Kvalitativna analiza modela časovne evolucije izotermalnega reakcijskega sistema

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Predstavila bom dvodimenzionalni sistem navadnih diferencialnih enačb, ki je mate-matični model za časovno evolucijo izotermalnega reakcijskega sistema. Osredotočimo se na vektorsko polje sistema pri pozitivnih vrednosti parametrov in reaktantov. Do sedaj je bilo znanih nekaj numeričnih primerov za obravnavani sistem, naš pristop pa je analitični in tako ponudi splošne rezultate. S teorijo Hopfovih bifurkacij poiščemo splošne zadostne pogoje za pogoje na parametrih sistema, pri katerih se v faznem prostoru lahko pojavi limitni cikel. Z uporabo Poincaréjeve kompaktifikacije in manj znane metode napihovanja opišemo obnašanje trajektorij v celotnem prvem kvadrantu, vključno s toškami v neskončnosti. Na primeru pokažemo tudi korelacijo med realnim delom lastnih vrednosti Jacobijeve matrike, izračunane v točki nestabilnega fokusa znotraj limitnega cikla in amplitudi limitnega cikla.

Reference

[1] Arcet, B., Dukarić, M., Kadyrsizova, Z. (2020). Qualitative Study of a Well-Stirred Isothermal Reaction Model. *Mathematics*, 8(6):938.

[2] Kadas, Z., Othmer, H. G. (1979). Stable Limit Cycles in a Twocomponent Bimolecular Reaction System. *J. Chem. Phys.*, 70, 1845-1850.

Qualitative analysis of a model for a temporal evolution of a well-stirred isothermal reaction system

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I will represent a two-dimensional system of ordinary differential equations which is a mathematical model for a temporal evolution of a well-stirred isothermal reaction system. We focuse on the behaviour of the vector field of this system for the positive values of the species and parameters. Some numerical results on this system were known till now, but we extend these results and approached it analytically. Using the theory of Hopf bifurcation we look for the general sufficient conditions on parameters of the system under which a stable limit cycle arises in the phase space of the system. We describe the behaviour of trajectories in the whole first quadrant, including the points at infinity, using Poincaré compactification and the blow-up method, which is not known in a big extend. Finally, we show the correlation between the real part of the eigenvalues of the Jacobian matrix, calculated at the unstable focus inside the limit cycle and the amplitude of the limit cycle on the example.

References

[1] Arcet, B., Dukarić, M., Kadyrsizova, Z. (2020). Qualitative Study of a Well-Stirred Isothermal Reaction Model. *Mathematics*, 8(6):938.

[2] Kadas, Z., Othmer, H. G. (1979). Stable Limit Cycles in a Twocomponent Bimolecular Reaction System. *J. Chem. Phys.*, 70, 1845-1850.

Simetrija superprevodnega ureditvenega parametra v kvazi-eno-dimenzionalnem superprevodniku $Rb_2Mo_3As_3$

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Kvazi-enodimenzionalni elektronski sistemi kažejo notranjo nestabilnost napram urejenim fazam dolgega dosega pri dovolj nizkih temperaturah. Superprevodni redi so še posebej zanimivi, ker imajo lahko singletno ali tripletno simetrijo ureditvenega parametra in pogosto tekmujejo z magnetizmom [1]. Tukaj poročamo o naši obsežni študiji ^{75}As jedrske kvadrupolne resonance, ^{87}Rb jedrske magnetne resonance in mionske spinske relaksacije (μSR) kvazi-enodimenzionalnega sistema $Rb_2Mo_3As_3$ za katerega je značilna ena najvišjih kritičnih temperatur $T_c = 10,4$ K med vsemi kvazi-enodimenzionalnimi superprevodniki [2,3]. Značilna potenčna temperaturna odvisnost spinsko-mrežnega ^{87}Rb relaksacijskega časa v širokem temperaturnem območju kaže na dominantno fiziko Tomonaga-Luttingerjeve tekočine (TLL) in določa efektivni parameter TLL interakcij $K_c = 1,4$. To postavlja študirani sistem v zelo nenavaden režim efektivnih privlačnih interakcij in odpre realne možnosti za tripletno superprevodnost [2]. Parameter magnetne vdorne globine $\lambda = 669$ nm smo primerjali s koherenčno dolžino $\zeta = 3,4$ nm in dobili Ginzburg-Landaujev parameter $\kappa \sim 200$ kar razvrsti $Rb_2Mo_3As_3$ med superprevodnike tipa II v čisti limiti. Signal μSR pomerjen v transverzalnem polju [3] kaže povečano relaksacijo pod T_c, kar je posledica tvorbe vrtinčne mreže. Primerjava okrepljene relaksacije zaradi tvorbe vrtinčne mreže z modeli, ki vključujejo $s-$, $p-$ in $d-$ simetrijo superprevodne reže kaže najboljše ujemanje za $s-$ scenarij, vendar z nenavadno majhno superprevodno režo, Δ_0 v razmerju do T_c – dobljeno razmerje je $2\Delta_0/T_c = 2,74(1)$. Alternativni $p-$ ali $d-$ scenariji z malenkost slabšim χ^2 pa vodijo do bolj realističnih vrednosti $2\Delta_0/T_c = 3,50(2)$ in $2\Delta_0/T_c = 4,08(1)$. Zaključimo torej lahko, da naše meritve $Rb_2Mo_3As_3$ ne izključujejo možnosti za tripletno superprevodnost.

Reference

[1] T. Giamarchi and H. J. Schulz, *Phys. rev. B* **37** (1988) 325.

[2] Ž. Gosar, N. Janša, T. Arh, P. Jeglič, M. Klanjšek, H. F. Zhai, B. Lv, and D. Arčon, *Phys. Rev. B* **101** (2020) 220508.

[3] Ž. Gosar, T. Arh, H. F. Zhai, B. Lv, and D. Arčon, *in preparation* (2022).

