Nenavadna spinska tekočina s spini atomskih skupkov v $1T$-TaS_2

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Obstoj kvantne spinske tekočine (QSL) v kateri močne kvantne fluktuacije spinov preprečijo spinsko urejanje vse do temperature 0, je bil teoretično predlagan že pred več kot 40 leti. Leta 1973 je Anderson vpeljal model resonančne valenčne vezi (RVB) [1], ki naj bi predstavljal osnovno stanje trikotne mreže $S = 1/2$ Heisenbergovega antiferomagneta namesto bolj običajnega Néel stanja. Predlog je bil osnovan na trikotni mreži Ta atomov v plastovitem $1T$-TaS_2 in je poskušal razložiti nekatere nenavadne magnetne lastnosti tega materiala. Od takrat je seznam kandidatov za QSL na trikotni mreži, t.j. stanje brez spontanega zloma simetrije in z nenavadnimi frakcionalnimi vzbuditvami, še vedno presenteljivo kratek: $YbMgGaO_4$ [2] in nekateri organski molekularni sistemi, npr. κ-$(ET)_2Cu_2(CN)_3$ [3]. V primerjavi s temi sistemi pa ima $1T$-TaS_2 idelano trikotno mrežo in šibkejšo spin-orbit sklopitev, kar ponuja nove možnosti za raziskave antagonističnih stanj QSL in Néelovega antiferomagneta. Tu poročamo o našem odkritju [4] skoraj idealne spinske tekočine, ki se vzpostavi na trikotni mreži spinov atomskih skupkov v CDW stanju $1T$-TaS_2. V tem sistemu imajo nabojne vzbuditve dobro določeno nabojno energijsko režo ~ 0.3 eV, medtem ko jedrska kvadrupolna resonanca in mionska spinska relaksacija kažeta na spinske vzbuditve brez energijske reže znotraj QSL ter odsotnost magnetnega reda vse do 70 mK. Značilno T^2 potenčno odvisnost spinske relaksacije, ki je značilna za QSL, smo opazili med 200 K in $T_f = 55$ K. Pod to temperaturo smo opazili novo stanje brez spinske energijske reže ter z zmanjšano gostoto spinskih vzbuditev znotraj stanja s povečanim neredom.

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An unconventional quantum spin liquid with atomic-cluster spins in $1T$-TaS_2

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The existence of a quantum spin liquid (QSL) in which quantum fluctuations of spins are sufficiently strong to preclude spin ordering down to zero temperature was originally proposed theoretically more than 40 years ago, but its experimental realisation turned out to be very elusive. In 1973 Anderson introduced a resonating valence bond (RVB) state [1] as a new kind of insulator that was proposed to be the ground state of the triangular-lattice S = 1/2 Heisenberg antiferromagnet instead of a more conventional Néel state. The proposal was put forward to account for the unusual magnetic properties of a perfect triangular atomic lattice of Ta atoms in the layered transition metal dichalcogenide $1T$-TaS_2. Since then, the list of materials with triangular lattice and with properties indicating the existence of QSL, i.e., a state without spontaneously broken triangular lattice symmetry and whose behaviour is dominated by emergent fractional excitations, is still remarkably short: it includes $YbMgGaO_4$ [2] and some organic molecular solids, e.g., κ-$(ET)_2Cu_2(CN)_3$ [3]. Compared to these compounds, layered dichalcogenides have perfect triangular lattice geometry and a weaker spin-orbit coupling, offering a possibility for obtaining a unique insight into the competition between antagonistic QSL and Néel states, however, no signatures of QSL behaviour have been observed so far with spins on atomic lattice sites. Here we report [4] on an almost ideal QSL that appears to be realized by atomic-cluster spins on the triangular lattice of a charge-density wave (CDW) state of $1T$-TaS_2. In this system, the charge excitations have a well-defined gap of about ~ 0.3 eV, while nuclear magnetic quadrupole resonance and muon spin relaxation experiments reveal that the spins show gapless quantum spin liquid dynamics and no long range magnetic order down to 70 mK. Canonical T^2 power-law temperature dependence of the spin relaxation dynamics characteristic of a QSL is observed from 200 K to $T_f = 55$ K. Below this temperature we observe a new gapless state with reduced density of spin excitations and high degree of local disorder signifying new quantum spin order emerging from the QSL.

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Dinamika porazdelitve energije in adiabatske invariante v homogenih časovno odvisnih Hamiltonskih sistemih

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Če se parametri sistema, katerega dinamika je ergodična na energijski lupini, spreminjajo počasi glede na ergodično časovno skalo, potem se sistem giblje tako, da je volumen znotraj energijske lupine na kateri se sistem nahaja ob času t, in ga označimo z $\Omega(t)$, približna konstanta gibanja oziroma adiabatska invarianta. Znana posledic tega je enačba stanja $V\,T^{f/2} =$ konstanta za adiabastke procese v idealnih plinih.

V primeru, da dinamika sistema ni egodična na energijski lupini, $\Omega(t)$ ni konstanta gibanja.

Kakorkoli, v tem predavanju bom pokazal, da obstaja neka druga koliina, ki se ohranja za vse homogene Hamiltonske sisteme, tudi neergodične.

Volumen faznega prostora znotraj energijske lupine v homogenih Hamiltonskih sistemih je oblike $\Omega(t) = E^{\gamma}\,\Sigma(t)$, kjer je E energija, γ nek eksponent in $\Sigma(t)$ nek časovno odvisni geometrijski faktor. Teoretično bom pokazal, da je količina $\Sigma(t)/\left\langle E^{-\gamma}\right\rangle$, kjer $\langle\rangle$ predstavlja povprečenje, adiabatska invarianta, neodvisna od dinamičnih lastnosti sistema. Še več, pokazal bom, da v primeru, ko je variacija sistema periodična, momenti porazdelitve energije, $\langle E^n\rangle$, kjer $n \in \mathbb{R}$, naraščajo eksponentno za vse n, ki zadoščajo $(n < -\gamma)$ in $(n > 0)$, in eksponentno padajo za $(-\gamma < n < 0)$. Za $n = 1$ sledi eksponentno Fermijevo pospeševanje [1].

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Evolution of energy distribution and adiabatic invariants in homogeneous time-dependent Hamiltonian systems

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If parameters of a system whose dynamics is ergodic are varied slowly compared to an ergodic time scale, then the system evolves in such a way that a volume of a phase enclosed by the corresponding energy shell, $\Omega(t)$, is an approximate constant of motion or adiabatic invariant. A well known consequence of this is the equation of state $V\,T^{f/2} = \text{constant}$ for an adiabatic process in the ideal gas.

If dynamics of a system is not ergodic then $\Omega(t)$ is not preserved.

However, in this talk I will show that there exists another quantity which is adiabatically preserved in all homogeneous Hamiltonian systems, including nonergodic.

In homogeneous Hamiltonian systems a volume of the phase space enclosed by an energy shell takes the form $\Omega(t) = E^{\gamma}\,\Sigma(t)$, where E is the energy, γ is some exponent and $\Sigma(t)$ is some time-dependent geometrical factor. I shall show theoretically that the quantity $\Sigma(t)/\left\langle E^{-\gamma}\right\rangle$, where $\langle\rangle$ denotes the averaging over an energy distribution, is an adiabatic invariant, independent of the dynamical properties of the system. Additionally, I shall show that if the parameters of the system vary periodically, then, in general, the moments of the energy distribution, $\langle E^n\rangle$, where $n \in \mathbb{R}$, grow exponentially with the number of oscillations for all exponents n that satisfy $(n < -\gamma)$ and $(n > 0)$, and decrease exponentially for $(-\gamma < n < 0)$. In particular, for $n = 1$ this implies exponential Fermi acceleration [1].

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Generalized entropies for stochastic models

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First I list wished properties of an entropic distance measure, then present the proof of its shrinking relative to the stationary distribution for stochastic dynamics linear in the occupation probability. It shall be emphasized that this proof does not rely on the *detailed balance* principle, as e.g. Boltzmann's H-theorem does, but on the contrary, it suffices with the *total balance*. The latter actually defines the stationary distribution, so it is not a further constraint on the transition rates between possible states.

Then I repeat the proof with a general (non-linear) functional dependence on the starting state probabilities in the master equation. The entropic distance constructed this way is guaranteed to shrink during the time evolution. However, it is no more in the familiar Kullback–Leibler form, nor can it be treated as a relative entropy.

Furthermore, the general entropic distance to the uniform distribution is the basis of deriving the formula for the entropy – probability relation. While in the linear dynamics our recepie leads to the Boltzmann–Gibbs–Planck–Shannon formula for the entropy, for a power-like dependence the Tsallis–entropy emerges. The non-extensivity of the generalized entropy stemming from nonlinear master equations is signalized among other in the fact, that the entropic distance to the uniform distribution (still being of maximal entropy without further constraints) is dependent on the total number of states.

Finally a particular stochastic model, describing unidirectional growth and random resets to a selected ground state, will be presented. It is simple and powerful at the same time, leading to ramified applications.

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Večdelčna lokalizacija v sistemih koreliranih elektronov

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V prvem delu [1] bom pokazal, da sklopitev med elektroni ter spinskimi valovi vodi do delokalizacije v sistemu z neredom, ki ga naboji čutijo preko naključno porazdeljenih potencialnih energij. Analiza temelji na analizi dinamike ene vrzeli v eno dimenzionalnem t-J modelu. Do delokalizacije naboja pride celo v primeru močnega nereda razen tedaj, ko obstaja mehanizem, ki lokalizira tudi spinski podprostor oziroma spinske valove. V primeru delokalizacije vrzeli je njena dinamika subdifuzivna.

