Oscilatorno gibanje v modelu aktivnosti hipotalamo-hipofizne-adrenalne osi

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Predstavila bom analizo tridimenzionalnega sistema diferencialnih enačb, ki predstavlja model aktivnosti hipotalamo-hipofizne-adrenalne osi. Temelji na obravnavi lastnih vrednosti in fokusnih količin ter pokaže možnost degenerirane Hopfove bifurkacije. S perturbacijo parametrov lahko dosežemo superkritično ali subkritično Hopfovo bifurkacijo, ob ustreznih pogojih pa lahko za kemijsko smiselne vrednosti parametrov v sistemu najdemo dva limitna cikla.

Referenca

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Oscillatory behavior in the model of hypothalamic-pituitary-adrenal axis activity

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I will present analysis of a three-dimensional system of differential equations which represents a sub-network of the model of hypothalamic-pituirary adrenal axes activity. It based on the examination of the eigenvalues and focus quantities and it found that the degenerated Hopf bifurcations can occur. By applying the parameter perturbation techniques, branches of supercritical and subcritical Hopf bifurcations were found, the parameter conditions for the degenerated Hopf bifurcations were derived and two limit cycles were detected in the system for chemically relevant values of parameters.

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Iskanje spinske nematske faze v frustranih spinskih verigah

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Raziskave kvantnega magnetizma so se izkazale kot izredno bogato področje za iskanje novih stanj snovi. Nizko-dimenzionalni sistemi še naprej ostajajo najpomembnejši modelni sistemi, kjer kvantne fluktuacije dominirajo pri nizkih temperaturah. V nekaterih primerih antiferomagnetov magnetni sistem paroma ne more minimalizirati vseh interakcij – takrat govorimo o geometrijski frustraciji. Posledice geometrijske frustracije se odražajo v močnem znižanju Neelove temperature magnetnega urejanja in stanju z zapleteno magnetno ureditvijo ali pa celo s stanjem, kjer se magnetni momenti ne uredijo vse do temperature 0. V prispevku bom predstavil ključno vlogo magnetnih frustracij v spinskih verigah. V modelnem sistemu β-$TeVO_4$ smo tako odkrili pri različnih temperaturah in magnetnih poljih spinsko kiralno fazo, kolinearno fazo z valom spina ter "spin-stripe" fazo z nenavadnimi spinskimi vzbuditvami [1-3]. V visokih magnetnih poljih, tik preden se magnetizacija popolnima nasiti, pa teorija napoveduje obstoj spinske nematske faze. V prispevku bom osvetlil magnetne lastnosti β-$TeVO_4$ v tem delu faznega diagrama, t.j. pri poljih med 20 T in 23 T, in obravnaval NMR meritve v luči napovedane nematske spinske faze.

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Search for spin nematic order in frustrated spin-1/2 chains

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The field of quantum magnetism has proven to be a very rich playground to uncover novel states of matter. Low dimensional antiferromagnets remain model systems to stabilize ground states where quantum fluctuations dominate the low-temperature physics. In certain low dimensional magnetic systems with geometrically frustrated lattice not all interactions can be pairwise optimized. In such cases, the role of geometrical frustration is typically manifested in a drastic suppression of Neel temperature, in a state with a very complicated non-collinear magnetic order or even in a complete suppression of long range magnetic order and establishment of elusive quantum spin liquid. In this talk I will demonstrate the crucial role of frustration on spin chains, which show remarkably rich phase diagrams as a function of temperature and magnetic field. On a archetypal example of β-$TeVO_4$, I will discuss vector chiral, collinear amplitude modulated and spin-stripe phases [1-3]. Finally, theoretical models predict the existence of elusive nematic spin order in high magnetic fields where magnetization is almost fully saturated. In the last part of my talk I will therefore focus on this part of the phase diagram of β-$TeVO_4$, i.e. in fields between 20 T and 23 T, and critically evaluate NMR data in light of possible nematic spin order.

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Income Distributions and Models

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Income distributions are being approximated by various formulas and a few have been supported by an underlying stochastic model. I shall review the main milestones of discovering a fat tail of this distribution at the end of the 19-th century by Vilfredo Pareto, and more modern approaches featuring dynamical processes behind. I put forward our simplified dynamical Local Growth Global Reset (LGGR) model describing a scaling in such distributions stemming from several countries.

This model, worked out in collaboration with Zoltán Néda at UBB Cluj and András Telcs at the Wigner RCP, considers a local growth rate, increasing the income by small amounts in a short time, and a global entry and exit rate (reset) describing entering and leaving the set of people within a given income bin. Naturally the exit (retirement) is more typical at higher incomes, while the entry at lower incomes. Hence our reset rate is smart, it depends on the income level, interpolating between negative and positive values.

A stationary solution to this process dynamics features a scaling with the average income; so disturbing factors, like inflation, are filtered out in the model.

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Spektralna funkcija Holsteinovega polarona pri končni temperaturi

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Predstavil bom spektralno funkcijo Holsteinovega polarona na enodimenzionalnem sistemu, dobljeno s pomočjo Lanczoseve metode pri končni temperaturi (T). Z večanjem T se v spektralni funkciji pojavijo odstopanja od njene oblike pri $T = 0$ celo pri temperaturah, ki so znatno manjše od fononske frekvence. Opazimo povečanje spektralne gostote pod energijo polaronskega pasu, kvazidelčni vrh se razširi. V področju šibke sklopitve se kvazidelčni vrh zelo razširi ter ga pri temperaturi, ki ustreza fononski frekvenci, ne moremo več ločiti od ozadja. Po drugi strani pa v področju močne sklopitve ostanejo značilne lastnosti kvazidelčnega vrha prepoznavne tudi pri visokih temperaturah. Efektivna masa kvazidelca kaže nemonotono temperaturno odvisnost v adiabatskem režimu, to je pri majhnih fononskih frekvencah. Lastna energija (*self -energy*) je neodvisna od valovnega vektorja v področju energij kvazidelčnega pasu celo pri končnih temperaturah. Izpeljali smo tudi analitične izraze za frekvenčne momente spektralne funckije, ki so veljavni v termodinamski limiti ter jih uporabili kot test numerične metode.

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Spectral Function of the Holstein Polaron at Finite Temperature

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I will present the Holstein polaron spectral function on a one dimensional ring obtained using the finite–temperature (T) Lanczos method. With increasing T additional features in the spectral function emerge even at temperatures below the phonon frequency. We observe a substantial spread of the spectral weight towards lower frequencies and the broadening of the quasiparticle (QP) peak. In the weak coupling regime the QP peak merges with the continuum in the high-T limit. In the strong coupling regime the main features of the low–T spectral function remain detectable up to the highest T used in our calculations. The effective polaron mass shows a non–monotonic behavior as a function of T at small phonon frequency but increases with T at larger frequencies. The self energy remains $k-$independent even at elevated T in the frequency range corresponding to the polaron band while at higher frequencies it develops a distinguishable $k-$dependence. Analytical expressions for the first few frequency moments are derived and they agree well with those extracted from numerical calculations in a wide-T regime.

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Onsager relations, nonequilibrium phase transitions and absolute negative mobility

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The understanding of the underlying dynamical mechanisms which determines the macroscopic laws of heat conduction is a long standing task of non-equilibrium statistical mechanics. A better understanding of such mechanism may also lead to potentially interesting applications based on the possibility to control the heat flow, and to new theoretical results. In particular, we show here the phenomenon of self- organization leading to 1d non equilibrium phase transition. In turns, this allows the possibility of absolute negative mobility (ANM) which is a highly counterintuitive phenomenon, where the sign of the induced current is opposite to the applied forces. We show that ANM can occurr in a one dimensional interacting Hamiltonian system when its equilibrium state is perturbed by coupled forces.