The pairing symmetry in quasi-one-dimensional superconductor $Rb_2Mo_3As_3$

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Quasi-one-dimensional electron systems display intrinsic instability towards long-range ordered phases at sufficiently low temperatures. The superconducting orders are of particular interest as they can possess either singlet or triplet pairing symmetry and frequently compete with magnetism [1]. Here we report on comprehensive ^{75}As nuclear quadrupole resonance, ^{87}Rb nuclear magnetic resonance and muon spin rotation/relaxation (μSR) study of $Rb_2Mo_3As_3$ characterised by one of the highest critical temperatures $T_c = 10.4$ K among quasi-one-dimensional superconductors [2,3]. A Tomonaga-Luttinger liquid (TLL)-characteristic power-law temperature dependence of the ^{87}Rb spin-lattice relaxation rates over a broad temperature range yield the TLL interaction parameter for charge collective modes $K_c = 1.4$ thus setting this system into very unusual regime of effective attractive interactions and open the possibility for the triplet superconductivity [2]. The magnetic penetration depth $\lambda = 669$ nm is compared to the coherence length $\zeta = 3.4$ nm to obtain the Ginzburg-Landau parameter $\kappa \approx 200$ and classify $Rb_2Mo_3As_3$ as a strong type-II superconductor in the clean limit. The transverse field μSR signal [3] shows enhanced damping below T_c, which is due to the formation of vortex lattice. Comparison of vortex lattice broadening against single gap $s-$, $p-$ and $d-$wave models shows the best agreement for the $s-$wave scenario but with the anomalously small superconducting gap, Δ_0, to T_c ratio $2\Delta_0/T_c = 2.74(1)$. The alternative $p-$wave or $d-$wave scenarios with marginally worse goodness of fit would yield more realistic $2\Delta_0/T_c = 3.50(2)$ and $2\Delta_0/T_c = 4.08(1)$, respectively. We thus conclude that scenario for the triplet superconductivity in $Rb_2Mo_3As_3$ remains a realistic option.

References

[1] T. Giamarchi and H. J. Schulz, *Phys. rev. B* **37** (1988) 325.

[2] Ž. Gosar, N. Janša, T. Arh, P. Jeglič, M. Klanjšek, H. F. Zhai, B. Lv, and D. Arčon, *Phys. Rev. B* **101** (2020) 220508.

[3] Ž. Gosar, T. Arh, H. F. Zhai, B. Lv, and D. Arčon, *in preparation* (2022).

Holografske termične korelacijske funkcije operatorjev s poljubno skalno dimenzijo

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S pomočjo korespondence AdS/CFT bom opisal obnašanje dvotočkovnega korelatorja operatorja s poljubno skalno dimenzijo Δ in poljubno sodo dimenzijo prostora-časa d za majhno a neničelno temparaturo. Dobljen korelator se sklada z znanim rezultatom za $d = 4$ v primeru velikega Δ ter v primeru $d = 2$ s prvimi členi razvoja po tempreraturi eksaktno znanega rezultata.

Reference

[1] B. Bajc in A. R. Lugo, v delu.

[2] D. Rodriguez-Gómez in J. G. Russo, *JHEP* **06** (2021), 048.

[3] M. Dodelson, A. Grassi, C. Iossa, D. Panea Lichtig in A. Zhiboedov, [arXiv:2206.07720 [hep-th]].

Holographic thermal correlation functions of operators with arbitrary scale dimensions

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Using the AdS/CFT correspondence we model the behaviour of the two point correlator of an operator with arbitrary scale dimension Δ and arbitrary spacetime even dimension d for small but non-zero temperature. The obtained correlator coincides with the known result for $d = 4$ for large Δ as well as with the low order expansion in temperature of the exact all order result for $d = 2$.

References

[1] B. Bajc and A. R. Lugo, work in progress.

[2] D. Rodriguez-Gómez and J. G. Russo, *JHEP* **06** (2021), 048.

[3] M. Dodelson, A. Grassi, C. Iossa, D. Panea Lichtig and A. Zhiboedov, [arXiv:2206.07720 [hep-th]].

Nanoplasmonic Enhancement of Laser Energy Absorption

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I introduce the NAPLIFE project we started in 2020 at the Wigner Research Centre for Physics cooperating with 3 Hungarian universities on enhancement of energy absorption by nanotechnology manipulation of targets with the perspective of increasing the effectivity of the ignition of laser inertial nuclear fusion. Setting into the scene of general energy production sources and mainstream and alternative nuclear fusion methods, I show preliminary and partially published results on spectral measurements on the prepared target polymers UDMA/TEGDMA doped with nanorod particles, adjusted to the laser frequency we have. We concentrate in this phase to deuteron measurements after the laser pulse digged a crater in the polymer target.

References

[1] A. Bonyar et.al., *Int. Journal of Molecular Sciences* **23** (2022) 13575.

[2] I. Papp et.al., *Physical Review X: Energy* **1** (2022) 023001.

[3] D. Vass, A. Szenes, B. Bánhelyi, M. Csete, *NANOMATERIALS* **12** (2022) 352.

[4] I. Papp, et.al., *Physics Letters A* **396** (2020) 187.

Relaksijska dinamika v večdelčnem sistemu z močnim neredom

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Predstavil bom vpliv simetrije na večdelčno lokalizacijo. Predstavil bom časovni razvoj več opazljivk v anizotropnem t-J modelu. Tako kot Hubbardova veriga tudi preučevani model vsebuje prostostne stopnje naboja in spina. Kljub temu vsebuje manjši Hilbertov prostor kar omogoča numerične študije večjih sistemov. Primerjal bom sistem v naključnem magnetnem polju, ki poruši spinsko Z_2 simetrijo, in sistem z naključno potencialno energijo, ki ohranja Z_2 simetrijo [1]. V prvem primeru dovolj močen nered vodi do lokalizacije vseh izmerjenih opazljivk, na končnih sistemih. Vendar pa v primeru naključne potencialne energije, ki ohranja Z_2 simetrijo, opazimo, da se operatorji, ki so lihi na rotacijo v spinskem prostoru, relaksirajo proti termodinamski vrednosti na relativno kratkih časovnih skalah. Slednje se skalirajo le polinomsko z velikostjo nereda. Po drugi strani pa sta dinamika sodih operatorjev in statistika znotraj posameznega simetrijskega sektorja skladni z lokalizacijo. Dobljeni rezultati kažejo, da znotraj vsakega simetrijskega sektorja obstaja lokalizacija za opazljivke katerih operatorji ohranjanjajo dane simetrije. Navidezna relaksacija lihih operatorjev je posledica njihovega časovnega razvoja med različnimi simetrijskimi sektorji.