V drugem delu [2] bom predstavil analizo dinamike ene vrzeli v primeru naključno porazdeljenih magnetnih polj. Pokazal bom, da močan nered, ki se sklaplja na spinski podprostor, vodi do lokalizacije naboja ter tudi spinskih prostostnih stopenj. Ne glede na dejstvo, da nismo uspeli natačno določiti vrednosti kritičnega nereda, naše analize kažejo na možnost obstoja dveh različnih lokalizacijskih prehodov. Z večanjem nereda se najprej lokalizirajo spinske prostostne stopnje. Do lokalizacije naboja pride šele pri večjih vrednostih nereda, ko spinska lokalizacijska dolžina pade pod velikost ene mrežne razdalje. Na koncu bom obravnaval tudi primer končnega dopiranja.

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Many Body Localization in Correlated Electron Systems

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In the first part [1] I will show that electron-magnon interaction delocalizes the particle in a system with strong charge disorder. The analysis is based on results obtained for a single hole in the onedimensional t-J model. Unless there exists a mechanism that localizes spin excitations, the charge carrier remains delocalized even for a very strong charge disorder and shows subdiffusive motion up to the longest accessible times [1].

In the second part [2] I will present a study of dynamics of a single hole subject to a random magnetic field. Strong disorder that couples only to the spin sector localizes both spin and charge degrees of freedom. While we cannot precisely pinpoint the threshold disorder, we conjecture that there are two distinct transitions. Weaker disorder first causes localization in the spin sector. Carriers become localized for somewhat stronger disorder when the spin localization length is of the order of a single lattice spacing. I will also discuss finite doping.

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The Importance of Asymmetry in the Dynamics of Coupled Laser Systems

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Coupled laser systems have been extensively studied in the presence of *PT-symmetry*, where one waveguide's loss equals the other's gain. Here, we exclusively consider asymmetric settings starting with two coupled waveguides with unequal gain and loss. We show that unlike the symmetric case, there exist *finite-power, constant-intensity nonlinear supermodes*, which are stable under *modulational perturbations* and thus ideal for controlled and directed transport in optical devices. Next, we study the "photonic dime" of two asymmetrically coupled semiconductor lasers with carrier density dynamics and show that, for large parameter regions, there exist stable asymmetric *phase-locked states*, which can be dynamically controlled by appropriate current injection. We also demonstrate that the eigenvalue spectrum of *its zero-state* possesses spectral transition properties and exceptional points under much more general conditions than those imposed by PT-symmetry, while its bifurcations explain experimentally observed self-termination effects. For *the nonzero states*, we show that their spectral transitions and exceptional points have *observable spectral features* that can be controlled by detuning and pumping to reveal a great potential for technological applications in integrated photonics.

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THAT KIND OF MOTION WE CALL HEAT

a major societal problem for the 21st century

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Providing a sustainable supply of energy to the worlds population will become a major societal problem for the 21st century as fossil fuel supplies decrease and world demand and environmental concern increases. Thermoelectric phenomena, which involve the conversion between thermal and electrical energy, and provide a method for heating and cooling materials, are expected to play an increasingly important role in meeting the energy challenge of the future.

To this end it is important to understand the microscopic mechanism which determines the macroscopic laws of heat and particles transport and allows to control the heat current.

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Dowserji in bowserji v nematskih mikrokanalih

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Nematski tekoči kristal v tanki plasti s pravokotnim sidranjem na površini, lahko zavzame poleg trivialnega stanja tudi pobeglo stanje z zlomjeno rotacijsko simetrijo, ki se obnaša kot kvazi-dvodimenzionalno vektorsko polje, t.i. dowser stanje [1]. Pri toku nematika po mikrokanalih so hidrodinamski učinki sklopljeni z energijo različnih stanj in prehodov med njimi, kar vodi do zanimive dinamike in novih pojavov [2-4].

Predstavil bom analitični model kvazi-dvodimenzionalnega dowser stanja v sklopitvi z različnimi zunanjimi polji. Model privede do sine-Gordonove enačbe s solitonskimi rešitvami ter napove relaksacijsko dinamiko stanja. Posvetil se bom tudi specifični sklopitvi s tokom in stabilizaciji dowser stanja v primeru nematika v mikrokanalih, ter raziskal gibanje fazne meje med dowser stanjem in upognjenim homeotropnim stanjem (t.i. bowser) [5].

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Dowsers and bowsers in nematic microchannels

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Nematic liquid crystal in a thin slab with homeotropic surface anchoring can, in addition to the trivial uniform state, assume an escaped broken-symmetry state, which behaves as a quasi-planar vector field, the so called dowser state [1]. When flowing in microchannels, hydrodynamic effects couple to the energy of different states and the transitions between them, leading to interesting dynamics and new phenomena [2-4].

I will present an analitical model of the quasi-planar dowser state, coupled to different external fields. The model leads to the sine-Gordon equtation with well known solitonic solutions and predicts the relaxation dynamics of the dowser state. I will also demonstrate the coupling to the flow and stabilization of the dowser state in the case of nematic flow in microchannels, and the motion of the phase boundary between the dowser state, and the bowed homeotropic state (bowser state) [5].

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Samo-sestavljanje amiloidnih fibrilov

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Sposobnost bioloških molekul, da se sestavijo v višje funkcionalne strukture, je temelj življenja. Večinoma ta sestava vključuje kompleksne celične mehanizme, vendar obstajajo proteinske strukture, ki so se zmožne reproducirati brez pomoči celic. Takšne so tudi patološki proteinski fibrili, imenovani amiloidi, ki so delno odgovorni za preko 30 človeških bolezni kot so Alzherimerjeva in Parkinsonova bolezen.
V sestavo amiloidnih fibrilov je vključenih več zapletenih procesov, med drugim nukleacija, elongacija, fragmentacija in samoreplikacija. Slednja se je izkazala za temeljno lastnost patološke samoizgradnje in dela proces sestave amiloidov avtokatalitičen in zato težko ustavljiv, ko se sproži.
V tem prispevku bom predstavil splošno kinetiko samoizgradnje amiloidov, se bolj podrobno posvetil avtokatalitični samoreplikaciji in povzel ključne posledice za premagovanje Alzheimerjeve bolezni.

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Self-assembly of amyloid fibrils

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The ability of biological molecules to assemble into higher order functional structures is the foundation of life. Mostly, this assembly processes involve complex cellular machinery. However, some protein structures are able to self-assemble without any aid, such as pathological protein fibrils, called amyloids, which are implicated in over 30 human diseases, including Alzheimer's and Parkinson's.
A number of intricate processes simultaneously participate in the formation of amyloid fibrils, including nucleation, elongation, fragmentation and self-replication. The later in particular has emerged as a general feature of pathological protein self-assembly, making the amyloid formation process auto-catalytic and quite uncontrollable once under way.
In this talk, I will present the general kinetics of amyloid self-assembly, more closely focus on the self-replication part of the assembly and discuss some major application for the research on Alzheimer's disease.

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Fizikalne lastnosti visokoentropijskih spojin

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Klasične kovinske zlitine so osnovane na enem večinskem kemijskem elementu kot matriki, v katero so lahko primešane majhne količine drugih kemijskih elementov za izboljšanje fizikalno-kemijsko-mehanskih lastnosti in lažjo sintezo materiala. Doslej je bilo razvitih okrog trideset tehnološko pomembnih kovinskih zlitin, ki temeljijo na enem od večinskih elementov Fe (razna jekla), Al, Cu, Ti, Mg in Ni. Sedemdeseta leta prejšnjega stoletja veljajo za obdobje, ko je razvoj kvalitetnih zlitin z enim večinskim elementom dosegel končno stopnjo. Poizkusi sintetizirati zlitine z več večinskimi elementi so vodili do razvoja intermetalnih spojin, kvazikristalov (translacijsko neperiodičnih struktur z redom dolgega dosega, ki vsebujejo kristalografsko prepovedane simetrije 5-, 8- 10- in 12-števne rotacijske osi) in amorfnih zlitin (kovinskih stekel). Praktično vse doslej znane kovinske zlitine iz omenjenih skupin še vedno temeljijo le na enem večinskem kemijskem elementu.

V zadnjih letih so bile razvite konceptualno nove kovinske zlitine z več večinskimi kemijskimi elementi v enakih ali približno enakih molarnih razmerjih. Te zlitine so bile poimenovane visokoentropijske kovinske spojine (ang. High-Entropy Alloys HEA; v nadaljevanju jih bomo okrajšano imenovali HEA zlitine) [1,2]. Velika mešalna entropija, ki je posledica slučajnega mešanja kemijskih elementov na kristalni mreži, lahko stabilizira kemijsko neurejeno trdno raztopino s preprosto kristalno strukturo, kot sta npr. telesno centrirana kubična (bcc) in ploskovno centrirana kubična (fcc) mreža z majhno osnovno celico. Za strukturo HEA zlitin je značilna topološko urejena kristalna mreža z izjemno velikim kemijskim neredom zaradi naključne razporeditve atomov različnih kemijskih elementov na mrežnih mestih, zato lahko HEA zlitino na nek način smatramo kot "kovinsko steklo na urejeni kristalni mreži". Primeri HEA zlitin so sistemi Al-Si-Co-Cr-Cu-Fe-Mn-Ni-Ti, W-Nb-Mo-Ta-V in Ta-Nb-Hf-Zr-Ti.