We also provide analytical and numerical evidence that Onsager reciprocal relations remain valid for systems with broken time-reversal symmetry as is typically the case when a generic magnetic field is present. Hence, the fundamental constraints that Onsager relations impose on heat to work conversion remain valid also with broken time-reversal symmetry. In particular, the possibility of an engine operating at the Carnot efficiency with finite power is ruled out on purely thermodynamic grounds.

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Oblikotvorje v nematskih suspenzijah

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Kompozitni materiali, kjer je ena komponenta tekoči kristal, so že dolgo pomembno podpodročje raziskav fizike mehke snovi [1]. Primeri tovrstnih snovi so disperzije koloidnih delcev različnih oblik v tekočekristalnem mediju [2], emulzije kapljic tekočih kristalov v mediju na vodni osnovi, ter tekočekristalne lupine [3]. V vseh primerih lahko izbiramo med različnimi fazami tekočega kristala ter z obdelavo površin, med različnimi tipi in jakostmi površinskega sidranja. V zmeseh, kjer sta tako razpršena kot nosilna faza tekočini, pa lahko vplivamo tudi na obliko kapljic. To lahko dosežemo z električnim poljem ali s hidrodinamskim tokom, lahko pa pustimo, da obliko spreminja interakcija med površinsko napetostjo ter nematoelastičnostjo.

Predstavil bom najnovejše izsledke raziskav na področju oblikovanja nematskih kapljic pri izredno nizki površinski napetosti [4]. Ko je površinska napetost primerljiva z elastično energijo, lahko razlike v direktorski strukturi inducirajo močne spremembe v obliki in v pravilnih pogojih sprožijo razvejano rast nematskih vlaken. Debelino vlaken lahko nastavljamo preko temperature, pri prehodu v smektično fazo pa pride do nestabilnosti, po kateri vlakna razpadejo na monodisperzne kapljice.

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Shaping of nematic suspensions

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Composite materials where one of the component is a liquid crystals, have long been an important topic of soft matter research [1]. Examples of such materials are dispersions of hard colloidal particles in a liquid crystalline host [2], emulsions of liquid crystal droplets in an aqueous medium, and liquid crystalline shells [3]. We can choose the type of the liquid crystalline phase, and with surface treatments, also the type and strength of the surface anchoring. In mixtures where both phases are liquids, we can also affect the shape of the droplets. This can be achieved with electric field or with hydrodynamic flow, or let the shape be determined by the interaction between the surface tension and nematic elasticity.

I will present the latest research on shaping nematic droplets at very low surface tension [4]. When the surface tension is comparable with bulk elastic energy, the differences in director structure can induce large changes of shape, and under right conditions, trigger growth of branching nematic filaments. The filament thickness can be tuned via temperature, and with transition into the smectic phase, an instability induces a breakup into monodisperse droplets.

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Samoorganiziranost in kritičnost določujeta kolektivni odziv celic beta v mišjih Langerhansovih otočkih

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Celice beta v organih, ki jih imenujemo Langerhansovi otočki, po draženju z glukozo oscilatorno spreminjajo znotrajcelično koncentracijo kalcijevih ionov. Te oscilacije so nujne za normalno izločanje inzulina, to pa je nujno za normalno homeostazo glukoze. Hetero- in homologne povezave preko presledkovnih stikov med celicami v otočku so najverjetnejši mehanicistični substrat, ki omogoča prenos informacije preko otočka, ki tvori kompleksni sincicij medsebojno povezanih endokrinih celic [1, 2]. Veliko bioloških sistemov izraža samoorganizirano kritično dinamiko s potenčno porazdelitvijo sistemskih opazljivk, med njimi tudi mreža povezanih celic beta [3]. Da bi bolje razumeli populacijsko dinamiko, smo sistematično raziskali mehanizme, ki povzročijo kritično in superkritično obnašanje s pomočjo eksperimentalnega in teoretičnega pristopa [4]. Uporabili smo konfokalno snemanje sprememb znotrajcelične koncentracije kalcijevih ionov v populaciji celic beta, posnetih v akutno pripravljeni mišji rezini trebušne slinavke. Pokazali smo, da se celice beta na draženje z glukozo odzovejo bifazično in koncentracijsko odvisno. Prva faza odziva, imenovana aktivacijska faza, je kazala znake kritičnosti med draženjem z nizko glukozo, opazili smo potenčno porazdelitev velikosti kalcijevih valov, medtem ko so patofiziološko visoke koncentracije glukoze sprožile odzive, ki so bili hitrejši, manj povezani in superkritični. Za naslednjo fazo odziva, imenovano faza platoja, so bili značilni globalni kalcijevi valovi ne glede na koncentracijo glukoze. V naslednjem koraku smo izgradili fenomenološki model sklopljenih vzdražnih celic in tako želeli bolje razumeti eksperimentalno pridobljene kompleksne vzorce aktivnosti. Dobro prekrivanje računskih in eksperimentalnih podatkov smo pridobili, če smo v modelu upoštevali heterogene in od dražljaja odvisne časovne zamike, variabilnost v nivoju vzdražnosti in heterogenost v sklopitvi med celicami. Takšen pristop omogoča določitev ključnih mehanizmov samoorganizirane kritičnosti na nivoju celic beta, ki v otočkih proizvajajo inzulin [4].

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Self-organization and Criticality Determine Collective Response of Beta Cells In Mouse Islets of Langerhans

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Beta cells within organs called Islets of Langerhans display calcium oscillations in response to natural stimuli. These oscillations in intracellular calcium concentration are vital for normal insulin secretion that is in turn critical for normal glucose homeostasis. Hetero- and homologous gap junction coupling between cells within an islets are most probably the mechanistic substrate allowing for the spreading of information across an islets, forming a complex syncytium of interconnected endocrine cells [1, 2]. Many biological systems were shown to express self-organized critical dynamics implying a power-law distribution of observables, including population of cells within networks of coupled beta cells [3]. To gain further insight in the population dynamics, we systematically explored the mechanisms that drive the critical and supercritical behavior using both an experimental and a computational approach [4]. Experimentally, we made use of confocal imaging of intracellular calcium concentration dynamics of beta cell populations in acute mouse pancreas tissue slices. We demonstrated that beta cells respond to stimulation with glucose in a biphasic manner that was concentration-dependent. The first phase, also called activation phase, displayed critical behavior under low stimulation levels with a power-law distribution of calcium wave sizes, whereas pathophysiologically high glucose concentrations elicited responses that were more rapid, less continuous, and supercritical. The subsequent phase, also called plateau phase, was characterized by a high number of global intercellular calcium waves irrespective of glucose levels. In the next step, we built a phenomenological model of coupled excitable cells in an attempt to gain an insight into the experimentally observed complex dynamical patterns. A good overlap between computational and experimental data was attained when both heterogeneous and stimulus-dependent time lags, variability in excitability levels, as well as a heterogeneous cell-cell coupling were included into the model. Thus, the presented model allows to determine key mechanism of self-organized criticality at the level of insulin secreting cells within islets [4].