Reference

[1] Janez Bonča and Marcin Mierzejewski, Phys. Rev. B **105**, 155146 (2022).

Relaxation dynamics in a strongly disordered many–body system

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I will discuss the interplay between many-body localization and spin-symmetry. I will present the time evolution of several observables in the anisotropic t-J model. Like the Hubbard chain, the studied model contains charge and spin degrees of freedom. Yet, it has a smaller Hilbert space and thus allows for numerical studies of larger systems. I will compare the field disorder that breaks the Z_2 spin symmetry and a potential disorder that preserves the latter symmetry [1]. In the former case, sufficiently strong disorder leads to localization of all studied observables, at least for the studied system sizes. However, in the case of symmetry-preserving disorder, we observe that odd operators under the Z_2 spin transformation relax towards the equilibrium value at relatively short time scales that grow only polynomially with the disorder strength. On the other hand, the dynamics of even operators and the level statistics within each symmetry sector are consistent with localization. Our results indicate that localization exists within each symmetry sector for symmetry preserving disorder. Odd operators apparent relaxation is due to their time evolution between various symmetry sectors.

References

[1] Janez Bonča and Marcin Mierzejewski, Phys. Rev. B **105**, 155146 (2022).

Long range interactions enhance global stability in 1-D Hamiltonian lattices

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Local and global stability properties of 1-D Hamiltonian lattices of N interacting particles have been studied extensively, in view of their important implications to many problems of mathematical physics [1]. A wealth of important results published since the pioneering numerical results of Fermi, Pasta, Ulam and Tsingou (FPUT) in the early 1950's, have greatly enhanced our understanding of such lattices in the case of nearest neighbor interactions. On the other hand, the importance of long-range forces to statistical physics has also been pointed out in many works (see for example [2]).
More recently, the non-extensive statistical analysis of FPUT 1-D lattices has revealed that long-range forces increase the global stability of the dynamics and lead to a novel view of their phase transition diagram [3,4]. In the last few years, this has further been supported by studies of the remarkable supratransmission phenomenon, where the first particle of a 1-D lattice is subjected to sinusoidal forcing: The critical amplitude for destabilizing the system increases as the interaction range goes to zero, except in the presence of local potentials!

References

[1] T. Bountis and H. Skokos, Complex Hamiltonian Dynamics, Synergetics series, Springer Verlag (2012).

[2] T. Dauxois, S. Ruffo, E. Arimondo and M. Wilkens, Lecture Notes in Physics, **602** (2002) Springer.

[3] H. Christodoulidi, C. Tsallis and T. Bountis, European Physics Journal Letters, **108** (2014) 40006.

[4] H. Christodoulidi, T. Bountis, C. Tsallis and L. Drossos, J. Stat. Mech. **12** (2014) 123206.

[5] J. E. Macias Diaz, A. Bountis, CNSNS, vol. 63 (2018) 307.

[6] H. Christodoulidi, A. Bountis and L. Drossos, EPJST **227** (5,6) (2018) 563.

[7] J. E. Macias Diaz and A. Bountis, Journal of Computational Nonlinear Dynamics, **16**(2)(2021) 021001.

Thermalization and Quantum Chaos

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Ergodic and chaotic motion in phase space was identified by Boltzmann as the key prerequisite to attain thermal equilibrium in classical many-body systems more than a century ago. The transcription of this notion to the realm of quantum mechanics has still remained a matter of lively debate. Does an isolated quantum many-body system initially prepared in a non-stationary state thermalize and, if so, what are the signatures and time scales of the approach to equilibrium? Moreover, can the notion of classical-quantum correspondence be extended to the concepts of ergodicity and chaos in statistical mechanics? Is the breakdown of quantum integrability and the appearance of quantum chaos as signified by universality classes of level statistics necessary to attain thermalization?

In this talk, I will discuss the interplay between quantum chaos and the emergence of the thermal state for a prototypical isolated Fermi-Hubbard many-body system. Such systems have become accessible in experiments with ultracold gases. We analyse the thermal state by determining the reduced one-particle density matrix (1RDM) of an impurity embedded in the Fermi-Hubbard system. Employing an exact diagonalization of the entire N-particle (impurity + bath) system we establish the direct connection between quantum chaos and the approach of the 1RDM to the canonical ensemble.

*Work in collaboration with Mahdi Kourepaz, Fabian Lackner, Stefan Donsa and Iva Brezinova

Classical Physics and Black Body Radiation

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The inability of classical physics to account for the experimentally observed frequency spectrum of blackbody radiation is at the origin of quantum theory. In spite of desperate attempts, the falloff of the blackbody curve at high frequencies could not be explained by classical mechanics. Here we discuss the properties of the blackbody spectrum by direct numerical solution of the classical equations of motion of a one-dimensional model that, however, contains the essential general features of the field-matter interaction. Our approach does not rely on any statistical assumption. We show that the classical blackbody spectrum exhibits remarkable properties: (i) a quasistationary state characterized by scaling properties, (ii) consistency with the Stefan-Boltzmann law, and (iii) a high-frequency cutoff. The present work is a preliminary step before addressing ergodicity in quantum field theories. This will require a nontrivial extension of concepts and tools recently developed for the investigation of thermalization and localization in many-body quantum systems.

Reference

[1] F. R. S. Lord Rayleigh, *Philos. Mag.* **49** (1900) 539.

[2] J. H. Jeans, *The Dynamical Theory of Gases, 4th ed., Cambridge University Press, Cambridge, England, 2009.*

[3] L. Boltzmann, *Ann. Phys., Berlin,* (1884) 258-291.

[4] L. Boltzmann *Nature* **51** (1895) 413.