Fizikalne lastnosti HEA zlitin doslej večinoma niso bile raziskovane. Leta 2014 je bila odkrita prva superprevodna HEA zlitina Ta-Nb-Hf-Zr-Ti [3]. Ta zlitina ima za

kovine spojine relativno visoko temperaturo prehoda v superprevodno stanje pri 7,3 K in visoko zgornje kritično magnetno polje 8,2 T. Mikroskopski izvor superprevodnosti v Ta-Nb-Hf-Zr-Ti HEA ostaja odprto vprašanje.

HEA zlitine s heksagonalno strukturo so bile odkrite pred kratkim v mešanicah lantanidov Gd-Tb-(Ce,Y,Lu)-Ho-Dy. Take HEA zlitine kažejo množico različnih magnetnih faz v diagramu temperaturamagnetno polje, kot so helikoidalna antiferomagnetna faza (komenzurabilna ali inkomenzurabilna s kristalno mrežo), neurejena feromagnetna faza in eksotične modulirane magnetne in metamagnetne faze [4].

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Physical Properties of HighEntropy Alloys

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Traditionally, metallic alloy systems have been based mainly on one principal chemical element as the matrix, even though a substantial amount of other elements is incorporated for property/processing enhancement. To date there has been about thirty practical alloy systems developed, including Fe (steels), Al, Cu, Ti, Mg, and Ni-based alloys. The attempts to produce alloys with more than one principal element have lead to the development of intermetallic compounds, quasicrystals (translationally non-periodic long-range ordered structures exhibiting crystallographically forbidden symmetries of 5-, 8-, 10-, and 12-fold rotation axes) and bulk amorphous alloys (metallic glasses). Within the past several years, a new approach to alloy design with multiple principal elements in equimolar or near-equimolar ratios, termed high-entropy alloys (HEAs), has been proposed [1,2]. According to this concept, high entropy of mixing can stabilize disordered solid solution phases with simple structures like a body-centered cubic (bcc), a face-centered cubic (fcc) and a hexagonal close-packed (hcp) lattice and prevent formation of intermetallic phases during solidification. In order to achieve high entropy of mixing, the alloys must be composed typically of five or more (up to thirteen) major elements in similar concentrations, ranging from 5 to 35 at. % for each element, but do not contain any element whose concentration exceeds 50 at. %.

The number of possible HEAs is unlimited. Examples are HEAs with bcc or fcc structure were derived within the systems Al-Si-Co-Cr-Cu-Fe-Mn-Ni-Ti, W-Nb-Mo-Ta-V, and Ta-Nb-Hf-Zr-Ti. Most existing studies are focused on the relationship between phase, microstructure and mechanical properties. It has been demonstrated that HEAs exhibit enhanced mechanical properties like high hardness and solid-solution strengthening, whereas no exceptional physical properties were reported. We have synthesized the first superconducting HEA with composition

Ta34Nb33Hf8Zr14Ti11 (in at. %). The measurements of the electrical resistivity, the magnetization and magnetic susceptibility and the specific heat reveal that the Ta34Nb33Hf8Zr14Ti11 HEA is a type II superconductor with a moderately high transition temperature 7.3 K, an upper critical field of 8.2 T, a lower critical field of 35 mT and an energy gap in the electronic density of states at the Fermi level of 2.2 meV [3]. NMR spectroscopy was used to study the electronic density of states.

HEAs with a hexagonal structure were discovered recently in the lanthanide series (Gd-Tb-(Ce,Y,Lu)-Ho-Dy), which show a rich diagram of magnetic phases in the temperaturemagnetic field phase diagram, comprising helical antiferromagnetic phases (both incommensurable and commensurable with the crystal lattice), ferromagnetic phases and exotic magnetic phases with long-range ordered moments [4].

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Preučevanje dejavnikov za kritično dinamiko in potenčno obnašanje v sklopljenih bioloških sistemih

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Samoorganizirana kritičnost in kritična dinamika sta med najbolj aktualnimi koncepti v fiziki in sta imela ključen vpliv na razvoj znanosti kompleksnih sistemov. V osnovi ta koncepta predvidevata, da je prostorska in/ali časovna razsežnost sistemskih opazljivk skalno-invariantna, kar se odraža s potenčno porazdelitvijo [1,2]. V zadnjem desetletju postajajo ti principi vse bolj popularni tudi pri preučevanju bioloških sistemov, predvsem zaradi tega, ker se jih povezuje z optimalnim načinom delovanja. Toda osnovni matematični formalizem predvideva, da naj bi sistem izkazoval kritično obnašanje le v neposredni bližini točke faznega prehoda [3], kar pa je z vidika realnih bioloških sistemov precej nerealna predpostavka. V naši študiji

problematiko v prvi vrsti naslovimo z izdelavo matematičnega modela sklopljenih ekscitabilnih oscilatorjev, v katerega vključimo nekatere realne fiziološke parametre, kot so variabilnost, večmodalna oscilatorna aktivnost in heterogeno okolje. Naši numerični rezultati pokažejo, da vključitev tovrstnih fizioloških determinant znatno razširi območje kritičnega delovanja. V nadaljevanju preučimo tudi, če lahko koncept samoorganizirane kritičnosti najdemo tudi v realnem biološkem sistemu - v mreži celic beta v Langerhansovih otočkih. Na podlagi statistične analize dinamike medceličnih kalcijevih valov, ki je bila izmerjena v akutnih tkivnih rezinah s konfokalnim mikroskopom, pokažemo, da pod fiziološkimi pogoji porazdelitev velikosti teh valov sledi potenčni funkciji, kar odraža kritičnost [4]. Naša študija podaja nova spoznanja na področju emergentne dinamike v večceličnih sistemih.

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Exploring the determinants for critical dynamics and power-law behavior in coupled biological systems

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Self-organized criticality and critical dynamics are one of the most stimulating concepts in physics and have played a significant role in the development of complexity science. The concept asserts that the spatial and/or temporal extent of system's observables is characterized by scale invariance, which is usually identified as a power-law distribution [1,2]. In the last decade, these principles are increasingly gaining on attention in biological systems research, as they are associated with optimal operational abilities. However, the basic mathematical formalism proclaims that criticality can only be found in the proximity of the phase transition point [3],

which is from the viewpoint of realistic biological systems, an unrealistic proposition. To address this issue we first build a mathematical model of coupled excitable oscillators and include some genuine physiological determinants, such as variability, multimodal oscillatory activity and a heterogeneous environment. Our numerical results reveal that building-in such particularities can significantly broaden the range of critical behavior. Second, we explore whether fingerprints of self-organized criticality can be found in a realistic biological system - the interconnected beta cells from islets of Langerhans. By statistically analyzing the spatio-temporal organization of intercellular calcium waves measured in acute tissue slices by means of confocal imaging we show that the distribution of wave sizes under physiological circumstances follows a power law, thus indicating critical behavior [4]. Our study provides new insights into the emergent dynamics of multicellular systems.

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Many-body chaos, black holes and hydrodynamics

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Establishing connections between the physics of black holes and properties of many-body chaos has been a prolific field of research in the past few years. In my talk, I will review this recent progress by focusing on the gravitational methods for computing the out-of-time-ordered correlation functions (OTOC's), which can be used to extract the Lyapunov exponent and the butterfly velocity of a (holographically) dual large-N system. Then, I will discuss why transient exponential growth of OTOC's is insufficient for establishing chaos and how one can propose new measures of chaos, which are sensitive to late-time dynamics. Drawing from our knowledge that late-time dynamics of typical holographic field theories is governed by hydrodynamics, in the last part of my talk, I will show a concrete realisation of how in strongly coupled, large-N theories with a holographic dual, hydrodynamics and many-body chaos are controlled by the same underlying microscopic processes.

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Difuzija v deterministič nih sistemih na mreži

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Predstavila bom model klasičnih nabitih trdih delcev na mreži. V sistemu opazimo različne transportne lastnosti; balističen transport, difuzijski transport in izolatorsko obnašanje. Za ta sistem je možno eksplicitno izraziti avtokorelacijsko funkcijo toka in izračunati dolgočasovno limito razporeditve naboja po začetnem nehomogenem stanju.

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Diffusion in deterministic interacting lattice systems

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I will discuss a model of classical charged partiles on a lattice with hard-core interaction. The system exhibits three types of transport phenomena, ranging from ballistic, throught diffusive to interacting. It is possible to explicitly obtain current-autocorrelation function and calculate the long-time charge profile after an inhomogeneous quench.

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Tipski model mnogodelčnega kvantnega kaosa

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Kaotično obnašanje klasične limite nekaj delčnega kvantnega modela nam da za obnašanje spektera rezultat naključnih matrik [1]. Spekter splošnih neintegabilnih mnogodelčnih kvantnih sistemov (ki nimajo klasičnih limit) tudi kaže obnašanje spektra naključnih matrik, za kar nimamo dobre razlage.

Poskusil bom osvetliti ta problem tako, da bom predstavil model naključnih faz. Razložil bom obnašanja spektra tega modela in predstavil povezavo z mnogodelčnimi brcanimi spinskimi modeli.

