta. Aerodinamični model je bil zgrajen na podlagi več konfiguracij skakalca in smuči med letom, pridobljenih s skeniranjem geometrije realnih skakalcev. Validacija modela je bila narejena na podlagi primerjave izračunanih krivulj njihovega leta z eksperimentalno merjenimi ter na podlagi primerjave izračunanih sil pri doskoku z meritvami teh sil. Na opisani način sodelujemo pri modifikaciji Planiške letalnice [2], na kateri je bil dosežen trenutno veljaven svetovni rekord 254,5 m, da bo omogočala varne polete do 270 m.

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Sky jumper aerodynamics

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In this paper, we present the concept of designing a ski flying hill to ensure safe flights. Safe flying should not be reasonably far from the ski flying hill's profile, and the forces on the ski jumper during landing should be as small as possible. To determine whether the ski flying hill meets these requirements, we have developed a computational model of the ski jumper's aerodynamics [1], which, based on the Reynolds-averaged Navier-Stokes equations, calculates the lift and drag forces during the three phases (takeoff, flight, and landing) of the flight. The aerodynamic model was built based on several configurations of the ski jumper and skis during flight, obtained from the scanned geometry of a real ski jumper. The model was validated by comparing the calculated flight curves with experimentally measured ones, as well as by comparing the calculated forces during landing with the measured ones. In this manner, we are contributing to the modification of the Planica ski flying hill [2], which currently holds the world record of 254.5 m, to enable safe flights up to 270 m.

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Random waves from Billiards to Fock space Celebrating 25 years of discussions with Hans-Jürgen Stöckmann

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The discovery by Michael Berry of a rigid backbone structure hidden in the apparent randomness of eigenfunctions in quantum systems with few degrees of freedom that display Hamiltonian chaos in their classical limit [1], is a cornestone of the field of quantum chaos [2]. During his prolific carrer, Hans-Huergen Stoeckmann has made key contributions to our understanding of both the theoretical and experimental impact of classical ergodicity in this hidden structure, that manifest in precise and extremely robust statistical signatures starting with the celebrated Bessel-type of amplitude correlation. In this talk I will review the fundamental ideas that became what it is widely known as Berry's Random Wave Model, its extensive benchmarking through the pioneering experiments of the Marburg group where I have the pleasure of being a small contributing part, and the recent encarnations of the model in bosonic Fock space [3] and the Eigenstate Thermalization Hypothesis.

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Skalirna teorija faznih prehodov z zlomom ergodičnosti

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V večini neinteragirajočih kvantnih sistemov skalirna teorija lokalizacije napoveduje enoparametrični potek skaliranja tako v ergodičnem kot tudi v lokaliziranem režimu. Ustrezna skalirna teorija za prelom ergodičnosti v večdelčnih sistemih pa še vedno ni vzpostavljena. V tem delu predstavljamo skalirno teorijo zloma ergodičnosti v interagirajočih sistemih, v kateri divergenca relaksacijskega časa sledi iz Fermijevega zlatega pravila, fluktuacije opazljivk v bližini kritične točke zloma ergodičnosti pa opisuje nedavno uvedeni scenarij pojemajoče ergodičnosti. Pokažemo, da enoparametrično skaliranje na splošno ni zadostno ter da skalirna teorija napoveduje kritični eksponent $\nu = 1$ pri kritični točki zloma ergodičnosti. Predstavljeni teoretični okvir lahko služi kot temelj za razvoj dvoparametričnih skalirnih teorij večdelčnih sistemov.

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Scaling theory of ergodicity breaking transitions

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In most noninteracting quantum systems, the scaling theory of localization predicts one-parameter scaling flow in both ergodic and localized regimes. A corresponding scaling theory of many-body ergodicity breaking is still missing. Here, we introduce a scaling theory of ergodicity breaking in interacting systems, in which the divergent relaxation time follows from the Fermi golden rule, and the observable fluctuations in proximity of the ergodicity breaking critical point are described by the recently introduced fading ergodicity scenario. We argue that, in general, the one-parameter scaling is insufficient, and we show that the scaling theory predicts the critical exponent $\nu = 1$ at the ergodicity breaking critical point. Our theoretical framework may serve as a building block for two-parameter scaling theories of many-body systems.

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Mixed eigenstates of interacting spin-boson systems

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In systems with a mixed phase space [1], a subset of quantum eigenstates exhibits characteristics associated with both regular and chaotic eigenstates [2]. These eigenstates are referred to as mixed eigenstates. A property that mixed eigenstates exhibit is the simultaneous localization of their quasiprobability distributions in both the regular and chaotic regions of phase space. However, the principle of uniform semiclassical condensation (PUSC) of quasiprobability distributions [3] indicates that in the semiclassical limit, the proportion of mixed eigenstates diminishes according to a power law, ultimately resulting in the presence of only regular or chaotic eigenstates. The PUSC has been verified across various types of systems [4], including billiards, driven systems, and spin-boson systems. In this talk, we will review the properties of mixed eigenstates in spin-boson systems featuring one-photon [5] and two-photon [6] interactions. We will emphasize the fundamental differences between the mixed eigenstates arising from these one-photon and two-photon interactions.