[5] Jiao Wang, G. Casati and G Benenti, *Phys. Rev. Lett.* **128** (2022) 134101

From NEOs to TNOs: A journey through asteroids in our Solar System

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There is growing interest in the investigations concerning asteroids in our Solar System because every now and then our Earth is in danger of being hit by extraterrestrial bodies. In my talk I report on the progress in the observation of Near Earth Asteroids (NEOs), then also about recent research of minor bodies in the main belt of Asteroids between Mars and Jupiter. I will present also results about Trojans around the planets - especially Jupiter but also around Earth, Mars, Uranus and Neptune. Quite interesting is the possibiliy of the existence of a kind of a belt between the gasgiants Jupiter and Saturn where small bodies may reside on almost circular orbits for up to hundreds of million years. Finally we jump outside of this region into the one of Pluto and beyond where many celestial bodies, namely the Trans Neptunian Object (TNOs) move. There we also find the so-called dwarf-planets with sizes up to the one of Pluto and even larger. In the appendix we will present the newest results about the DART (Double Asteroid Redirection Test) mission, where NASA (later together with ESA) tries 'to test and validate a method to protect Earth in case of an asteroid impact threat'

Reference

[1] R. Dvorak and M. Kubala, *Astronomische Nachrichten* **343** (2022)

[2] R. Dvorak, C. Lhotka and L. Zhou, *Astronomy and Astrophysics* **541** (2012)

Metoda napihovanja za dokazovanje integrabilnosti ravninskih polinomskih sistemov diferencialnih enačb

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Predstavila bom učinkovito metodo za dokazovanje integrabilnosti resonantnega sedla, ki temelji na uporabi metode napihovanja in reševanju rekurzivnih diferencialnih enačb z uporabo indukcije. S to metodo so rešeni nekateri odprti problemi integrabilnosti za določena resonantna sedla.

Reference

[1] B. Ferčec, J. Giné, *A blow-up method to prove formal integrability for some planar differential equations*, Journal of Applied Analysis and Computation, **8**, No. 6 (2018) 1833–1850.

[2] B. Ferčec, J. Giné, *Blow-up method to compute necessary conditions of integrability for planar differential systems*, Applied Mathematics and Computation, **358** (2019) 16–24.

A Blow-up method for proving integrability of some planar polynomial systems of differential equations

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I shall discuss an effective method for proving integrability of the resonant saddles. The method is based on the use of a blow-up transformation and solving the recurrence differential equations using induction. Using this method some open integrability problems for certain resonant saddles are solved.

References

[1] B. Ferčec, J. Giné, *A blow-up method to prove formal integrability for some planar differential equations*, Journal of Applied Analysis and Computation, **8**, No. 6 (2018) 1833–1850.

[2] B. Ferčec, J. Giné, *Blow-up method to compute necessary conditions of integrability for planar differential systems*, Applied Mathematics and Computation, **358** (2019) 16–24.

Thermalization Universality Classes for Weakly Nonintegrable Many-Body Dynamics

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We observe different universality classes in the slowing down of thermalization of many-body dynamical systems upon approaching integrable limits. We identify two fundamentally distinct long-range and short-range classes which stem from the type of nonintegrable perturbations - weak two-body interactions (nonlinearities) versus weak lattice coupling (hopping) [1,2,3]. We study the scaling properties of the full Lyapunov spectrum [4,5]. The long-range class results in a single parameter scaling of the Lyapunov spectrum, with the inverse largest Lyapunov exponent being the only diverging time control parameter and the rescaled spectrum approaching an analytical function [4]. The short-range class results in a dramatic slowing down of thermalization and a rescaled Lyapunov spectrum approaching a non-analytic function. An additional diverging length scale controls the exponential suppression of all Lyapunov exponents relative to the largest one [4].

References

[1] Mithun Thudiyangal, Carlo Danieli, Yagmur Kati and Sergej Flach, *Dynamical Glass Phase and Ergodization Times in Classical Josephson Junction Chains*, Phys. Rev. Lett. **122** 054102 (2019)

[2] Carlo Danieli, Thudiyangal Mithun, Yagmur Kati, David K. Campbell and Sergej Flach, *Dynamical glass in weakly non-integrable Klein-Gordon chains*, Phys. Rev. E **100** 032217 (2019)

[3] T. Mithun, C. Danieli, M. V. Fistul, B. L. Altshuler and S. Flach, *Fragile Many Body Ergodicity From Action Diffusion*, Phys. Rev. E **104**, 014218 (2021)

[4] Merab Malishava and Sergej Flach, *Lyapunov spectrum scaling for classical many-body dynamics close to integrability*, Phys. Rev. Lett. **128**, 134102 (2022)

[5] Merab Malishava and Sergej Flach, *Thermalization dynamics of macroscopic weakly nonintegrable maps*, Chaos **32**, 063113 (2022)

Mrežna analiza kot sredstvo za preučevanje medsebojnih odnosov centralnih in ritmovniških celic v Langerhansovih otočkih trebušne slinavke

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Dekodiranje celičnih odzivov na spremembe v okolju je temeljnega pomena za razumevanje delovanja živih organizmov. Medtem ko se je v preteklosti večina študij osredotočala na izolirane celice ali populacijska povprečja, se področje preučevanja preusmerja na omrežja celičnih populacij. To velja tudi za celice beta Langerhansovih otočkov trebušne slinavke, ki izločajo inzulin. Te so električno vzdražne, zelo heterogene in tvorijo funkcionalni sincicij. Kljub njihovi heterogenosti električna sklopitev prek presledkovnih stikov omogoča njihovo usklajeno delovanje in koherentne oscilacije koncentracije Ca^{2+} ob stimulaciji z glukozo. Njihova sinhronost je pomembna za zagotavljanje ustreznih vzorcev izločanja inzulina, hormona, ki je ključen za nadzor presnovne homeostaze [1]. Pomen heterogenosti celic beta in kako te z mediacijo medceličnih signalov zagotavljajo usklajeno celično aktivnost, je še vedno nepopolno razumljen. Nedavni napredek na področju večceličnega snemanja, optogenetskih in fotofarmakoloških intervencij ter teorije omrežij je pripomogel k identifikaciji specializiranih subpopulacij celic beta, ki bistveno vplivajo na skupno aktivnost [1-3]. Predpostavljeno je bilo, da tako imenovane centralne celice, tj. celice s številnimi funkcionalnimi povezavami, bistveno povečajo komunikacijske zmogljivosti omrežja celic in omogočajo učinkovito širjenje medceličnih valov Ca^{2+}. Slednji se sprožajo v specifičnih subpopulacijah celic beta, tj. območjih ritmovnikov, ki so opredeljeni z njihovo lokalno vzdražnostjo in presnovnimi profili. Vendar je treba še pojasniti, ali in v kolikšni meri se vloge teh subpopulacij prekrivajo ter kakšne so njihove funkcionalne