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Toy Model of Many-body Quantum Chaos

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It has been shown that the chaos in the classical limit of the few-body quantum system leads to the random matrix behaviour of the quantum model's spectrum [1]. The spectra of a generic non-integrable many-body quantum system (which lacks classical limit) also follows the random matrix behaviour, but there is no satisfactory explanation of this phenomena.

I will try to shed some light on this problem by discussing a toy model called the random phase model. After explaining its solution, I will discuss the connection to the kicked spin models.

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Družina stanj z difuzijskim spinskim transportom v izotropnem Heisenbergovem modelu

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Tako nove kot stare numerične študije namigujejo, da je spinski transport v izotropnem Heisenbergovem modelu superdifuzijski. Predstavil bom družino stanj v tem modelu, za katero se da pokazati, da je spinska dinamika difuzijska do eksponentno dolgih časov.

A class of states supporting diffusive spin dynamics in the isotropic Heisenberg model

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Both recent and past numerical studies suggest that the spin transport in the Heisenberg model at the isotropic $\Delta = 1$ point should be superdiffusive. I will briefly present a set of states for which the dynamics can be shown to be diffusive up to exponentially long times.

Vidiki difuzije pri biljardu v stadionu

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Dinamični biljardi so pomembni modelski sistemi, uporabni pri študiju tako kvantnega kot klasičnega kaosa. V klasičnem biljardu opazujemo točkast delec v območju ograjenem s stenami. Delec se znotraj ograde giblje in se ob trku z njo odbije po odbojnem zakonu. Različne oblike stene lahko porodijo Hamiltonske sisteme vseh vrst od integrabilnih, ter sistemov mešanega tipa do popolnoma kaotičnih.

Predstavil bom nekaj nedavnih rezultatov o difuziji v biljardu oblike stadiona, ki ga je uvedel Bunimovič. Ta biljard je dokazano ergodičen in ima lastnost mešanja. Pokazal bom, da se numerični rezultati difuzije v impulznem prostoru, zaradi biljardne dinamike, skladajo z nehomogeno difuzijsko enačbo. Difuzijska konstanta je parabolična funkcija kanoničnega impulza.

Model nam omogoči, da razberemo klasične transportne čase, ki so pomembni za študij lokalizacije kaotičnih lastnih stanj kvantnega biljarda v stadionu.

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Aspects of diffusion in the stadium billiard

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Dynamical billiards are valuable model systems in the study of both classical and quantum chaos. A classical dynamical billiard consists of a point particle inside a prescribed region bounded by walls, where the particle is specularly reflected. By varying the shape of the boundary anything from an integrable to a mixed type and even an ergodic, fully chaotic, Hamiltonian system can be achieved.

In this report I will present some very recent results on the diffusion in the stadium billiard introduced by Bunimovich. The stadium billiard is proven to be rigorously ergodic and mixing. I will show that the results for the diffusion in momentum space obtained by numerical calculations of the stadium dynamics agree very well with an inhomogeneous diffusion equation. The diffusion constant is a parabolic function of the canonical momentum.

The model enables us to extract the classical transport time, an important parameter in the study of localization of chaotic eigenstates in the quantum stadium billiard.

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Prediktivne metode v energetiki

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Človeštvo porablja vedno več energije, pri čemer gospodinjstva porabijo približno 20% od skupno porabljene energije v državah EU. Zmožnost napovedovanja energetskih zahtev skupnosti, mest, držav ali kontinenta ter učinkovita proizvodnja energije sta tesno povezana pojma z zmožnostjo napovedovanja porabe energije v gospodinjstvih [2]. Za slednje je bilo uporabljenih in razvitih več metod, ki segajo od preprostih linearnih regresijskih modelov do nevronskih mrež [3,4]. V našem prispevku bomo predstavili rezultate, ki se nanašajo na natančnost različnih metod napovedovanja. V ta namen bomo uporabili realne podatke porabe energije za več 1000 gospodinjstev. V analizo vključimo tudi različne vremenske dejavnike znotraj istega časovnega obdobja, ki jih pridobimo z uporabo podatkovnega rudarjenja. Vpliv posameznih vremenskih dejavnikov bomo tudi klasificirali glede na njihov doprinos k porabi energije posameznega gospodinjstva.

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Predictive methods in energetics

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Humanity is using increasingly more energy, whereby around 20% of the total energy consumption in EU countries is consumed by buildings [1]. The ability to predict the energy demands of a community, state, country, continent and to produce energy in a more efficient way is therefore in a mayor way linked to the prediction of household energy consumption [2]. Several methods have been implemented and developed for this task and they range from simple linear regression models to neural network [3,4]. In this presentation we will show our results regarding the accuracy of different prediction methods. For this purpose we will use real datasets from more than 1000 households. By using our own datamining algorithm, we additionally enrich the datasets by gathering several environmental factors in the same time period. The later will be classified based on their contribution to the energy consumption of individual households.

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Kompleksna emergentna stanja ustvarjena izven ravnovesja

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Nedavna odkritja nenavadnih skritih stanj v različnih snoveh ustvarjenih s pomočjo laserske kratkočasovne fotoeksitacije so stimulirala hiter razvoj novih eksperimentalnih tehnik za raziskovanje osnovnih elektronskih, spinskih in fononskih vzbuditev na ultrakratkih časovnih skalah. Odličen primer snovi, kjer prepletanje elektronske, spinske in fononske prostorske stopnje vodi do raznolikih ravnovesnih in neravnovesnih stanj je plastoviti kvazidvodimenzionalni tantal disulfid. Stanja je bilo z dosedanjimi tehnikami zelo težko razločiti. Z razvojem tunelske mikroskopije in spektroskopije vzbujene s pomočjo femtosekundnih laserskih sunkov pa si lahko odpremo povsem nov in zelo detajlen pogled v strukturo tovrstnih skritih stanj. V predavanju bom prikazal najnovejše eksprimentalne rezultate o elektronski ureditvi snovi ustvarjeni pod različnimi neravnovesnimi pogoji, kot sta dvo-vrtinčno in amorfno elektronsko stanje. Oba sta brez primera v ravnovesnem faznem diagramu.

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COMPLEX EMERGENT STATES CREATED OUTSIDE OF EQUILIBRIUM

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Recent discoveries of unusual hidden states in diverse materials revealed by photoexcitation experiments were stimulated by rapid developments of new techniques allowing investigations of elementary electronic, spin and lattice structural excitations on short timescales. An excellent example of a material in which the interplay of electronic, spin and lattice degrees of freedom lead to a plethora of equilibrium and non-equilibrium states is the layered quasi-2D tantalum disulphide, whose states are hard to distinguish spectroscopically, but are reveled for the first time with femtosecond-excited scanning tunneling microscopy. The aim of the presentation is to present experimental data on such states, including a remarkable new high density amorphous electronic state created under warm dense matter conditions. The new discoveries open the way to understanding new states of matter created under controlled non-equilibrium conditions.

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Mesonic degrees of freedom in baryons

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Hadrons are commonly understood in terms of their valence-quark contents, mesons as $\{Q\overline{Q}\}$ and baryons as $\{QQQ\}$ states. In fact, all known hadrons are organized as such, with their particular flavor contents, in the particle-data book [1]. However, only at low energies hadrons can be described effectively on the basis of their valence-quark configurations. This is particularly true for baryonic ground states, e.g. along the relativistic constituent-quark model, effective field theories, and lattice quantum chromodynamics. For excited baryons this description usually fails. They need to be treated as true resonant states with complex eigenvalues. This can be achieved by coupling to the hadronic decay channels of the respective resonances. A relativistic coupled-channels treatment of baryon resonances represents a challenging problem essentially for all current approaches to quantum chromodynamics.

After studying the role of explicit pionic degrees of freedom in the nucleon and the Delta masses [2], we have started to develop a relativistic coupled-channels quark model for baryons by including explicit mesonic channels on top of the $\{QQQ\}$ configurations. So far, we have arrived at results for the nucleon and the Delta masses. Due to pion contributions, in the first case the real nucleon mass gets a downshift, while in the second case the Delta mass in addition becomes complex thus acquiring a finite decay width.

The above results depend on the prescriptions employed for the extended hadronic vertices (πNN, $\pi N\Delta$ vertices etc.). Ongoing work attempts to describe both the masses and the strong-interaction vertices consistently in a relativistic coupled-channels quark model [3].

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Vloga gradbene fizike v sodobni gradnji in analiza balkonskega toplotnega mostu

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V prvem delu bom na kratko predstavila kaj je to gradbena fizika in kakšna je njena vloga v sodobnem gradbeništvu. Predstavila bom štiri glavna področja, ki jih gradbena fizika obravnava: toplotne izgube, vdor vlage v objekt, akustiko in osvetlitev.

V drugem delu se bom osredotočila na problem toplotnih mostov. Zaradi varovanja okolja, zmanjševanje toplotnih izgub v stavbah vse bolj pridobiva na pomenu. Že dlje časa je znano, da ustrezna obravnava toplotnih mostov pri tem igra pomembno vlogo. Žal pa opažamo, da je ta, vsaj na slovenskem področju, pogosto zanemarjena. Glavni razlog je v tem, da izračun toplotnih izgub skozi toplotne mostove zahteva uporabo dragih računalniških paketov. Zato inženirjem želimo ponuditi enostavno semi-empirično enačbo, preko katere bodo lahko ocenili toplotne izgube skozi nekaj najbolj problematičnih vrst toplotnih mostov, kot so recimo balkoni.