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The importance of comets for life and the fantastic journey to 67/P Churyumov-Gerasimenko

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Would there be life on Earth without comets? This is a question which scientists try to answer since the last century! With the help of spacecrafts to visit comets we have now a good knowledge of the physics of these quite interesting and in ancient days terrifying astronomical objects. Up to now seven comets could 'welcome' guests from the Earth: 1P/Halley (1986), 19P/Borrelly (2001), (1P/Wild (2004), 9P/Tempel(2005), 103P/Hartley (2010), 9P/Tempel (2011) and recently 67/P Churyumov-Gerasimenko. We will discuss shortly the results of the former visitors of the comets but we will in much more detail present the outstanding flight of ESA's spacecraft Rosetta in 2014. But the answer to the question of the formation of life on Earth is still opened!

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Ionically-charged topological defects in nematic fluids

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We theoretically show that topological defects in a nematic electrolyte can become electrically charged by the build up of an electric double layer within the core region. We demonstrate first the physical principles behind the electrical charging by using the flat isotropic-nematic interface as a basic example of how orientational order couples to ions and to order electricity. The uniaxial radial hedgehog defect is then used as an example of how a point defect can become electrically charged. Finally, we investigate half-integer wedge disclinations and show that their core region can capture ions, implying that charged disclination loops can be realized in nematic liquid crystals. Finally, we will investigate the repercussions of our findings in (charged) liquid-crystal colloids.

Limitni cikli v sistemih kemijskih reakcij

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Kemijske reakcije kažejo več vrst eksotičnega obnašanja: nihanja, multistabilnost, multistacionarnost ali kaos. Zanimive niso samo s stališča matematike, pač pa tudi zato, ker nihanje v reakcijah lahko tvori osnovo za periodično obnašanje v bioloških sistemih, ki ima lahko različne periode: minute, dan, leto itd. Obstoj multistacionarnosti, nihanja ali kaosa je običajno dokazan z numeričnimi metodami. Mi raziskujemo razmeroma enostavno reakcijo med dvema vrstama, sestavljeno iz petih reakcijskih korakov. S simboličnimi metodami najdemo potrebne in zadostne pogoje za parametre kinetične diferencialne enačbe, ki predstavlja reakcijo, pri katerih limitni cikel bifurcira iz stacionarne točke v pozitivnem kvadrantu. Prav tako poiščemo parcialne integrale sistema.

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Limit cycles in chemical reaction systems

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Chemical reactions show all kinds of exotic behavior: oscillation, multistability, multistationarity, or chaos. They are interesting not only from the mathematical point of view, but oscillatory behavior in a reaction may also form the basis of periodic behavior in biological systems that can have different periods: minutes, one day, one year etc. However, the existence of multistationarity, oscillation or chaos is usually proved by numerical methods. Here we investigate a relatively simple reaction among two species consisting of five reaction steps. Using symbolic methods we find the necessary and sufficient conditions on the parameters of the kinetic differential equation of the reaction under which a limit cycle bifurcates from the stationary point in the positive quadrant. We also perform the search for partial integrals.

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Astrofizikalni tranzienti

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Pregledi neba, ki ponavljajoče pokrivajo velike dele neba (npr. sateliti Swift, Fermi in Gaia, Veliki pregledovalni sinoptični teleskop LSST) detektirajo številne nove, tranzientne (kratkotrajne ali prehodne) astrofizikalne izvore različnih vrst in izsevov v različnih valovnih dolžinah. Veliko zanimanje za to hitro razvijajoče se področje astrofizike je še podžgala prva neposredna detekcija gravitacijskih valov z observatorijem LIGO leta 2015, ki je odprla novo okno v vesolje.
Predstavila bom tri vrste visoko-energijskih tranzientov povezanih z nevtronskimi zvezdami in črnimi luknjami: plimska raztrganja zvezd, izbruhe sevanja gama in dogodke gravitacijskih valov ter nekaj nedavnih rezultatov naše raziskovalne skupine.

Astrophysical Transients

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Sky-surveys which are repeatedly covering large areas of the sky (e.g. Swift, Fermi, Gaia, Large Synoptic Survey Telescope) are detecting a large number of new, transient astrophysical sources of various types and luminosities in different wavelengths. High interest in this rapidly developing field of astrophysics was further fuelled by the first direct detection of gravitational waves by the LIGO observatory in 2015, which opened a new window to the Universe.
I will discuss three types of high-energy transients involving neutron stars and black holes: Tidal Disruption Events, Gamma Ray Bursts and Gravitational Wave Events, and present some recent results of our research group.

Integracija biofizikalnih termičnih modelov v klinično okolje

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Številne znanstvene panoge se v zadnjih letih ukvarjajo s preučevanjem regulacije prenosa toplote znotraj človeškega telesa in s tem, kako telo izmenjuje toploto z okoljem. Tovrstne raziskave vključujejo tudi izgradnjo računskih modelov, ki opisujejo termodinamske procese, ki se vršijo v telesu. Takšni modeli nam omogočajo boljše razumevanje in napovedovanje termičnih odzivov v različnih okoliščinah [1]. V zadnjih letih termo-fiziološki modeli pridobivajo na veljavi tudi v kontekstu klinične relevantnosti [2]. Uporabo termičnih terapij za zdravljenje različnih obolenj poznamo že iz pradavnine in zelo pomembno je, da razumemo fiziološke spremembe na ravni celic in tkiv, ki jih povzroči oddana ali prejeta toplota. V predavanju bomo na začetku podali kratek pregled razvoja termofizioloških modelov. V nadaljevanju bomo podrobneje predstavili naš več-segmentni in več-vozliščni model, ki ga uporabljamo v naših raziskavah. V modelu je človeško telo obravnavano kot sestav 15 cilindričnih segmentov in vsak izmed njih vsebuje 4 vozlišča: jedro, kožo in arterijsko ter venozno kri. Izmenjava toplote med segmenti poteka preko pretoka krvi, medtem ko med posameznimi vozli znotraj segmentov prevajanje toplote uravnava perfuzija. Model upošteva, da na termično ravnovesje vplivajo tako dejavniki iz okolja (temperatura zraka, hitrost vetra, relativna vlažnost, itd.), kakor tudi individualni fiziološki parametri (stopnja metabolizma, pretoki krvi, perfuzija tkiv, itd.). Rešitev modela vključuje vse lokalne temperature na koži in v jedrih. Uspešnost modela testiramo s simuliranjem različnih okoliščin, s katerimi se srečujemo v termični medicini in pri kliničnem uravnavanju temperature. Rezultate prav tako primerjamo z eksperimentalnimi podatki [4]. Menimo, da je uporaba tovrstnih biotermičnih modelov lahko zelo koristna, in sicer ne le zaradi tega, ker omogoča podrobno spremljanje lokalnih temperatur pod različnimi pogoji, temveč tudi zato, ker se lahko modeli uporabljajo tudi pri optimizaciji hladilnih metod ali izboljšanju postopkov in naprav za termične terapije. Z vidika klinične prakse so to zelo pomembna vprašanja, ki jih je težko nasloviti z eksperimentalnimi merjenji.