značilnosti. Teh vprašanj smo se v naši študiji lotili s kombiniranjem večceličnega snemanja dinamike Ca^{2+} z visoko časovno in prostorsko ločljivostjo v tkivnih rezinah trebušne slinavke miši s pristopi s področja znanosti o omrežjih. Na podlagi posameznih Ca^{2+} valov smo zgradili mrežne plasti za prepoznavanje iniciatorjev valov, funkcionalne mreže določene na podlagi medceličnih korelacij v Ca^{2+} aktivnosti pa za odkrivanje centralnih celic. Naši rezultati kažejo, da obe vrsti celic izkazujeta nadpovprečno aktivnost, vendar se razlikujeta v drugih značilnostih njihove aktivnosti. Oscilacije Ca^{2+} v centralnih celicah so bolj redne, njihova vloga pa je v času stabilnejša. Najpomembneje je, da v nasprotju z ritmovniškimi celicami centralne celice kažejo krajše časovne zakasnitve aktivacije kot njihove sosede, kar implicira njihovo močnejšo junkcijsko prevodnost. Naše ugotovitve kažejo, da so tako centralne kot ritmovniške celice inherentna značilnost otočkov, vendar se njihove vloge ne prekrivajo [4].

Reference

[1] R.K.P. Benninger and V. Kravets, *Nature Reviews Endocrinology* **18** (2022) 9-22.

[2] V. Salem, et al., *Nature Metabolism* **1** (2019) 615-629.

[3] A. Stožer, et al., *Frontiers in Endocrinology* **13** (2022) 922640.

[4] M. Šterk, et al., *submitted*.

Network analysis as a means of studying interrelations of hub and pacemaker cells in the pancreatic islets of Langerhans

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Decoding cellular responses to changes in the environment is of fundamental importance to our understanding of living systems. While in the past, most of the studies focused on isolated cells or population averages, the scope is shifting towards networked cell populations. This holds true also for the insulin-secreting beta cells from pancreatic islets of Langerhans. They are electrically excitable, highly heterogeneous and form a functional syncytium. Despite their inherent heterogeneity, electrical coupling via gap junctions facilitates their well-coordinated behavior and coherent Ca^{2+} concentration oscillations when stimulated with glucose. Their synchronous behavior is vital for ensuring proper secretion of insulin, a hormone crucial for controlling metabolic homeostasis [1]. The importance of beta cell heterogeneity and how they ensure coordinated cellular rhythmicity through the mediation of intercellular signals is still incompletely understood. Recent advances in multicellular imaging, optogenetic and photopharmacological strategies, and network theory have aided the identification of specialized beta cells subpopulations, which affect the collective activity substantially [2-4]. It has been postulated that so-called hub cells, i.e., cells with many functional connections, significantly enhance the communication capacities of the intercellular network and facilitate an efficient spreading of intercellular Ca^{2+} waves. The latter was triggered within specific beta cell subpopulations, i.e., pacemaker regions, defined by their local excitability and metabolic profiles. However, if and to what extent the roles of these subpopulations overlap, and what are their functional characteristics re-

mains to be elucidated. We addressed these issues by combining high-temporally-resolved multicellular Ca^{2+} imaging in mouse pancreatic tissue slices with complex network-based approaches. We constructed network layers based on individual Ca^{2+} waves to identify wave initiators and functional correlation-based networks to detect hub cells. Our results reveal that both cell types exhibit a higher-than-average activity under physiological and supraphysiological glucose concentrations but differ in other signaling characteristics. Ca^{2+} oscillations in hub cells are more regular, and their role appears to be more stable in time. Most importantly, in contrast to pacemaker cells, hub cells display shorter activation time delays than their neighbors, which implies stronger junctional connectivity. Our findings indicate that both hub and pacemaker cells are natural features of islets, but their roles do not overlap [5].

References

[1] R.K.P. Benninger and V. Kravets, *Nature Reviews Endocrinology* **18** (2022) 9-22.

[2] V. Salem, et al., *Nature Metabolism* **1** (2019) 615-629.

[3] A. Stožer, et al., *Frontiers in Endocrinology* **13** (2022) 922640.

[4] M. Šterk, et al., *submitted*.

Koliko informacij je potrebnih za rekonstrukcijo spektra?

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Predpostavimo poznavanje disperzijske relacije za le eno fizikalno ekscitacijo v spektru dvo-točkovne funkcije v kvantni teoriji polja ali v spektru črne luknje. Na tem predavanju bom predstavil kdaj in kako je s to informacijo mogoča popolna rekonstrukcija celotnega spektra. Natančneje, predstavil bom algoritem, ki z rabo teoremov Darbouxja in Puiseuxja omogoča rekonstrukcijo vseh ekscitacij, ki se lahko povežejo s 'prehajanjem nivojev'. Na koncu predavanja pa bom s pomočjo pojava 'preskakovanja polov' poskusil odgovoriti še na vprašanje v naslovu.

Reference

[1] S. Grozdanov and T. Lemut, "Reconstruction of spectra and an algorithm based on the theorems of Darboux and Puiseux," [arXiv:2209.02788 [hep-th]].

[2] S. Grozdanov, A. O. Starinets and P. Tadić,"Hydrodynamic dispersion relations at finite coupling," JHEP **06** (2021), 180 [arXiv:2104.11035 [hep-th]].

[3] S. Grozdanov, P. K. Kovtun, A. O. Starinets and P. Tadić, "The complex life of hydrodynamic modes," JHEP **11** (2019), 097 [arXiv:1904.12862 [hep-th]].

[4] S. Grozdanov, P. K. Kovtun, A. O. Starinets and P. Tadić, "Convergence of the Gradient Expansion in Hydrodynamics," Phys. Rev. Lett. **122** (2019) no.25, 251601 [arXiv:1904.01018 [hep-th]].

How much information is required to reconstruct a spectrum?

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Assume a known dispersion relation of only a single mode in the spectrum of a two-point function in some quantum field theory or the quasinormal spectrum of a black hole. In this talk, I will discuss when and how the reconstruction of the complete spectrum of physical excitations is possible given this information. In particular, I will demonstrate our recently developed constructive algorithm based on the theorems of Darboux and Puiseux that allows for such a reconstruction of all modes connected by 'level-crossings'. Finally, I will attempt to answer the question posed in the title by utilising the phenomenon of 'pole-skipping'.

References

[1] S. Grozdanov and T. Lemut, "Reconstruction of spectra and an algorithm based on the theorems of Darboux and Puiseux," [arXiv:2209.02788 [hep-th]].