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Role of the building physics in civil enginereeing and analysis of the balcony thermal bridge

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In the first part of the talk, the definition of the building physics and its role in modern civil engineering will be explained. Building physics covers four major fields: heat losses, moisture intrusion, acoustics and illumination.

In the second part of the talk, the problem of the thermal bridges will be presented. Due to ecological reasons, reduction of heat losses in buildings is gaining in significance. Thermal bridges play an important role in this matter. Nevertheless, heat loses trough thermal bridges are usually inadequately analyzed or even neglected. One of the main reasons for this is that the calculation of heat loses trough thermal bridges is complicated, and requires the usage of expensive computer packages. The idea is to find a semi-empirical expression that can describe the heat losses trough some of the most important thermal bridges (e.g. balcony thermal bridges) to a satisfying accuracy.

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Kvantni kaos v mnogodelčnih sistemih: K izpeljavi spektralnih korelacij v okviru naključnih matrik

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Osredje vprašanje kvantnega kaosa je iskanje povezave med opaženimi univerzalnimi spektralnimi fluktuacijami v preprostih kvantnih sistemih in teorijo slučajnih matrik (*random matrix theory*, RMT). Za enodelčne sisteme s povsem kaotično klasično limito je problem delno rešil M. Berry [1], v okviru t.i. diagonalne aproksimacije, v popolni semiklasični sliki pa so rešitev v prebojnem delu [2] podali F. Haake in sodelavci [2].

V zadnjih letih so vprašanja dolgočasovne dinamike pri visokih energijah, kjer postane relevanten celoten mnogodelčni energijski spekter, stopila v ospredje tudi pri diskusiji preprostih mnogodelčnih kvantnih sistemov, kot so npr. spinske verige z lokalno interakcijo. Ekstenzivne numerične študije in redki analitični argumenti kažejo na to, da takšni sistemi izkazujejo dva univerzalna tipa obnašanja, namreč fazo 'mnogodelčne lokalizacije' in 'ergodično fazo'. V ergodični fazi se spektralne fluktuacije tipično odlično ujemajo z RMT, navkljub enostavnosti interakcij in odsotnosti zunanjega vira nereda.

V predavanju bom najprej širše orisal problem in njegovo zgodovino, potem pa bom predstavil hevristično izpeljavo RMT spektralnega oblikovnega faktorja v čistih neintegrabilnih spinskih verigah, npr. v Isingovi verigi periodično brcani s poševnim magnetnim poljem. Na koncu bom diskutiral glavna odprta vprašanja, ki jih je še potrebno razrešiti, da bi naše ideje lahko povzdignili v dokaz.

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Quantum chaos in many-body systems: Towards derivation of random-matrix spectral fluctuations

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A central goal of quantum chaos is to establish a relationship between the observed universal spectral fluctuations of simple quantum systems and random matrix theory. For single particle systems with fully chaotic classical counterparts, the problem has been partly solved by M. Berry [1], within the so-called diagonal approximation, and in full semiclassical picture by the seminal work [2] of Haake and collaborators.

In recent years, the questions of long-time dynamics at high energies, for which the full many-body energy spectrum becomes relevant, are coming at the forefront also for simple many-body quantum systems, such as locally interacting spin chains. Such systems seem to display two universal types of of behavior which are now usually termed as 'many-body localized phase' and 'ergodic phase'. In the ergodic phase, the spectral fluctuations are typically excellently described by random matrix theory, despite simplicity of interactions and lack of any external source of disorder.

After giving a broad overview of the problem, I will outline a heuristic derivation of random matrix spectral form factor for clean non-integrable spin chains, an example of which is the Ising chain in a tilted periodically kicking magnetic field (*kicked Ising chain*). I will discuss the main open issues which are still needed to be resolved in order to lift our ideas to a proof.

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Teorija magičnih števil za razmerja prevodnosti elektronov skozi posamezne molekule

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Kot je bilo prikazano pred kratkim, je mogoče električno prevodnost skozi posamezne molekule različnih policikličnih aromatskih ogljikovodikov izraziti kot celoštevilčen večkratnik količine, ki je odvisna le od načina priključka molekule na vodila. Razmerja prevodnosti pri različnih načinih priključevanja enakih molekul so kvadrati celih števil - *t.i.* "magična razmerja" [1]. Osnovna teorija magičnih razmerij temelji na izpeljavi, kjer je za pojav odločilna le kvantna interferenca v molekuli, pri čemer so vplivi medelektronskih interakcij in vplivi senčenja zaradi elektrod zanemarjeni. Podrobna kvantitativna analiza vpliva Coulombove interakcije med elektroni v molekuli in elektroni v molekuli in v vodilih je pokazala, da ostaja teorija magičnih razmerij dokaj stabilna tudi v realističnih sistemih z interakcijami. Napovedani so tudi primeri, kjer enostavna teorija magičnih razmerij odpove in so zato ti primeri še posebno zanimivi za eksperimentalno preverbo. Primerjava rezultatov metode gostotnih funkcionalov, metode povprečnega polja Hatree-Fock (HF) in točne diagonalizacije je na manjših molekulah nakazala, da z metodo HF lahko zelo zanesljivo napovemo prevodnost tudi za molekule, kjer druge metode zaradi numerične zahtevnosti niso na voljo [2,3].

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Magic number theory for conductance ratios in single-molecule electron transport

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Recently it was demonstrated that conductance ratios of molecules with aromatic cores, with different connectivities to electrodes, can be predicted using a simple and easy-to-use "magic number theory" [1]. We find that due to cancellations of opposing trends, when Coulomb interactions and screening due to electrodes are switched on, conductance ratios are rather resilient. A comprehensive analysis of conductance ratios was performed using three different numerical methods, the density functional method, the mean field Hartree-Hock method (MF) and the Lanczos exact diagonalization. It was demonstrated that HF method can be used to reliably predict conductances also for large molecules where other methods due to numerical limitations are not applicable. Consequently, qualitative trends in conductance ratios of molecules can be predicted. On the other hand, for certain connectivities, deviations from non-interacting conductance ratios can be significant and therefore such connectivities are of interest for probing the interplay between Coulomb interactions, connectivity and quantum interference in single-molecule electron transport [2,3].

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Dinamična lokalizacija kaotičnih lastnih stanj in statistika spektrov

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V dovolj globoki semiklasični limiti (majhna efektivna Planckova konstanta, ali kratke valovne dolžine, ali visoke energije) velja za statistiko spektrov klasično povsem kaotičnih sistemov teorija gaussovsko naključnih matrik, kar je znano kot domneva Bohigasa-Giannoni-Schmita (1984), ki je bila dokazana s semiklasičnimi metodami postopoma (Berry 1985, Richter in Sieber 2001, Haake s sodelavci 2006-2014). Pomembni semiklasični kriterij za veljavnost zgornje domneve je, da mora biti Heisenbergov čas t_H daljši od vseh klasičnih transportnih časov. t_H je definiran kot $2\pi\hbar/\Delta E$, kjer je ΔE srednji razmik med energijskimi nivoji, in je pomembna časovna skala v poljubnem kvantnem sistemu. Ker velja $\Delta E \propto \hbar^N$, kjer je N število prostostih stopenj, je ta kriterij zmerom asimptotsko izpolnjen. V biljardnih sistemih je majhna Planckova konstanta $\hbar$ ekvivaletna visokim energijam. Za energije manjše od navedenega kriterija opazimo kvantno ali dinamično lokalizacijo kaotičnih lastnih stanj, ki se jasno pokaže v "kvantnem faznem prostoru" Wignerjevih funkcij. Definirali smo lokalizacijsko mero kaotičnih lastnih stanj na osnovi informacijske entropije (A) ter korelacij (C), in ugotovili, da sta ekvivalentni. Nadalje, pokazali smo, da je porazdelitev razmikov med sosednjimi nivoji kaotičnih lastnih stanj dobro opisana z Brodyjevo porazdelitvijo, z Brodyjevim parametrom β, ki je enolična funkcija A (ali C). Še več, β je univerzalna funkcija $\alpha = t_H/t_T$, kjer je t_T klasični transportni čas (difuzijski čas, relaksacijski čas), in empirična evidenca pokaže $\beta = \beta_0 s\alpha/(1 + s\alpha)$, kjer ob primerni definiciji t_T najdemo $\beta_0 \approx 0.98$ in $s \approx 0.13$. Ta analiza je bila izvedena za biljardni sistem stadion, ki je povsem kaotičen sistem (ergodičen), in tudi za biljard mešanega tipa uvedenega v (Robnik 1983), kjer smo ločili regularna in kaotična lastna stanja, in nato izvedli analizo lokaliziranih kaotičnih lastnih stanj.