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Integrating biophysical thermal models into clinical settings

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The regulation of heat exchange within the human body and its interaction with the environment has in the past years been the research focus of different scientific disciplines. To assess the thermodynamic processes that govern the thermal balance of the body computational models have been developed as well. They can help us to better understand and predict human thermal responses in different conditions [1]. Recently, thermophysiological models are increasingly gaining attention also in the context of clinical relevance [2]. The use of thermotherapies in treating diseases is known since ancient times and it is of paramount importance to understand the physiological changes provoked by the deposited thermal energy, which elicit molecular or cellular responses to thermotherapies. In the present seminar first a brief overview of the development of thermophysiological models will be provided. Then, a multi-segment and multi-node model will be described in more detail, which is used as the main cornerstone of our study. In the model the body is divided into 15 cylindrical segments and each segment is composed to four nodes: core, skin, arterial blood, and venous blood. The heat exchange between segments is governed by blood flow rates, whereas the transfer of heat between nodes within each segment is regulated via perfusion [3]. The model takes into account that the thermal balance of the body is influenced by local environmental conditions (air temperature, air velocity, relative humidity, etc.) and individual physiological characteristics (metabolic rates, cardiac output, blood flowrates, etc.). As output, the model is able to predict local skin and the body's core temperatures. We test the model by simulating various modalities of thermal medicine and clinical temperature management strategies and by comparing the model's predictions with experimental data [4]. We argue that the utilization of such bioheat models can be very beneficial, not only because they provide a detailed evolution of local temperatures in various circumstances, but also because they can be used to optimize cooling methods or to suggest improvements in the design of devices for thermal therapy. These are very important issues from the clinical point of view, which are hard to assess experimentally.

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Convergence of the gradient expansion in hydrodynamics

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Hydrodynamics is a theory of collective properties of fluids and gases that can also be successfully applied to the description of the dynamics of quark-gluon plasma. It is an effective field theory formulated in terms of an infinite-order gradient expansion. Hydrodynamics predicts the dispersion relations of collective physical modes, which express the modes' frequencies in terms of infinite series in powers of momentum. By using the theory of complex spectral curves from the mathematical field of algebraic geometry, I will describe how these dispersion relations can be understood as Puiseux series in complex momentum. The series have finite radii of convergence determined by the critical points of the associated spectral curves. For theories that admit a dual gravitational description through holography, the critical points correspond to level-crossings in the quasinormal spectrum of the dual black hole. Interestingly, holography implies that the convergence radii can be orders of magnitude larger than the naive expectation. This fact could help explain the "unreasonable effectiveness of hydrodynamics" in describing the evolution of quark-gluon plasma.

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Razkrivanje latentne podstrukture hadronskih curkov

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S pomočjo metod bayesijskega generativnega statističnega modeliranja lahko razkrijemo skrite lastnosti opazljivk podstrukture hadronskih curkov, ki razlikujejo med a priori neznanimi fizikalnimi procesi v dogodkih z mnogimi hadronskimi curki v trkalnikih delcev. Natančneje, z uporabo statističnega modela mešanega članstva lahko zasnujemo podatkovno gnan, nenadzorovan algoritem za označevanje hadronskih curkov kvarkov t oziroma dogodkov tvorbe parov kvarkov t. Metodo bom primerjal z obstoječimi tradicionalnimi metodami in drugimi pristopi na podlagi strojnega učenja. Nazadnje bom na primeru modela z masivnim vektorskim in skalarnim bozonom pokazal potencial za modelsko neodvisne in nenadzorovane metode odkrivanja signalov nove fizike v dogodkih z mnogimi hadronskimi curki.

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Uncovering latent jet substructure

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Applying techniques from Bayesian generative statistical modeling one can uncover hidden features in jet substructure observables that discriminate between different a priori unknown underlying short distance physical processes in multi-jet events. In particular, using a mixed membership model known as *Latent Dirichlet Allocation*, we have built a data-driven *unsupervised* top-quark tagger and $t\bar{t}$ event classifier. I compare our proposal to existing traditional and machine learning approaches to top jet tagging. Finally, employing a toy vector-scalar boson model as a benchmark, I demonstrate the potential for discovering New Physics signatures in multi-jet events in a model independent and unsupervised way.

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Kvantni biljardi: numerična knjižnica v programskem okolju Python

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Biljardi so pomemben razred dinamičnih sistemov z širokim naborom dinamičnih lastnosti tako s stališča klasičnega kot kvantega kaosa. Kvantni biljard sestoji iz prosto gibajočega se kvantnega delca ujetega znotraj predpisane domene obdane z neskončnim potencialom. Stacionarna Schrödingerjeva enačba se znotraj domene prevede na Helmholtzovo enačbo z robnim pogojem, da je valovna funkcija na robu enaka nič. Lastni problem je mogoče učinkovito rešiti preko numeričnih metod kot so Hellerjeva metoda razstavitve na ravne valove [1] in skalirna metoda Verginija in Saracena [2]. Eksperimentalno je kvantne biljarde mogoče realizirati v mezoskopskih sistemih ali pa v mikrovalovnih resonatorjih preko analogije [3]. Predstavil bom numerično knjižnico za izračun in vizualizacijo lastnih stanj biljardov implementirano v programskem jeziku Python [4]. Implementacija sloni na delu predstavljenem v doktorski disertaciji Barnetta [5]. Numerična knjižnica je bila pred kratkim uporabljena za izračun spektrov večih družin biljardov pri študiji lokalizacije lastnih stanj [6,7].

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Quantum billiards: a Python numerical library

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Billiards are an important class of dynamical systems, exhibiting a wide range of dynamical properties in both classical and quantum chaos. A quantum billiard consists of a free moving quantum particle trapped inside a fixed domain bordered by an infinite potential. Inside the domain the stationary Schrödinger equation reduces to the Helmholtz equation with the boundary condition that the wave function vanishes at the border. The eigenvalue problem may be solved using very efficient numerical methods such as the plane wave decomposition method of Heller [1] and the scaling method of Vergini and Saraceno [2]. Experimentally quantum billiards may be realized in microscopic devices or using microwave resonators as an analogue [3]. I shall present a numerical library for the computation and visualization of billiard eigenstates, implemented in the Python programming language [4]. The implementation is based on the work presented by Barnett in his PhD thesis [5]. The numerical library has been recently used for the computation of the spectra for several billiard families for the study of the localization of eigenstates [6,7].

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Complex Systems, Nonlinear Dynamics, and Machine Learning

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Complexity can be understood as dynamical concept in mathematical physics as well as algorithmic concept in computer and information science. In information dynamics, both concepts are combined and play and important role to model complexity in natural as well as engineering sciences up to machine learning and complex neural networks. The principle of local activity explains the emergence of complex patterns in homogeneous medium. At first defined in the theory of nonlinear electronic circuits in a mathematically rigorous way, it can be generalized and proven at least for the class of nonlinear reaction-diffusion systems in physics, chemistry, biology, and brain research. We argue that the principle of local activity is really fundamental in science and can even be identified with the emergence of nonequilibrium states, symmetry breaking at critical points of phase transitions, and risk taking at the edge of chaos. Machine learning and complex neural networks become an exciting application in the age of digitalization and artificial intelligence.

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Človeško sodelovanje in moralnost

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Sodelovanje nas pomembno ločuje od ostalih živalskih vrst, vendar je v nasprotju z osnovnimi principi evolucije. Statistična fizika že vrsto let pomembno prispeva k boljšemu razumevanju sodelovanja [1]. Predstavil bom osnovne matematične modele, ki se uporabljajo v ta namen, in nekatere bolj zanimive rezultate [2,3]. V zadnjih letih tudi druge oblike (ne)moralnega obnašanja postajajo predmet raziskav v fiziki [4]. Primeri vključujejo empatijo in pravičnost [5], kakor tudi laganje [6]. Predstavil bom tudi te modele, in diskutiral odprta vprašanja za prihodnje raziskave.

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Human cooperation and morality

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Cooperation distinguishes us definitively from other species, but it is at odds with the fundamental principles of evolution. For many years, research in statistical physics has been contributing significantly to the better understand of cooperation [1]. I will present basic mathematical models that are used to that effect, as well as some of the more interesting results [2,3]. In recent years, other forms of (im)moral behavior have also begun to be studied in the realm of physics [4]. Examples include empathy and fairness [5], as well as lying [6]. I will also present these models, and discuss open question for future research.