[2] S. Grozdanov, A. O. Starinets and P. Tadić,"Hydrodynamic dispersion relations at finite coupling," JHEP **06** (2021), 180 [arXiv:2104.11035 [hep-th]].

[3] S. Grozdanov, P. K. Kovtun, A. O. Starinets and P. Tadić, "The complex life of hydrodynamic modes," JHEP **11** (2019), 097 [arXiv:1904.12862 [hep-th]].

[4] S. Grozdanov, P. K. Kovtun, A. O. Starinets and P. Tadić, "Convergence of the Gradient Expansion in Hydrodynamics," Phys. Rev. Lett. **122** (2019) no.25, 251601 [arXiv:1904.01018 [hep-th]].

Superdifuzija v kvantni Heisenbergovi verigi

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Heisenberg je leta 1928 predlagal preprost mikroskopski teoretični model kvantnega feromagneta na mreži, ki vključuje le izmenjalno sklopitev med sosednjimi spini. V eni prostorski razsežnosti lastna stanja Heisenbergove verige popiše Bethejeva valovna funkcija vzbujenih magnonskih valovnih načinov. Obstoj dolgoživih kvazidelcev privede do zloma ergodičnosti, kar porodi mnoge nenavadne lastnosti kot sta npr. odsotnost termalizacije in anomalni transport. Čeprav točen izračun dinamičnih opazljivk trenutno presega okvirje teorije kvantne integrabilnosti, je časovni razvoj ohranjenih lokalnih količin na hidrodinamski skali možno obravnavati v sklopu točnega efektivnega opisa posplošene hidrodinamike. V predavanju predstavimo nenavadni pojav spinske superdifuzije v izotropni Heisenbergovi verigi. Poleg osnovnega teoretičnega ozadja, se navežemo tudi na nedavne eksperimentalne dosežke z nevtronsko spektroskopijo in s hladnimi atomi v optičnih mrežah.

Reference

[1] M. Žnidarič, *Physical Review Letters* **106** (2011) 220601.

[2] M. Ljubotina, M. Žnidarič and T. Prosen, *Physical Review Letters* **122** (2019) 210602.

[3] E. Ilievski et al., *Physical Review X* **11** (2020) 031023.

[4] V. B. Bulchandani, S. Gopalakrishnan amd E. Ilievski, *Journal of Statistical Mechanics* **(2021)** 084001.

[5] Scheie et al., *Nature Physics* **17** (2021) 726-730.

[6] Wei et al., *Science* **376** (2022) 716-720.

Superdiffusion in quantum Heisenberg chain

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Back in 1928, Heisenberg proposed a simple microscopic theoretical model of a quantum ferromagnet in which spins interact via exchange coupling only with their neighbours on a lattice. In one spatial dimension, all eigenstates of the Heiseneberg chain can be represented by the Bethe wavefunction, describing interacting spin waves propagating ballistically through the system. Ergodicty breaking induced by the long-lived quasiparticles leads to various unorthodox properties such as, most prominently, lack of thermalization and anomalous transport. While exact computation of dynamical quantities goes currently beyond the capabilities of the quantum integrability theory, the hydrodynamic evolution of conserved quantities can be accurately described by the effective theory of generalized hydrodynamics. In this talk, we shall introduce the peculiar phenomenon of spin superdiffusion in the isotropic Heisenberg spin chain, provide some of the theoretical background and also review the most recent experimental breakthroughs with inelastic neutron scattering and with cold atoms in optical lattices.

References

[1] M. Žnidarič, *Physical Review Letters* **106** (2011) 220601.

[2] M. Ljubotina, M. Žnidarič and T. Prosen, *Physical Review Letters* **122** (2019) 210602.

[3] E. Ilievski et al., *Physical Review X* **11** (2020) 031023.

[4] V. B. Bulchandani, S. Gopalakrishnan amd E. Ilievski, *Journal of Statistical Mechanics* **(2021)** 084001.

[5] Scheie et al., *Nature Physics* **17** (2021) 726-730.

[6] Wei et al., *Science* **376** (2022) 716-720.

Nematski biti in univerzalna logična vrata

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Topološke strukture v nematskih tekočih kristalih si delijo matematične in fenomenološke podobnosti z ostalimi sistemi kondenzirane snovi. Razvite eksperimentalne tehnike omogočajo natančen nadzor nad orientacijo in dinamiko nematskih struktur, manj pa je znano, kako bi lahko takšne strukture uporabili za shrambo in manipulacijo informacij. V predavanju bom uvedel koncept nematskih bitov (nbitov), ki so zasnovani na kvaternionski preslikavi med nematskimi defekti in Bloch-Poincaréjevo sfero. V članku sva z J. Dunklom s simulacijami in teoretičnimi pristopi pokazala, kako lahko z električnim poljem udejanimo logične operacije na nematskih bitih, v analogiji s Paulijevemi, Hadamardovimi in ostalimi logičnimi vrati [1]. Pari nematskih bitov kažejo močne ali šibke statistične korelacije, kar je odvisno od izbire načina meritve in relavantnih časovnih skal. Poleg tega pa sva pokazala, da lahko več-nbitne interakcije vodijo do univerzalnih klasičnih NOR in NAND logičnih vrat, kar je poseben primer preslikave med Bloch-Poincaréjevimi sferami vhodnih in izhodnih nematskih bitov. Ti rezultati kažejo smer potencialnega razvoja računskih strategij v mehki topološki snovi.

Reference

[1] Ž. Kos and J. Dunkel, *Science Advances* **8** (2022) eabp8371.

Nematic bits and universal logic gates

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Topological field structures in nematic liquid crystals are known to share phenomenological and mathematical analogies with other condensed matter systems. While the experimental control of orientation and dynamics of nematic structures has been developed, little is known about how such structures could be used for information storage and computation. Here, we introduce the concept of nematic bits (nbits) by building on a previously established quaternionic mapping from nematic defects to a Bloch-Poincaré sphere. Considering suitable electric fields, we show in theory and simulations how logic operations can be applied to nbits, analogous to Pauli, Hadamard and other logic gates [1]. Pairs of nbits can exhibit strong or weak statistical correlations, depending on the choice of the measurement procedure and time scales involved. We further demonstrate how multi-nbit interactions can realize universal classical NOR and NAND gates as special cases of general mappings between the Bloch spheres of the input and output nbits. These results provide a route towards implementing classical and more general computation strategies in topological soft matter systems.