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Dynamical localization of chaotic eigenstates and the spectral statistics

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In the sufficiently deep semiclassical limit (small effective Planck constant, or small wavelengths, or high energies) the spectral statistics of classically fully chaotic systems obeys the Gaussian random matrix theory, which is known as Bohigas-Giannoni-Schmit conjecture (1984), and has been proven by semiclassical methods stepwise (Berry 1985, Richter and Sieber 2001, Haake and coworkers 2006-2014). The important semiclassical criterion for the above conjecture to be true is that the Heisenberg time t_H must be longer than any classical transport time. t_H is defined as $2\pi\hbar/\Delta E$, where ΔE is the mean energy level spacing, and is an important time scale in any quantum system. Since $\Delta E \propto \hbar^N$, N being the number of degrees of freedom, for sufficiently small $\hbar$ this condition will always be satisfied asymptotically. In billiards, small effective Planck constant $\hbar$ is equivalent to large eigenenergies. For energies smaller than by the above criterion, we observe the quantum or dynamical localization of chaotic eigenstates, which is clearly revealed in the "quantum phase space" of Wigner functions. We have defined the localization measure of chaotic eigenstates in terms of the information entropy (A) and in terms of correlations (C), and found that they are equivalent. Furthermore, we have shown that the level spacing distribution of chaotic eigenstates obeys Brody level spacing distribution, with the Brody parameter β, which turns out to be a unique function of A (or C). Moreover, β is a universal function of $\alpha = t_H/t_T$, where t_T is the classical transport time (diffusion time, or relaxation time), and the empirical evidence shows $\beta = \beta_0 s\alpha/(1 + s\alpha)$, where under an appropriate definition of t_T we find $\beta_0 \approx 0.98$ and $s \approx 0.13$. This analysis has been performed for the stadium billiard, which is a fully chaotic (ergodic) system, and also for the billiard of the mixed type introduced in (Robnik 1983), where we have separated the regular and chaotic eigenstates, and then performed the above analysis for the localized chaotic eigenstates.

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Centri in integrabilnost nekaterih polinomskih sistemov NDE

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Obravnavamo družino kubičnih sistemov, ki imajo izrojeno singularno točko v neskončnosti in nehiperbolično singularno točko v izhodišču koordinatnega sistema. Predstavljeni so pogoji za obstoj lokalnega analitičnega prvega integrala v okolici izhodišča.

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Centers and integrability of some polynomial systems of ODEs

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We study a family of cubic systems with degenerate infinity. For systems of the family having a non-hyperbolic singularity at the origin the sets in the space of parameters corresponding to the systems with a local analytic first integral are found.

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Modeliranje in simulacije plinsko fokusiranih mikro curkov

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Skupina za koherentno slikanje v DESY-CFEL razvija inovativne metode za slikanje bioloških delcev in makro molekul s pomočjo rentgenskega laserja na proste elektrone in sinhrotronskih izvorov sevanja. Taki vzorci so dostavljeni v visoko intenziven femtosekundni žarek rentgenske svetlobe s pomočjo usmerjenega curka tekočine v obliki mikro curka. Proteinski nanokristali so ponavadi na voljo le v majhnih količinah. Zatorej je eden izmed pomembnih ciljev minimiziranje porabe dragocenega proteinskega vzorca in pri tem hkrati pridobivanje visokokvalitetnih meritev tudi iz curkov tanjših od enega mikrona. Dobre meritve zahtevajo, da je tak curek hiter, raven, tanek, stabilen ter dolg kolikor je to le možno. Ti pogoji morajo biti izpolnjeni tudi za zelo majhne pretoke, neodvisno od velikosti nanokristalov, njihove koncentracije ter nosilne tekočine. Razvijamo računske modele, ki bodo pomagali najti operativne parametere in bodo ustrezali zgoraj navedenim pogojem. V tej predstavitvi bomo pokazali elemente takega računskega modela (fizikalni model, način reševanja, analiza rezultatov), njegovo verifikacijo in validacijo, kakor tudi simulacije za različne geometrijske oblike šob.

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Modeling and simulation of gas focused micro-jets

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Coherent Imaging Group at DESY-CFEL is developing innovative methods for imaging with the use of X-ray Free Electron Laser (XFEL) and synchrotron sources, with an emphasis on bioparticles and macromolecules. Such samples are delivered into the interaction region via strongly focused liquid or aerosol jets where they are exposed to intense femtosecond pulses of X-rays. Protein nanocrystals are usually available in very small amounts. Hence, an important goal is to minimize the consumption of the valuable protein sample 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 nanocrystal size, buffer solution and concentration. We are developing computational models that help to find parameters to design gas-focused microjets that meet these requirements. In this presentation we will show the elements of such a computational model (physical model, solution procedure, post-processing), its verification and validation as well as simulation of different nozzle designs.

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Mesoscopic Molecular Ions in Ultracold Atom-Ion Hybrid Systems

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We explore the structure and dynamics of individual ions immersed into a sea of ultracold bosons in a quasi one-dimensional trapping environment. As a first step we investigate the situation by which the ion is strongly localized such that its motion can be effectively neglected. With the development of a model potential for the atom-ion interaction, we are able to numerically obtain the exact many-body ground state of the atomic ensemble in the presence of an ion. We analyse the influence of the atom number and the atom-atom interaction on the ground state properties. Interestingly, for weakly interacting atoms, we find that the ion impedes the transition from the ideal gas behaviour to the Thomas-Fermi limit. We show that this effect can be exploited to infer the presence of the ion both in the momentum distribution of the atomic cloud and by observing the interference fringes occurring during an expansion of the quantum gas. In the strong interacting regime, the ion modifies the fragmentation process in dependence of the atom number parity which allows a clear identification of the latter in expansion experiments. In a next step we explore the quantum dynamics in the course of a sudden creation of the ion. The dynamics is analyzed via a cluster expansion approach, which provides a comprehensive understanding of the occurring many-body processes. After a transient during which the atomic ensemble separates into fractions which are unbound and bound with respect to the ion, we observe an oscillation in the atomic density which we attribute to the additional length and energy scale induced by the attractive long-range atom-ion interaction. This oscillation is shown to be the main source of spatial coherence and population transfer between the bound and the unbound atomic fraction.

Finally we show how a single ion can bind multiple atoms on mesoscopic scales, forming a correlated bound many-body compound. We explore these mesoscopic molecular ions from weak to strong atomic repulsion, thereby taking atom-ion and

atom-atom correlations fully into account. We show the existence of a critical atom number at which dissociation occurs, resulting in an unbound fraction which forms a background gas for the molecule. Moreover, we present the self-localization behavior of the ion, originating from the generation of an effective mass and an effective trap.

Our study is carried out by means of the Multi Layer Multi-Configuration Time-Dependent Hartree method for Bosons (ML-MCTDHB), an ab initio approach to simulate the correlated quantum many-body dynamics.

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Quantum Transport after Inhomogeneous Quenches in Integrable Models

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We study quantum dynamics and transport properties of integrable models that are initially split in two halves lying at different temperature or particle density and abruptly connected. Under such inhomogeneous out-of-equilibrium settings, a Non-Equilibrium Steady State (NESS) forms in the thermodynamic and large time limit, which has been recently conjectured to be described by a Generalised Hydrodynamic (GHD) approach. Focusing on the expansion of a Lieb-Liniger gas, we show that certain predictions of this conjecture can be derived analytically from the properties of the Slavnov formula for the overlaps between Bethe states.

Spectra and spectral correlations of microwave graphs with symplectic symmetry

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Following an idea by Joyner et al. [1] a microwave graph with antiunitary symmetry $\mathcal{T}$ obeying $\mathcal{T}^2 = -1$ has been realized. The Kramers doublets expected for such systems have been clearly identified and could be lifted by a perturbation which breaks the antiunitary symmetry. The observed spectral level spacings distribution of the Kramers doublets is in agreement with the predictions from the Gaussian symplectic ensemble (GSE), expected for chaotic systems with such a symmetry. In addition results on the two-point correlation function, the spectral form factor, the number variance and the spectral rigidity are presented, as well as on the transition from GSE to GOE statistics by continuously changing $\mathcal{T}$ from $\mathcal{T}^2 = -1$ to $\mathcal{T}^2 = 1$.

This talk is based on a joint work with A. Rehemanjiang, M. Allgaier, M. Richter and U. Kuhl from Marburg/Nice [2,3] and C. H. Joyner, S. Müller, and M. Sieber from Bristol/London, Great Britain [2]. All colleagues and coworkers are thanked for their contributions.

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Uporaba znanosti o mrežah na bioloških sistemih: Langerhansovi otočki kot študija primera

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V zadnjih dveh desetletjih je znanost o mrežah veliko prispevala k našemu razumevanju strukture in delovanja različnih fizikalnih, kemičnih, bioloških, tehnoloških in družbenih sistemov [1]. V prvem delu tega seminarja na kratko predstavimo nekatere ključne napredke pri preučevanju bioloških sistemov, ki jih je navdihnila in omogočila znanost o mrežah [2]. V drugem delu se osredotočimo na Langerhansove otočke kot kompleksni biološki sistem, katerega delovanje se zmeraj bolj preučuje s pomočjo te metodologije. Langerhansovi otočki so poučen primer, saj njihovo normalno delovanje zahteva kompleksne signalne mehanizme med posameznimi celicami beta, ki zagotavljajo sinhronizirano kolektivno oscilatorno aktivnost populacij celic, ki nato vodi v natančno regulirano izločanje inzulina [3, 4]. S teoretičnega vidika se celice beta obnašajo kot oscilatorji limitnega cikla, ki so sinhronizirani, kadar

je sklopitev dovolj močna, da premaga notranje heterogenosti [5]. Tovrstna pot do sinhroniziranega obnašanja ima veliko konceptualnih podobnosti s faznimi prehodi in kritičnim obnašanjem. Predstavili bomo svoje zadnje rezultate, ki temeljijo na računalniškem modeliranju populacij celic beta v kombinaciji z napredno konfokalno mikroskopijo z veliko prostorsko in časovno ločljivostjo in ki raziskujejo odnos med medcelično sklopitvijo in dinamičnimi lastnostmi posameznih oscilatorjev, to je celic beta [6], in kolektivno obnašanje aktivnosti celic beta izzvano po stimulaciji z glukozo, za katero se zdi, da se podreja podobnim organizacijskim principom kot drugi sistemi iz realnega življenja, kot sta samoorganizacija in kritično obnašanje [7]. Nazadnje bomo pokazali nekaj nedavnih rezultatov, pridobljenih s sodobnim pristopom večplastnih mrež k raziskovanju delovanj otočkov [2,8]. V zaključki bomo izpostavili nekaj izzivov in možnih smeri prihodnjih raziskav Langerhansovih otočkov in kompleksnih sistemov nasploh.