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Ravninski kvadratični sistemi NDE z dvema integrabilnima singularnima točkama

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Center ravninskega sistema navadnih diferencialnih enačb je singularna točka z lastnostjo, da je vsaka trajektorija v neki okolici te točke sklenjena krivula. Za realne kvadratične ravninske sisteme je znano, da je vsak center integrabilna točka, kar je pomembna kvalitativna lastnost dinamičnega sistema. Ravninski kvadratičen sistem ima lahko največ dva centra. V obliki semialgebraičnih raznoterosti v prostoru parametrov sistema bomo predstavili družino vseh realnih kvadratičnih sistemov z dvema centroma, ki imajo posledično vsaj dve integrabilni točki. Želene polinomske enačbe bomo pridobili z eliminacijsko teorijo polinomskih idealov. S podobno metodo lahko določimo tudi sisteme z dvema integrabilnima šibkima sedloma.

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Planar quadratic systems of ODEs with two integrable singular points

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A center of a planar system of ODEs is such a singular point which has the property that every trajectory in a neighbourhood of this point is closed. For a real quadratic planar systems it turns out that every center is an integrable point, which is an important qualitative property of a dynamical system. A planar quadratic system can have at most two centers. It is our aim to identify, as a semialgebraic variety of parameter space of the given system, the family of all real planar quadratic systems having two centers, thus also having two integrable singular points. The method we use is the elimination theory in polynomial ideals. A similar method can be applied for finding systems with two integrable weak saddles.

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Strong Dynamics in Hadrons and Nuclei

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70 years ago, in 1949, Hideki Yukawa received the Nobel Prize for his "prediction of the existence of mesons on the basis of theoretical work on nuclear forces". Fourteen years earlier he had published a paper, wherein he had postulated - in analogy to quantum electrodynamics - a new sort of quantum responsible for the strong interaction between a proton and a neutron [1]. In 1947 the corresponding particle, the pion π, was identified in experiment [2].

In 1973 quantum chromodynamics (QCD) was proposed as the fundamental quantum gauge theory for strong interactions [3]. From then on all conceptions of strong forces in particle and nuclear physics have been expected to be described on the basis of QCD. Now, more than 46 years later, despite tremendous efforts, QCD has neither been amenable to a universally valid solution in particle physics nor a direct application for strong forces in nuclear physics. Rather resorts to models and approximations have prevailed.

I will review the developments of the theory of strong interactions over the times, emphasize the cornerstones, highlight the principal achievements, and discuss the present challenges in explaining strong-interaction phenomena in particle and nuclear physics as far as possible on fundamental grounds. It will become clear that different degrees of freedom are dominant in distinct areas of applications. Therefore it remains as an essential task to determine and understand, which degrees of freedom govern strongly interacting matter under different conditions in hadrons and nuclei, from low to high energies, say, or from vacua to high pressures.

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Uporaba vodika in gorivnih celic za pogon letal

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Evropska unija se vztrajno prizadeva za razvijanje novih tehnologij na področju prevoznih sredstev na alternativna goriva. Električni avtomobili že niso več nobena novost, pojavljajo pa se tudi že prvi avtomobili, avtobusi in vlaki na vodik in gorivne celice. Vodik je zlasti v letalstvu obetavajoče pogonsko sredstvo. Pri letalih je namreč poraba goriva sorazmerna z maso letala. Ker baterije imajo zelo nisko specifično energijo, je uporaba le-teh omejena na ozko področje ultralahkih letal s kratkim dosegom. Vodik s visoko specifično energijo pa je po drugi strani primerenejši za večja letala in letala z dolgim dosegom. Uporaba vodika kot pogonskega goriva v letalstvu sicer že nekaj časa buri duhove, vendar so se do sedaj raziskave razvijale v smeri izgorevanja vodika. Gorivne celice s svojo visoko efektivnostjo pa predstavljajo dodatni potencijal za uporabo vodika v letalstvu. *Raziskava je bila izvedena v okviru projekta MAHEPA, ki je prejel sredstva iz programa Evropske unije Obzorje 2020 v skladu s sporazumom št. 723368. Predstavitev odraža samo avtorjev pogled in Evropska unija ni odgovorna za uporabo informacij, ki jih predstavitev vsebuje.*

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Usage of hydrogen and fuel-cells for aircraft propulsion

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The European Union is working hard to find and develop vehicles powered by alternative fuels. Electric cars are no longer a novelty, and the first cars, buses and trains running on hydrogen and fuel cells are emerging. Hydrogen is a promising propulsion agent especially in aviation. For aircraft, the fuel consumption is proportional to the mass of the aircraft. Because the batteries have very low specific energy, their use is limited to the narrow range of short-range ultra-light aircraft. Hydrogen with high specific energy, on the other hand, is more suitable for larger and longer range aircraft. The use of hydrogen as a fuel in aviation has been topic of reasearch for some time, but so far, research has evolved only towards hydrogen combustion. High efficiency fuel cells, however, present additional potential for the usege of hydrogen in aviation. *The research has been done within project MAHEPA that have received funding from European Union's Horizon 2020 research and innovation programme under grant agreement No. 723368. The presentation reflects only the author's view and the European Union is not liable for any use that may be made of the information contained therein.*

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Strukture pasivnih in aktivnih nematskih defektov

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Kompleksne -pasivne in aktivne- nematske tekočine so določene z internim orientacijskim redom, v katerem se lahko ob nastavljanju ali frustraciji, tvorijo topološki defekti. Tip defektov in njihova vloga so naravno odvisni od dimenzionalnosti sistema, pomembno pa tudi od geometrije, ograditve, toka, gnanja in tudi aktivnosti. V tem prispevku bomo predstavili strukture topoloških defektov v pasivnih in aktivnih nematskih kompleksnih tekočinah in sicer na osnovi ubiličnih defektov, singularnih zank, točkovnih defektov in disklinacij. Posebej bomo pokazali vlogo ograditve pasivnih nematikih s fraktalnimi površinami in posebno geometrijo, kar vodi do tvorbe različnih defektnih nematskih profilov, vključno z visokimi elastičnimi multipoli. V aktivnih nematikih bomo pokazali profile v tridimenzionalni aktivni nematski kapljici, pri čemer bomo izpostavili tudi pomen različnih sklopitev s površino.

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Structures of passive and active nematic defects

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Complex -passive or active- nematic fluids are characterised by internal orientational order, which upon tuning or frustration, can exhibit topological defects. The type of defects and their role naturally depend on dimensionality of the system, but importantly also on the geometry, confinement, flow, driving or even activity. Here, we present structures of topological defects in passive and active nematic complex fluids – forming umbilic defects, singular loops, point defects and disclinations. Specifically, we show in passive nematics how confinement in the form of complex geometry and fractal surfaces can lead to formation of various defect-based nematic profiles, including exhibiting high-elastic multipoles. In active nematics, we show defect profiles in three-dimensional active nematic droplet, also highlighting the role of different surface coupling regimes.