References

[1] Ž. Kos and J. Dunkel, *Science Advances* **8** (2022) eabp8371.

Univerzalne anomalne fluktuacije v nabitih enovrstičnih sistemih

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Konvencionalna klasifikacija dinamičnih fenomenov bazira na univerzalni hidrodinamski relaksaciji, ki jo karakterizirata dinamiňi eksponent in asimptotska oblika dinamičnega strukturnega faktorja. Argumentiramo da se dinamični univerzalnostni razredi naravno razlikujejo na podlagi fluktuacijskih lastnosti. Kot primer obravnavmo splošen razred enodimenzionalnih enovrstičnih sistemov nabitih delcev s trdo sredico. Dinamične vezi porodijo univerzalne anomalne statistične lastnosti pretoččnega naboja, ki se odražajo tako na časovni skali tipičnih kot tudi redkih dogodkov. Tipične fluktuacije v ravnovesju sledijo univerzalni distribuciji, ki močno odstopa od pričakovane Gaussovske porazdelitve, medtem ko velike fluktuacije opisuje t.i. "rate" funkcija z izredno trojno kritično točko. Daleč stran od ravnovesja tekmovanje dveh dinamiččih faz vodi do dinamičnih faznih prehodov prvega in drugega reda. Nakažemo nekaj povezav s fluktuacijami magnetizacije v integrabilnih spinskih verigah.

Reference

[1] Ž. Krajnik, E. Ilievski, and T. Prosen, *Physical Review Letters* **128**, 090604 (2022).

[2] Ž. Krajnik, J. Schmidt, V. Pasquier, E. Ilievski, and T. Prosen, *Physical Review Letters* **128**, 160601 (2022).

[3] Ž. Krajnik, J. Schmidt, V. Pasquier, T. Prosen and E. Ilievski, *arXiv:* 2208.01463 (2022).

Universal anomalous fluctuations in charged single-file systems

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Conventional classification of dynamical phenomena is based on universal hydrodynamic relaxation characterized by algebraic dynamical exponents and asymptotic scaling of the dynamical structure factor. We argue that dynamical universality classes can instead be naturally distinguished based on their full-counting statistics. As an example we consider a general class of one-dimensional single-file systems of interacting hardcore charged particles. Dynamical constraints give rise to universal anomalous statistics of cumulative charge currents, manifested both on the timescale characteristic of typical fluctuations and also in the rate function describing rare events. Typical fluctuations in equilibrium are governed by a universal distribution that markedly deviates from the expected Gaussian statistics, whereas large fluctuations are described by a large-deviation rate function featuring an exceptional triple critical point. Far from equilibrium, competition between dynamical phases leads to dynamical phase transitions of first and second order. We point out some connections with charge fluctuations in integrable spin chains.

References

[1] Ž. Krajnik, E. Ilievski, and T. Prosen, *Physical Review Letters* **128**, 090604 (2022).

[2] Ž. Krajnik, J. Schmidt, V. Pasquier, E. Ilievski, and T. Prosen, *Physical Review Letters* **128**, 160601 (2022).

[3] Ž. Krajnik, J. Schmidt, V. Pasquier, T. Prosen and E. Ilievski, *arXiv:* 2208.01463 (2022).

Temna stran Belle II

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V predavanju bom najprej predstavil motivacijo za iskanje delcev temne snovi in mediatorjev med običajno in temno snovjo in detektor, s katerim jih iščemo. Sledil bo pregled najbolj zanimivih rezultatov meritev. Na koncu bom predstavil še načrte za bodočnost.

The Dark Side of Belle II

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In the talk we will first discuss the motivation for the next searches for dark matter particles and mediators between the dark and ordinary matter. We will then present the detector and make an overview of the most interesting results. We will finish by our plans for the future.

Exploring quantum chaos and ergodicity with quantum billiards

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Billiard systems are ideal test-beds for exploring concepts in classical and quantum chaos. In spite of the simplicity of the dynamics, many interesting dynamical regimes may be realized by considering different shapes of the billiard table. The Quantum Chaos or Bohigas-Giannoni-Schmit (BGS) conjecture states that spectra of quantum chaotic systems will exhibit the same statistical properties as random matrices. By contrast, integrable systems are expected to have Poissonian level statistics (Berry-Tabor conjecture). However, many dynamical regimes between chaos and integrability exist. I will present some recent numerical studies of spectral statistics and eigenfunctions of quantum billiards that explore these intermediate regimes. A robust methodology based on the study of the Poincaré-Husimi functions and their localization measures enables us to study, describe and classify a wide range of dynamical phenomena like quantum ergodicity, scarring, stickiness, dynamical localization, "weak" chaos, mixed regular-chaotic states, semiclassical condensation on invariant structures etc. The presented methodology is directly applicable to other single-particle quantum systems.

References

[1] Č. Lozej, D. Lukman, and M. Robnik, *Physical Review E* **106** (5), 054203 (2022).

[2] Č. Lozej, G. Casati, and T. Prosen, *Physical Review Research* **4** (1), 013138 (2022).

[3] Č. Lozej, D. Lukman, and M. Robnik, *Physical Review E* **103** (1), 012204 (2021).

[4] B. Batistić, Č. Lozej, and M. Robnik, *Physical Review E* **100** (6), 062208 (2019).

From the Quantum World to the 2nd Quantum Revolution: Challenges for Europe

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Since the beginning of the last century, fundamental epistemological questions about the reality and causality of the quantum world have arisen that seemed to break with classical physics. These include, for example, the superposition and entanglement of quantum states, which were initially formulated in 1935 in thought experiments such as Schrödinger's cat and Einstein's EPR experiment, but were then mathematically specified and transferred into empirically decidable experiments [1]. After this phase of basic research of the quantum world, a second quantum revolution has been emerging since the 1980s at the latest, in which the findings of the quantum world are being translated into technological innovation. This technological revolution is taking place in different generations.