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Network Science of Biological Systems: Islets of Langerhans as a Case Study

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During the last two decades, network science has contributed a lot to our understanding of structure and function of various physical, chemical, biological, technological, and social systems [1]. In the first part of this seminar, we briefly review some crucial advances in the study of complex biological systems that were inspired and enabled by network science [2]. In the second part, we focus on islets of Langerhans as a complex biological system whose functioning is increasingly being studied by this methodology. Islets of Langerhans are an illuminating case example, since their normal functioning requires complex signaling mechanisms between individual beta cells to ensure a synchronized collective oscillatory activity of cell populations, which

in turn leads to well-regulated exocytosis of insulin [3, 4]. From a theoretical point of view, beta cells behave as coupled limit-cycle oscillators which are synchronized when coupling is sufficient to overcome the intrinsic heterogeneities [5]. Such a path to synchronized behavior bears many conceptual similarities with phase transitions and critical behavior. We present our latest findings based on computational modeling of beta cell populations combined with advanced high spatial and temporal resolution confocal imaging, exploring the interplay between intercellular coupling and dynamical features of individual oscillators, i.e. beta cells [6], and the collective behavior of glucose-evoked spatiotemporal beta cell activity, which seems to obey similar organizing principles as other real-life systems, such as self-organization and critical behavior [7]. Finally, we present some latest results obtained by the most recent multilayer approach to exploring islet function [2,8]. We conclude by pointing out some challenges and possible directions for future investigation of islets of Langerhans and complex systems in general.

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Vektorski in tenzorski ohranitveni zakon za polimerne nematike z glavno verigo

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Tekočekristalni red v bioloških sistemih nastopa zelo pogosto in njegove glavne lastnosti se da analizirati v okviru standardnega pristopa Landau-de Gennesa, ne da bi se pri tem ozirali na polimerno zgradbo materiala. Kljub temu so že pred mnogimi leti spoznali, da je treba omenjeni pristop nadgraditi, če želimo upoštevati povezanost monomerov v glavno verigo [1,2]. Ta mikroskopska povezanost privede do makroskopske sklopitve med gostoto oz. koncentracijo ter orientacijskim redom polimernih molekul. Vektorska "kontinuitetna enačba", ki jo opisuje, je temeljnega pomena za konsistenten opis makroskopskih lastnosti takih sistemov [3-5]. Pred kratkim smo pokazali, kako se ta ohranitveni zakon za t.i. geometrični polimerni tok posploši [6] v enačbo za popolno polarno ureditveno polje in kako lahko le-to uporabimo [7,8] na nematskem sistemu, ki je inherentno nepolaren. Izpeljali smo tudi novo tenzorsko kontinuitetno vez [7], ki sklaplja gradiente nematskega ureditvenega tenzorja z variacijami gostote oz. koncentracije. Zanimiva posebnost tega t.i. tenzorskega ohranitvenega zakona je, da je prisoten že v izotropni fazi [8] in je tako precej generičen – potencialno bi lahko vodil do novih pojavov, kot sta akusto-dvolomnost ali osmotsko inducirana dvolomnost.

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Vectorial and tensorial conservation laws for main-chain polymer nematics

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Liquid crystalline order is ubiquitous in biological materials and many properties of these systems can be analyzed in terms of the standard Landau-de Gennes approach, without particularly worrying about e.g. the polymer nature of the main-chain polymer nematogens. Nevertheless, it was recognized long ago, that the Landau-de Gennes approach needs to be modified to take into account the polymer nature, i.e. the microscopic connectivity of the underlying mesogens [1,2]. This connectivity leads to a coupling between density/concentration and orientational order of the polymer molecules. The ensuing vectorial continuity equation was shown to matter fundamentally for a consistent description of macroscopic properties of these systems [3-5]. Recently we showed how this conservation law for the so-called geometrical polymer current is generalized [6] to include the complete polar order variable and how it can be applied [7,8] to the nematic system, which is however nonpolar. Moreover, we have derived a new tensorial continuity constraint [7] connecting gradients of the nematic order tensor and variations of density/concentration. An amusing peculiarity of this so-called tensorial conservation law is that it is present even in the isotropic phase [8] and is therefore quite generic, potentially giving rise to phenomena like acousto-birefringence or osmotic-stress-induced birefringence.

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Želje in stvarnost v eksperimentalni fiziki: Zgledi iz magnetizma

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Kako pomeriti zelo šibka magnetna polja je star izziv. Šibko magnetno polje Zemlje je pomeril že v 19. stol. K.F. Gauss. V nadaljevanju so sledila še mnoga odkritja, kot npr. kaj lahko sklepamo iz anomalij v magnetnem polju Zemlje. Tukaj je dal odgovor fluxgate magnetometer (Foerster). S prvimi uspešnimi sateliti v zemeljski orbiti so postale zahteve za občutljivost vse večje - do 10^{-12} T. Odkritje kvantizacije magnetnega pretoka (Deaver, Fairbank; Josephson) in tuneliranja superprevodnih parov (B.D. Josephson 1962) je vodilo do zelo občutljivega magnetnega senzorja SQUID tako v dc kot ac področju. Z njim lahko merimo do 10^{-15} T. Aplikacije SQUID senzorja so takoj sledile. Pomerili so magnetna polja, ki spremljajo elektrofiziološke pojave (srce, možgani, periferni živčni sistem, ena sama celica, rastline,..). Kot že mnogokrat se je izkazalo, da je 10^{-15} T premajhna občutljivost za nekatere aplikacije. Posodobitev optičnega magnetometra z nadomeščanjem spektralnih svetilk z uglasljivimi laserskimi diodami nam je omogočila meritve pod 10^{-15}T. Teoretično tudi velikostni red ali več niže. To je omogočilo podobne uspehe pri raziskavah aktivnosti možganov, ne da bi potrebovali tekoči helij, ki ga rabimo pri SQUID senzorjih. Možna je tudi radiofrekvenčna spektroskopija v Zeemanovem polju, ki je veliko nižje od zemeljskega.

Navedel bom nekatere naše rezultate v zadnjih nekaj desetletjih.

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Wishes and Reality in Experimental Physics: Examples from Magnetism

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To measure the smallest magnetic field is an old challenge. The Earth magnetic field was measured by K.F. Gauss already in the 19th cent. Subsequently, a question appeared on the anomalies in the Earth magnetic field and what that can tell us. The answer was given by the fluxgate magnetometer invented by F. Foerster just before the W.W. 2 started. With first Earth satellites in the late 50-ties the requirements for the sensitivity of fluxgate magnetometers reached 10^{-12} T in detecting dc magnetic field. After the discovery of magnetic flux quantization and electron pair tunnelling in 60-ties it was necessary to build a SQUID sensor, still today one of the two most sensitive magnetometers with sensitivity up to 10^{-15} T in measuring dc and low frequency magnetic fields. A number of applications followed very soon starting with electrophysiologic measurements of heart, brain, peripheral nerve system, single cell magnetic measurements, low frequency RF applications. To fulfil the need for more sensitive magnetic measuring systems the existing optical magnetometers were improved with the tunable diode laser which replaced spectral lamp for optical pumping of alkali metal atoms. The potassium optical magnetometer can reach sensitivity below 10^{-15} T, possibly 10^{-16} T, thus surpassing SQUID magnetometer. No liquid helium is needed in its operation and we will soon have a better tool for brain research and very low frequency NMR experiments.

The use of mentioned magnetometers will be illustrated with our group measurements in the past few decades.

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Matrix ansatz in integrable non-equilibrium models

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I will present new examples of exactly solvable exclusion processes. They are models of particles in interaction on a one dimensional lattice with L sites. The particles are evolving randomly on the lattice following simple stochastic rules. The lattice is connected at its extremities to particle reservoirs with different densities which drive the system out-of-equilibrium. I will explain how to compute exactly the stationary distribution (which does not obey a Boltzmann statistics) in a matrix product form. This will allow us to compute analytically physical quantities such as particle current and correlation functions.

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Nanomodulirane vijačne faze s homogeno elektronsko gostoto

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Obravnavala bom periodične strukture v fazah tekočih kristalov z orientacijskim ureditvenim redom, a homogeno elektronsko gostoto. Takšne faze lahko preiskujemo z resonančno rentgensko spektroskopijo (RSoXS) na ogljikovem robu K [1]. Raziskovali smo holesterično fazo, modre faze tipa I in II ter zvojno-upogibno nematično fazo. Rezultate eksperimentalnih meritev smo primerjali z napovedmi teoretičnega modela [2]. Pokazali smo, da lahko tip modre faze nedvoumno določimo iz lege in intenzitete sipalnih vrhov, pri čemer je ključno upoštevanje polarizacije vpadnega in sipanega rentgenskega valovanja.