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Kvantna lokalizacija v kaotičnih sistemih

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Pregledali bomo glavne vidike kvantnega kaosa (valovnega kaosa) v hamiltonskih sistemih mešanega tipa z razdeljenim faznim prostorom, kjer sobivajo regularna območja z invariantnimi torusi s kaotičnimi območji. Kvantna evolucija klasično kaotičnih vezanih sistemov nima lastnosti občutljive odvisnosti od začetnih pogojev, in posledično ni kaotičnega vedenja, saj je gibanje zmerom skoraj periodično. Toda, študij stacionarnih rešitev Schrödingerjeve enačbe v kvantnem faznem prostoru (Wignerjeve ali Husimijeve funkcije) pokaže natančno analogijo strukture klasičnega faznega portreta. V klasično integrabilnih območjih je spektralna statistika (energije) Poissonova, medtem ko v ergodičnih kaotičnih območjih velja teorija naključnih matrik. Če imamo fazni prostor mešanega tipa, je v semiklasični limiti (aproksimacija kratkih valovnih dolžin) spekter sestavljen iz Poissonovih sekvenc, ki jih podpirajo klasično regularna območja, in kaotičnih sekvenc, ki jih podpirajo klasično kaotična območja. Če so statistično neodvisne, jih opisuje t.i. Berry-Robnikova porazdelitev. V kvantnih sistemih z diskretnim spektrom je Heisenbergov čas $t_H = 2\pi\hbar/\Delta E$, kjer je ΔE srednji razmik med nivoji (recipročna gostota stanj), pomembna časovna skala. Klasični transportni čas t_T (časovna skala) v odnosu do Heisenbergovega časa t_H (njuno razmerje je parameter $\alpha = t_H/t_T$) določa stopnjo lokalizacije kaotičnih lastnih stanj, katerih mera A je osnovana na informacijski entropiji. Pokazal bom, da je A linearno odvisen od normiranega inverznega udeležnega razmerja (*angl. normalized inverse participation ratio*), zato sta ekvivalentna. Proučujemo strukturo lokaliziranih kvantnih lastnih stanj (Wignerjevih in Husimijevih funkcij) ter porazdelitev lokalizacijske mere A. Le-ta je dobro opisana z beta distribucijo, če ni območij lepljivosti v klasičnem faznem prostoru. V nasprotnem primeru pa imajo kompleksno neuniverzalno strukturo. Pokazal bom, da lokalizirana kaotična stanja izkazujejo ulomljeno potenčno odbijanje med sosednjimi nivoji v tem smislu, da je verjetnostna porazdelitev razmikov med najbližnjimi sosednjimi nivoji (*angl. level spacing distribution*), da najdemo dva nivoja na razdalji S, potenca $\propto S^\beta$ za majhne S, kjer je $0 \leq \beta \leq 1$, in $\beta = 1$ ustreza povsem razširjenim stanjem, medtem ko $\beta = 0$ ustreza maksimalno lokaliziranim stanjem. β gre od 0 do 1, ko gre α od 0 do ∞. β je funkcija $\langle A \rangle$, kot je bilo pokazano za kvantni brcani rotator, biljard stadion ter biljard mešanega tipa.

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Quantum localization in chaotic systems

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We review the basic aspects of quantum chaos (wave chaos) in mixed-type Hamiltonian systems with divided phase space, where regular regions containing the invariant tori coexist with the chaotic regions. The quantum evolution of classically chaotic bound systems does not possess the sensitive dependence on initial conditions, and thus no chaotic behaviour occurs, as the motion is always almost periodic. However, the study of the stationary solutions of the Schrödinger equation in the quantum phase space (Wigner functions or Husimi functions) reveals precise analogy of the structure of the classical phase portrait. In classically integrable regions the spectral (energy) statistics is Poissonian, while in the ergodic chaotic regions the random matrix theory applies. If we have the mixed-type classical phase space, in the semiclassical limit (short wavelength approximation) the spectrum is composed of Poissonian level sequence supported by the regular part of the phase space, and chaotic sequences supported by classically chaotic regions, being statistically independent of each other, as described by the Berry-Robnik distribution. In quantum systems with discrete energy spectrum the Heisenberg time $t_H = 2\pi\hbar/\Delta E$, where ΔE is the mean level spacing (inverse energy level density), is an important time scale. The classical transport time scale t_T (transport time) in relation to the Heisenberg time scale t_H (their ratio is the parameter $\alpha = t_H/t_T$) determines the degree of localization of the chaotic eigenstates, whose measure A is based on the information entropy. We show that A is linearly related to the normalized inverse participation ratio, and therefore they are equivalent. We study the structure of quantum localized chaotic eigenstates (their Wigner and Husimi functions) and the distribution of localization measure A. The latter one is well described by the beta distribution, if there are no sticky regions in the classical phase space. Otherwise, they have a complex nonuniversal structure. We show that the localized chaotic states display the fractional power-law repulsion between the nearest energy levels in the sense that the probability density (level spacing distribution) to find successive levels on a distance S goes like $\propto S^\beta$ for small S, where $0 \leq \beta \leq 1$, and $\beta = 1$ corresponds to completely extended states, and $\beta = 0$ to the maximally localized states. β goes from 0 to 1 when α goes from 0 to ∞. β is a function of $\langle A \rangle$, as demonstrated in the quantum kicked rotator, the stadium billiard, and a mixed-type billiard.

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Hopfove bifurkacije v nekaterih biokemičnih modelih

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Obstoj periodičnih nihanj je pomembna značilnost raznih modelov kemičnih reakcij. Najbolj običajna metoda za iskanje teh je raziskava Hopfovih bifurkacij. Predstavil bom pristop, ki temelji na eliminacijski teoriji računske algebre, s katerim poiščemo pogoje za obstoj Hopfovih bifurkacij v polinomskih sistemih navadnih diferencialnih enačb ter ga uporabimo za iskanje periodičnih rešitev v nekaterih modelih.

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Hopf bifurcations in some biochemical models

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Existence of periodic oscillations is an important feature of various chemical reaction models. The most common method to find such bifurcations is the investigation of Hopf bifurcations. We propose an approach based on the elimination theory of computational algebra to find conditions for the existence of Hopf bifurcations in polynomial systems of ordinary differential equations and use it for the investigation of periodic solutions in some models.

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Konstituentni kvarki kot vmesna tvorba med golimi kvarki in hadroni

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Globoko neelastično sipanje polariziranih elektronov na polariziranih protonih je razkrilo, da spini kvarkov prispevajo manj kot 1/2 k spinu protona. To je že davna uganka in bilo je že mnogo predlogov za dodatne partone in dodatno tirno vrtilno količino. V naši raziskavi skušamo uskladiti velik uspeh trikvarkovske slike hadronov z opaženim primanjkljajem spina. Poudarimo vlogo oblečenih ("konstituentnih") kvarkov kot kompaktnih gruč iz golih kvarkov, antikvarkov ter gluonskih in mezonskih polj. Nastopajo kot gradniki hadronov. S primerjavo polariziranih in nepolariziranih sipalnih amplitud kot funkcij prenosov gibalne količine in energije (tako imenovane Bjorkenove spremenljivke x) prepoznamo, da je prispevek spina zmanjšan pri majhnih x (krepki trki), pri katerih se konstituentni kvark zdrobi in se prispevki njegovih partonov izpovprečijo.

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Constituent quarks as an intermediate structure between bare quarks and hadrons

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The deep inelastic scattering of polarized electrons on polarized protons has revealed that the quark spins do not add up to the spin 1/2 of the proton. This is a long-standing puzzle and several proposals of additional partons and of orbital angular momentum contribution have been proposed. We are trying to reconcile the great success of the 3-quark picture of baryons with this spin defficiency. We propose that the constituent quarks in the baryons (the dressed quarks) are very compact object composed of bare quarks, antiquarks and gluon and meson fields. They are a physical entity inbetween bare quarks and hadrons. By comparing the polarized and unpolarized scattering amplitudes as a function of momentum and energy transfer (the so called Bjorken x variable) we recognize that the spin contribution is depleted at low x (violent collision) where the constituent quark is fragmented and the spin contribution of its partons is averaged out.