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Decoherence of Histories: Chaotic Versus Integrable Systems

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We study the emergence of decoherent histories in isolated systems based on exact numerical integration of the Schrödinger equation for a Heisenberg chain. We reveal that the nature of the system, which we switch from (i) chaotic to (ii) interacting integrable to (iii) non-interacting integrable, strongly impacts decoherence of coarse spin observables. From a finite size scaling law we infer a strong exponential suppression of coherences for (i), a weak exponential suppression for (ii) and no exponential suppression for (iii) on a relevant short (nonequilibrium) time scale. Moreover, for longer times we find stronger decoherence for (i) but the opposite for (ii), hinting even at a possible power-law decay for (ii) at equilibrium time scales. This behaviour is encoded in the multi-time properties of the quantum histories and it can not be explained by environmentally induced decoherence. Our results suggest that chaoticity plays a crucial role in the emergence of classicality in finite size systems.

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Role of long-range interaction in critical quantum metrology

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Long-range interacting quantum systems are useful for improving the performance of various applications of quantum technologies. In this work, we carry out a detailed analysis of how the long-range interaction affects the measurement precision in critical quantum metrology. We focus on the ground state, as it not only provides a theoretical foundation for studying dynamical critical quantum metrology, but also has great potential for practical applications. By employing the paradigmatic model of a Kitaev chain with power-law decaying interaction, we investigate the impacts of long-range interaction on the critical sensing for the scenarios with and without uncertainty in system parameters. We show that the long-range interaction can be used as a valuable resource for enhancing the sensitivity of critical parameter estimation in both scenarios. Our findings not only provide more insights into the features of the long-range interacting systems, but also verify the usefulness of long-range interacting systems in quantum metrology.

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Multifractal Scaling in the Steady State of Dissipative Chaotic Systems

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Open quantum systems governed by Lindblad dynamics can exhibit multifractality in their steady states when the corresponding mean-field dynamics is chaotic, with the phase-space distribution showing genuine multifractal scaling. We conjecture that the fractal dimension of the quantum steady state is directly related to that of the underlying classical strange attractor, thereby establishing a direct correspondence between classical chaotic structures and quantum steady states. Numerical results from the dissipative kicked top and the kicked rotator support this conjecture. Our findings provide a new perspective on the interplay of dissipation, chaos, and multifractality in open quantum systems described by the Lindblad master equations.

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Topološka mehka snov na osnovi nematske disperzije nanoporoznih lupinic

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Kiralni in nekiralni nematski tekoči kristali z dispergiranimi koloidnimi delci ali tesno ograjeni v različnih geometrijah, so dobro poznani primeri topološke mehke snovi. Njihove strukture zaznamujejo stabilni ali metastabilni topološkimi defekti. Disperzija tankih nanoporoznih silicijevih lupinic v nematskem mediju pa omogoča hkratno manipulacijo učinkov koloidov in ograditve. To je mogoče zaradi naključne poroznosti lupinic, ki omogoča nematiku, da zapolni notranjost lupin in oblikuje notranje nematske kapljice z redom, ki ni odvisen od zunanjega nematskega reda. Visoka gostota nanopor daje lupinicam efektivno lahkost. Poleg tega nanometrska hrapavost površine lupin zagotavlja šibko efektivno sidranje nematika na notranji in zunanji površini lupinic, kar povzroča šibkejše elastične med delčne interakcije in posledično manjšo segregacijo takih koloidnih delcev. Fiziko in materialne lastnosti teh fascinantnih disperzij opišemo s fenomenološkim modeliranjem nematske ureditve, ki ga spremljajo optične simulacije povezanih mikroskopskih slik in njihova primerjava z eksperimentalnimi [1]. Ti kompleksni sistemi odpirajo možnosti za nove vrste pametnih oken na osnovi kontroliranega sipanja svetlobe, kjer električno polje lahko nadzira tako nematik v kapljicah kot v okolici. Dodatno, pa lahko silicijeve lupinice s poroznostjo na nanoskali, delujejo tudi kot filter za nanodopante, kar omogoča obstoja več domenskega sistema, v katerem so posamezne domene, tj. kapljice, čistega nematičnega materiala razpršene v okolju dopiranega nematičnega materiala, kar omogoča njihovo ločeno manipuliranje z zunanjimi polji.

Študija je bila izvedena v sodelovanju s Simonom Čoparjem in tajvanskimi eksperimentalnimi skupinami pod vodstvom Kuang-Yao Lo in Hong-Ping Lin.

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Topological soft matter based on nematic dispersion of nanoporous shells

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Achiral and chiral nematic liquid crystals with dispersed colloidal particles or tightly confined in different geometries are examples of topological soft matter. Stable or metastable topological defect structures characterise these systems. Dispersing thin nanoporous silica shells in a nematic medium allows for the simultaneous manipulation of colloidal and confining effects. This is possible because of the random porosity of shells that allows nematic to fill the interior of shells and form inner nematic droplets with an order uncorrelated with outer nematic ordering. A high density of nanopores yields an effective lightness of shells. In addition, nanoscale shell surface roughness provides weak effective nematic anchoring on both internal and external shell surfaces, resulting in weaker elastic interparticle interactions and, consequently, lower segregation of such colloidal particles. The physics and material properties of these fascinating dispersions are described through phenomenological modeling of nematic ordering, accompanied by optical simulations of related microscope images and their comparison to experimental ones [1]. These complex systems open up a potential for new light-scattering-based smart window applications, where an electrical field can control both the droplet and host. Further silica shells with nanoscale porosity can act as a filter for nanoscale dopants, enabling the construction of a multi-domain system in which subdomains, i.e., droplets, of pure nematic are dispersed in the bulk of a doped nematic, which can enable their separate control.

The study was conducted in collaboration with Simon Čopar and Taiwanese experimental groups led by Kuang-Yao Lo and Hong-Ping Lin.

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