Za zvojno-upogibno nematično fazo je zelo široko sprejet strukturni model, ki privzame, da se dolge osi ukrivljenih molekul vrtijo po plašču stožca. Ko teoretično obravnavamo resonančno sipanje rentgenskega valovaja na taki strukturi, napovemo dva resonančna vrha, enega povezanega s polno in drugega s polovično dolžino vijačnice. Vrha imata tudi bistveno različno polarizacijsko odvisnost. Eksperimentalno opazimo samo en vrh, pri katerem intenziteta ni odvisna od polarizacije vpadnega valovanja, zato ga lahko nedvoumno opredelimo kot vrh, ki ustreza periodi dolžine vijačnice. To, da ni vrha pri polovični dolžini vijačnice, lahko razložimo, če predpostavimo, da je struktura zvojno-nematične faze dvojna vijačnica [2,3].

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Nanoscale-modulated helical phases with homogeneous electron density distribution

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Periodic structures of phases with orientational order of molecules, but homogenous electron density distribution were probed by a resonant soft x-ray scattering (RSoXS) at the carbon K-edge [1]. A short pitch cholesteric, type I and II blue phases and twist-bend nematic phase were studied both experimentally and theoretically by modelling the scattering pattern, assuming a structure of each phase [2]. It was shown that the symmetry of a blue phase can unambiguously be determined through a resonant enhancement of the x-ray diffraction signals. Polarization effects turn out to be an important indicator in the phase structure determination.

For the twist-bend nematic phase, for which a structural model with a heliconical spatial variation of the long molecular axes is widely accepted, theoretical modelling shows that in case of a simple heliconical structure two resonant signals corresponding to the full and half pitch band should be present and they should have a very different polarization dependence. Experimentally, only one signal was found, with the intensity independent of the beam polarization. It can thus be unambiguously identified as the full pitch band. The lack of the half pitch band strongly suggests that the twist-bend nematic structure is made of two interlocked and shifted helices [2,3].

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Kvantni model Hirote, lokalni integrali gibanja in robni procesi

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Predstavil bom kvantni model Hirote, njegovo integrabilno strukturo in možnost posplošitve problema z vključitvijo disipativnih procesov na robu. Kvantni model Hirote je integrabilna diskretizacija sine-Gordonove teorije polja v 1+1 dimenzijah. Posebna oblika tega modela je model Volterre, katerega klasična limita se uporablja pri študiju populacijske dinamike.

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Quantum Hirota model, local integrals of motion and boundary processes

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I will present the quantum Hirota model, its integrable structure and the possibility of generalizing the problem by including the dissipative processes at the boundary. Quantum Hirota model is an integrable discretization of the sine-Gordon field theory in 1+1 dimensions. A special version of this model is the Volterra model, whose classical limit is used to study the population dynamics.

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Polovični skirmioni v ograjenih modrih fazah

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Skirmioni so delcem podobni topološki objekti v zveznih poljih, ki igrajo pomembno vlogo v nizko temperaturni kondenzirani snovi, kamor med drugim spadajo: dve dimenzionalni elektronski plin, Bose-Einsteinovi kondenzati in kiralni magneti. Manj so poznani skirmioni v tekočih kristalih, ki so lahko stabilni pri sobni temperature. Spodbujeni s pojavom mreže skirmionov v kiralnih magnetih [1], smo pred nekaj leti s fenomenološkim modeliranjem napovedali obstoj heksagonalne mreže polovičnih skirmionov v tanki plasti močno kiralnega nematskega tekočega kristala - modre faze [2]. Sledila je realizacija skirmionov v prisilno odviti strukturi v tanki plasti kolesteričnega tekočega kristala [3] in vzporedno tudi njihovo fenomenološko modeliranje [4]. Pred kratkim pa je uspela tudi realizacija naše napovedi struktur s polovičnimimi skirmioni v zelo tanki plasti modre faze [5].

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Half-skyrmions in confined blue phases

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Skyrmions are localized particle-like topological objects in continuous fields that play important roles in various low temperature condensed matter systems, like two-dimensional electron gases exhibiting the quantum Hall effect, BoseEinstein condensates, and chiral magnets. Much less is known about room temperature liquid crystalline skyrmions. In analogy to skyrmion lattices in thin layers of chiral magnets [1], we have few years ago using phenomenological modelling predicted a hexagonal lattice of half-skyrmions in thin layers of blue phases highly chiral nemaic liquid crystals [2]. Latter full skyrmions were realized [3] and described [4] in unwound layers of cholesteric liquid crystals. Recently our anticipations on half-skyrmion structures have been realized in thin blue phase layers [5].

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Dinamični fazni prehodi v kvantnih sistemih z interakcijo dolgega dosega

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Po krajši predstavitvi sistemov z interakcijo dolgega dosega [1] bom predstavil dinamične fazne prehode v Isingovem modelu z interakcijami dolgega in kratkega dosega. Ob odsotnosti slednjih ima model fazni prehod med dinamično feromagnetno fazo z neničelno magnetizacijo in dinamično paramagnetno fazo, kjer je časovno povprečje magnetizacije nič. Ko dodamo interakcijo kratkega dosega, torej povečamo kvantne fluktuacije, se kritična točka razveji v novo fazo, za katero je značilna hiperobčutljivost dinamike in končne magnetizacije na začetne pogoje in parametre modela [3].

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Dynamical phase transitions in long-range quantum systems

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After a short introduction to long-range quantum systems [1] I will focus on dynamical phase transitions in the transverse-field Ising chain with competing long and short-range interactions. In the absence of the latter the model exhibits a dynamical phase transition from a ferromagnetic phase with non-zero long-time magnetization to a paramagnetic phase with a vanishing time-averaged magnetization [2]. Upon adding short-range interactions (i.e. increasing the strength of the quantum fluctuations), the dynamical critical point fans out into a chaotic dynamical ferromagnetic phase within which the non-equilibrium evolution is characterised by strong sensitivity to the parameters and initial conditions [3].

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Natančne meritve velikih vzorcev zvezd in galaktična arheologija

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Kot sodelujoči pri misiji Gaia Evropske vesoljske agencije pričakujemo, da bomo aprila 2018 sodelovali pri javni objavi meritev, ki bodo v veliki meri rešile problem negotovih razdalj znotraj naše Galaksije in širše. Meritvam razdalje s točnostjo nekaj odstotkov za več kot milijardo zvezd bodo dodane tudi izjemno natančne meritve njihovega prečnega gibanja. Tretjo, to je radialno komponento hitrosti, pa bo Gala lahko izmerila le za relativno svetle zvezde. V predavanju bom razložil, zakaj potrebujemo točne radialne hitrosti in kako si tu lahko pomagamo z rezultati spektroskopskih pregledov GALAH in Gaia-ESO, narejenih s teleskopi na Zemlji. Za študij kinematike Galaksije nam sicer zadostuje točnost nekaj kilometrov na sekundo, če jo izboljšamo proti 100 m/s pa se odprejo pomembne fizikalne uporabe, kot je študij gibanj v zvezdnih atmosferah in preučevanje notranje dinamike tokov zvezd in zvezdnih kopic. Tako točnost dosegata oba omenjena pregleda neba. Polega tega lahko s pregledom GALAH izmerimo tudi kemične zastopanosti 30 različnih elementov v več kot pol milijona zvezdah. To bistveno razširja dimenzionalnost prostora parametrov, s katerim opišemo lastnosti zvezd. Omogoča tudi ugotoviti, katere zvezde so bile rojene skupaj, s tem pa tudi študij sedanje strukture in zgodovine naše Galaksije, kot ene od tipičnih spiralnih galaksij v Vesolju. Tem raziskavam, ki dopolnjujejo klasično kozmologijo, pogosto pravimo bližnja kozmologija, oziroma galaktična arheologija.

Reference

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Precise measurements of large stellar samples and galactic archaeology

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As members of the data analysis consortium of the Gaia satellite of the European Space Agency we expect to contribute to its public data release in April 2018 which will largely solve the long-standing problem of inaccurate distances within the Galaxy and beyond, with a billion+ stars having distances measured to a few per-cent. Similarly, their proper motions will reach exquisite accuracy compared to what was achievable so far. But radial velocities could be measured only for a rather bright stellar sample by Gaia. I will discuss important physical applications of accurate radial velocities and how to obtain them with ground-based spectroscopic surveys, where GALAH and Gaia-ESO surveys are pushing the envelope. I will argue that while accuracy of a few km/s is needed for studies of Galactic kinematics a measurement at a 100 m/s level opens up statistical studies of kinematics within the stellar atmosphere and kinematics of stars within a cluster or a stream. These requirements are achieved by both ground-based surveys mentioned above. Moreover GALAH accurately measures chemical abundances of 30 different elements in 500,000+ stars. This is a game changer, as it significantly increases dimensionality of the parameter space to describe stellar properties. It allows to identify stars that were born together, thus studying formation history and present structure of our Galaxy, as a typical spiral galaxy in the Universe. These efforts are complimentary to classical cosmology, so they are frequently called near-field cosmology or galactic archaeology.

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