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Integrable Schrödinger Operators on Unitary Lattices

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We develop the mathematical setting for discretized Schrödinger equations on so-called unitary lattices. Unitary lattices show the property that the inverse of the lattice shift operator is essentially the formal adjoint of the lattice shift operator. Equidistant lattices and basic exponential lattices are the most prominent examples for unitary lattices.

Integrability situations for several classes of the arising discretized Schrödinger equations are investigated. Various ladder operator concepts are studied which help determining the desired point spectrum of the lattice Schrödinger operators under consideration.

We elucidate main differences between the continuum and the discrete scenario revealing how different the approaches in these two - at first sight so similar - worlds of integrable quantum systems are. We confirm the nice motto "Be wise, discretize" and show where one has to be careful with analogies between the continuum and the discrete world, i.e. completing the sentence: "Be aware, do this with care".

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RAČUNALNIŠKO PROJEKTIRANJE MIKRO-CURKOV ZA DOSTAVO VZORCEV V FEMTOSEKUNDNI KRISTALOGRAFIJI

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Skupina za koherentno slikanje v DESY-CFEL razvija inovativne metode za slikanje različnih bioloških vzorcev s pomočjo rentgenskega laserja na proste elektrone (XFEL) in sinhrotronskih izvorov sevanja. Beljakovine so dostavljene v visoko intenziven femtosekundni žarek rentgenske svetlobe v obliki mikro-curka v katerem plavajo kristali z vzorci. Ti kristali so ponavadi na voljo le v majhnih količinah. Zatorej je pomemben cilj minimiziranje porabe dragocenega proteinskega vzorca in pri tem hkrati pridobivanje visokokvalitetnih meritev tudi iz curkov tanjših od enega mikrona. Dobre kristalografske meritve zahtevajo, da je tak curek hiter, raven, tanek, stabilen ter karseda dolg. Ti pogoji morajo biti izpolnjeni tudi za zelo majhne pretoke, neodvisno od velikosti kristalov, njihove koncentracije ter nosilne tekočine. Razvoj, verifikacijo in eksperimentalno validacijo računalniških modelov tovrstnih curkov smo že predstavili na Božičnem simpoziju 2017. Tokrat predstavimo nadaljnji razvoj naprednega računalniškega modela in študijo občutljivosti vseh procesnih parametrov in snovnih lastnosti na obnašanju mikro-curkov, pa tudi zasnovo novih vrst šob, ki proizvajajo takšne curke.

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COMPUTATIONAL DESIGN OF MICRO-JETS FOR SAMPLE DELIVERY IN FEMTOSECOND CRYSTALLOGRAPHY

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Coherent Imaging Group at DESY-CFEL is developing innovative methods for imaging of the biological samples with the use of X-ray Free Electron Laser (XFEL) and synchrotron sources. The proteins are delivered to a high intensity femtosecond X-ray beam in the form of a micro jet in which the crystals of the sample float. Such crystals are usually available in very small amounts. Hence, an important goal is to minimize the consumption of the valuable samples and to get good quality data even from the sub-micron jets. This requires the jets to be fast, stable, thin, straight and as long as possible even for very small flow rates independent on the crystal size, buffer solution and concentration. We have already elaborated the development, verification and experimental validation of the computational model of such jets at Christmas symposium 2017. This time we show further developments of the advanced computational model and sensitivity study of all process parameters and material properties on the micro-jet behaviour as well as the design of new types of the nozzles that produce such jets.

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Long-range interacting particles on helices

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We explore the structure and dynamics of long-range interacting equally charged classical particles confined to a helix. The confinement renders the purely repulsive interaction in free space into an oscillating two-body force and potential which exhibits a variable number of minima and potential wells depending on the pitch and the radius of the helix [1]. We discuss few- and many-body systems and their peculiar behaviour due to this oscillating two-body interaction. Scattering from a helical inhomogeneity can lead to bound oppositely charged particles as well as their dissociation in a collision process [2]. We explore the formation of Wigner crystals for charged particles on a toroidal helix. Focusing on certain commensurate cases we show that the ground state undergoes a pitchfork bifurcation from the totally symmetric polygonic to a zig-zag-like configuration with increasing radius of the helix. The collapse of the vibrational frequency spectrum to a single frequency allows for an essentially independent small-amplitude motion of the individual particles and localized excitations can propagate without significant spreading. Increasing the radius beyond the degeneracy point, the band structure is inverted [3]. Nonlinear excitations [4] as well as a pinned-to-sliding transition and structural crossover are explored as well [5]. Finally we discuss the unusual bending behaviour of charged helices [6].

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Non-smooth optimization in the geometric inverse problem of gravimetry

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Here I shall present some new results for geometric inverse problem of geophysical gravimetry. Long-lasting oil and gas field mining can lead to negative consequences. Main geodynamic negative effects include deformation and seismic. Gravimetric monitoring can help predict these phenomena [1]. 2D inverse problem is stated: to locate a homogeneous gravitational anomaly by the results of on-surface gravimetry. The model is based on Poisson's equation $\Delta\eta = -4\pi G\psi$, and has some specific conditions for the part of boundary. It is shown that the target functional has a derivative in any direction, but its gradient does not exist. An esteem of its subgradient is given. For the numerical solution of the problem, subgradient method, Nelder-Mead, and the genetic algorithms are used. A comparative analysis of the applied algorithms is given based on the calculation results. According to this, among the named, 1) the subgradient method is least effective (error about 2%-22%), and the Nelder-Mead is the best; 2) all 3 algorithms show better accuracy for abscissae, due to given initial conditions (genetic is most precise about 6 times); 3) Nelder-Mead method has slight advantage in restoring the ordinate (about 0.15%) [2] *Acknowledgements*: The research was supported by project AP ÀÐ05135158 (SC MES RK).

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Širjenje valov v ekscitabilnih tkivih: od teoretičnih in komputacijskih modelov do analize eksperimentalnih podatkov

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Širjenje eksitacijskih valov med električno sklopljenimi ekscitabilnimi celicami je eden izmed glavnih sinhronizacijskih mehanizmov v večceličnih sistemih. V Langerhansovih otočkih trebušne slinavke so presledkovni stiki glavni deležniki električne sklopitve med celicami beta in imajo pomembno vlogo pri koordinaciji pulzirajočega sekrecijskega odziva inzulina na povišano raven glukoze v krvi in s tem na ravnovesje nutrientov v telesu. Izkazalo se je, da motnje v medcelični signalizaciji vodijo do desinhronizirane aktivnosti celic beta. To privede do porušenja normalnih vzorcev izločanja inzulina pri povišani glukozi, kakor je to značilno tudi za sladkorno bolezen tipa 2 [1]. Ker je povezanost celic beta zelo pomemben vidik patogeneze sladkorne bolezni, je kolektivna aktivnost celic beta predmet teoretičnih in eksperimentalnih raziskav že več desetletji [2, 3, 4]. Kljub temu pa je funkcionalna organiziranost sinhrnonizacije aktivnosti celic beta preko Ca^{2+} valov slabo razumljena. Ena glavnih ovir je težavnost detekcije in ovrednotenja Ca^{2+} valov v eksperimentih, predvsem zaradi razmeroma hitrega širjenja valov v treh dimenzijah in njihove heterogenosti, pri izvedbi meritev pa smo omejeni na opazovanje na eni ploskvi oziroma optični ravnini. Zaradi tega nam eksperimentalni podatki nudijo zelo omejene informacije o dejanskem dogajanju in komunikaciji med celicami. Da bi boljše razumeli vzorce eksperimentalnih meritev Ca^{2+} valov v Langerhansovih otočkih trebušne slinavke smo razvili teoretični in komputacijski model. S preprostim teoretičnim modelom opičemo širjenje in hitrostni profil homogenih valov v treh dimenzijah. Komputacijski model pa je bolj realističen in opisuje širjenje eksitacijskih valov med heterogenimi in heterogeno sklopljenimi ekscitabilnimi celicami. Slednje je še posebej pomembo za raziskovanje vpliva resnične morfološke heterogenosti v tkivih na hitrostni profil širjenja valov. Pridobljeni teoretični in komputacijski rezultati nam ne pomagajo samo pri interpretaciji netrivialnih eksperimentalnih opažanj, ampak tudi pri določanju pomembnih fizioloških karakteristik, kot na primer območja proženja valov, njihova obstojnost in hitrost širjenja valov med celicami [5].

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Wave propagation in excitable tissues: from theoretical and computational models to the analysis of experimental data

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Excitation wave propagation between electrically coupled excitable cells is one of the main synchronization mechanisms in multicellular systems. In pancreatic islets of Langerhans, gap junction-mediated electrical coupling between β cells plays a major role in coordinating a pulsatile secretory response of insulin at elevated glucose levels, thereby playing a major role in whole body homeostasis of nutrients. Most importantly, disrupted intercellular communication pathways were found to cause a loss of synchronized β cell activity, leading to an impairment of normal oscillatory patterns of insulin secretion elicited by glucose, a defining characteristic of obesity and type 2 diabetes mellitus [1]. Motivated by the fact that the β cell connectivity is a very important aspect in the pathogenesis of diabetes, the collective activity of β cell populations has been intensively studied experimentally and theoretically for decades [2, 3, 4]. Regardless of the many endeavors, the functional organization of synchronized β cell activity via Ca^{2+} waves is incompletely understood. One of the major obstacles is that the waves are hard to assess experimentally. They propagate rather fast in three dimensions and they are heterogeneous. However, optical imaging enables high spatio-temporal resolution recordings only in two-dimensions, i.e. in one focal plane. Experimental data therefore offers only limited information. To better understand the measured patterns, we designed a theoretical and a computational model with the aim to better understand the principles of Ca^{2+} wave propagation in the islets. The theoretical model is very simple and describes the propagation and velocity profiles of uniform waves in three-dimensional space. The computational model is more realistic and describes the propagation of excitation waves between heterogeneous and heterogeneously

coupled excitable cells. The latter is particularly important for investigating how such genuine distortions and morphological anomalies disrupt the velocity profiles, as it is the case in realistic tissues. The obtained theoretical and computational results do not only help us to interpret the non-trivial experimental observations, but also help us to extract important physiological characteristics, such as the identification of initiation sites, their persistence, and the intercellular wave propagation speed [5].

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A microwave realization of the chiral ensembles

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Random matrix theory has proven very successful in the understanding of the spectra of chaotic systems [1, 2]. Depending on symmetry with respect to time reversal and the presence or absence of a spin 1/2 there are three ensembles, the orthogonal, unitary, and symplectic one. If there is in addition a particle-antiparticle symmetry, the chiral variants of these ensembles appear [3]. The list is completed by four more random matrix ensembles resulting in the *ten-fold way* [4].

A microwave study of the chiral orthogonal, unitary, and symplectic ensembles is presented using a linear chain of evanescently coupled dielectric cylindrical resonators [5]. A typical feature of these ensembles is a mirror symmetry of the spectrum with respect to an energy zero E_0. Close to E_0 the eigenvalues feel the neighborhood of their symmetry equivalent partners leading to a possible eigenvalue repulsion at E_0. In all cases the predicted repulsion behavior could be experimentally verified.

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Non-steady resonant wave scattering by small particles

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A survey of the recent results of the author in the unsteady high-Q resonant scattering of ultrashort pulses by a particle, whose size is comparable or smaller than the wavelength of the incident radiation at the carrier frequency is presented. It is shown that the unsteadiness of the scattering process may result in qualitative changes in the manifestation of the phenomenon both in the near-field and in far-field wave zones. Most attention is paid to the dynamics of the nonradiating anapole modes and dynamic Fano resonances, which are discussed in detail. Simple, analytically tractable models of driven coupled oscillators are proposed to describe the transient processes. Their comparison with the results of the direct numerical integration of the complete set of the Maxwell equations shows that the models exhibit high accuracy in the quantitative description of the phenomenon.

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Probing an excited-state quantum phase transition in a quantum many-body system via an out-of-time-order correlator

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Out-of-time-order correlators (OTOCs) play an increasingly important role in different fields of physics and, in particular, they provide a way of quantifying information scrambling in quantum many-body systems. We verify that an OTOC can be used to probe an excited-state quantum phase transition (ESQPT) in a quantum many-body system. We examine the dynamical properties of an OTOC in the Lipkin-Meshkov-Glick (LMG) model, which undergoes an ESQPT, using the exact diagonalization method. We show that the long time evolution of the proposed OTOC is remarkably different in the different phases of the ESQPT. In consequence, we put the long-time averaged value of the OTOC forward as a possible ESQPT order parameter. Our results highlight the connections between OTOCs and ESQPTs, opening the possibility of using OTOCs for accessing experimentally ESQPTs in quantum many-body systems.

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Določanje kemične sestave zvezd

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Del helija in skoraj vsi težji kemični elementi v vesolju zlagoma nastajajo v zvezdah. Torej mešanica kemičnih elementov v zvezdnih ovojnicah priča o kemični sestavi medzvezdne snovi ob nastanku zvezde, pri starih zvezdah je bilo to lahko pred 10 milijardami let in več. Žal je meritev kemične sestave draga, saj klasična spektroskopska analiza preučuje vsako zvezdo posebej in je bila zato narejena le za majhne vzorce.

Veliki pregledi neba, kot so Gaia, RAVE, Gaia-ESO in GALAH sliko močno spreminjajo, saj je spektroskopijo sedaj mogoče narediti za stotisoče ali milijone zvezd, s tem pa prvič razkriti tudi zgodovino nastajanja kemičnih elementov v naši Galaksiji. Predstavil bom tekoče rezultate teh velikih pregledov neba, pri katerih sodelujemo, obenem pa se bom dotaknil ideje, ki je medtem prerastla v projekt Evropske vesoljske agencije, ki predlaga grobo meritev kemične sestave s prilagojenim direktnim slikanjem, ki je mnogo cenejše od spektroskopije.

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Measurement of chemical composition of stars

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Part of helium and all heavier chemical elements are being produced in stars. So the chemical mix in stellar envelopes is a witness to chemical composition of interstellar matter at the time of star's formation; in old stars these could mean 10 or more billion years ago. Unfortunately chemical composition measurement is expensive, as classical spectroscopy can analyse only one star at a time. So it is limited to small samples.

Large sky surveys, like Gaia, RAVE, Gaia-ESO and GALAH, are changing this picture, as spectroscopy is now doable for hundreds of thousands or for millions of stars. So we can build a picture of chemical enrichment of the Galaxy for the first time. Some current results of these surveys (to which we are contributing) will be presented. Moreover, an idea which promises a rough measurement of chemical composition using a much cheaper direct imaging technique and which now became a project of the European Space Agency will be introduced.

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