Since many years, transistors, diodes, and laser are already well known devices of everyday technology. After this first generation of quantum technology, we are living in the 2nd generation which applies principles of quantum mechanics (e.g. superposition, entanglement) in a targeted manner [2]. Examples are first prototypes of quantum computers, classical supercomputer with quantum simulation, quantum communication, and quantum cryptography. There are already hints that we are in the transition to a 3rd generation of quantum technology with, e.g., universal quantum computers, quantum Internet, and quantum artificial intelligence [3]. Obviously, quantum computing does not only concern deep epistemic foundations of nature, but also revolutionary impact on economy and society [4]. This talk considers bridging foundational research as well as applied engineering and societal impact for Europe.

References

[1] J. Audretsch, K. Mainzer (eds.), *Wieviele Leben hat Schrödingers Katze? Zur Physik und Philosophie der Quantenmechanik, Spektrum Akademischer Verlag 2nd ed.* (1996) (1st ed. 1990).

[2] G. Benenti, G. Casati, G. Strini, *Principles of Quantum Computation and Information 2 vols., World Scientific Singapore* (2004, 2007).

[3] K. Mainzer, *Artificial Intelligence. When do Machines take over? Springer: Berlin 2nd ed.* (2019).

[4] K. Mainzer, *Quantencomputer – Von der Quantenwelt zur Künstlichen Intelligenz, Springer: Berlin* (2020).

Natančna določitev verjetnosti faznih prehodov v zgodnjem vesolju

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Naše vesolje je morda bilo (ali pa je) obtičalo v metastabilnem stanju, ki lahko s tuneliranjem razpade v stabilno. Takšni procesi bi sprožili opazne gravitacijske valove in zahtevajo globlje teoretično razumevanje. V pionirskih delih so Coleman et al. zastavili problem v evklidskem prostoru in zgradili teoretično osnovo s semi-klasično odbojno rešitvijo in kvantnimi popravki. Nedavno smo razvili univerzalno semi-klasično konstrukcijo s poligonalnimi odboji in jo implementirali v FindBounce paketu. Poleg tega smo našli analitični izraz za popravke ene zanke v meji tanke stene (nad običajnim vodilnim redom) za poljubno dimenzijo prostor-časa.

Reference

[1] V. Guada, A. Maiezza and M. Nemevšek, Phys. Rev. D **99** (2019) no.5, 056020.

[2] V. Guada, M. Nemevšek and M. Pintar, Comput. Phys. Commun. **256** (2020), 107480.

[3] V. Guada and M. Nemevšek, Phys. Rev. D **102** (2020), 125017.

[4] A. Ivanov, M. Matteini, M. Nemevšek and L. Ubaldi, JHEP **03** (2022), 209.

Precise determination of phase transition probabilities in the early universe

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Our universe may have been (or may be) stuck in a metastable state, which can decay to a stable one via tunnelling. Such processes would have triggered observable gravitational waves and require a deeper theoretical understanding. The pioneering works of Coleman et al. posed the problem in Euclidean space and constructed the theoretical groundwork with a semi-classical bounce and quantum corrections. We recently developed a universal semi-classical construction with polygonal bounces and implemented it in the FindBounce package. Moreover, we found a closed form expression for one loop corrections in the thin wall limit (beyond the usual leading order) for an arbitrary spacetime dimension.

References

[1] V. Guada, A. Maiezza and M. Nemevšek, Phys. Rev. D **99** (2019) no.5, 056020.

[2] V. Guada, M. Nemevšek and M. Pintar, Comput. Phys. Commun. **256** (2020), 107480.

[3] V. Guada and M. Nemevšek, Phys. Rev. D **102** (2020), 125017.

[4] A. Ivanov, M. Matteini, M. Nemevšek and L. Ubaldi, JHEP **03** (2022), 209.

Ekonomska upravičenost letal z gorivnimi celicami

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V mnogih primerih je letenje hitrejši in udobnejši način potovanja kot potovanje po cesti ali z železnico in zato njegova priljubljenost narašča. Danes letalstvo prispeva k 2% deležu svetovnih in 3% deležu evropskih izpustov toplogrednih plinov, vendar bo hitra rast letalskih potovalnih storitev lahko povzročila 300% povečanje CO_2 emisij do leta 2050. Zato se izvajajo številne nove študije in projekti za iskanje ustreznih alternativ fosilnim gorivom v letalstvu. Zanimiva rešitev je letalo z gorivnimi celicami. V takšnih letalih se v gorivnih celicah iz vodika ustvarja električna energija, ki preko elektromotorja poganja propeler. Ker je edini stranski produkt takšnega letala voda oziroma vodna para, lahko letala z gorivnimi celicami obravnavamo kot okolju prijazno rešitev brez CO_2 emisij. To seveda pod pogojem, da je vodik, ki se uporablja kot gorivo, proizveden z električno energijo iz obnovljivih virov (tako imenovani zeleni vodik).

Vendar pa je vsakršna naložba v novo letalo, še posebej če gre za letalo z novo pogonsko tehnologijo, tvegana naložba. Nobeden proizvajalec ne bo pripravljen prevzeti takšnega tveganja, če ni prepričan, da so letalske družbe pripravljene takšno letalo tudi kupiti. Letalski prevozniki pa ne bodo pripravljeni kupiti letala, če to ne ustreza njihovim potrebam po zmogljivosti (npr. številu sedežev, dometu, pristajalni in vzletni razdalji) in če cena letala in obratovalni stroški niso ustrezni. Cilj tega predavanja je predstaviti model, ki primerja neposredne obratovalne stroške konvencionalnih 19-sedežnih letal z letali na gorivne celice in ugotoviti, kje so priložnosti in kje slabosti v smislu ekonomske upravičenosti. Letalo z 19 sedeži je bilo izbrano, ker je to največje potniško letalo, ki ga lahko certificiramo pod predpisi FAR–23. Zato ga je možno lažje in hitreje registrirati kot večja letala in istočasno ima manjšo maksimalno vzletno maso na potnika in posledično manjše obratovalne stroške v primerjavi z manjšimi letali iz iste kategorije.

Reference

[1] M. Marksel and A. Prapotnik Brdnik, *Sustainability* **14** (2022) 8392.

[2] A. Prapotnik Brdnik, R. Kamnik, M. Marksel, S. Božičnik, *Energies* **12** (2019) 1864.

[3] M. Marksel, R. Kamnik, S. Božičnik, A. Prapotnik Brdnik in: C.O. Colpan (ed.), A. Kovač (ed.) *Fuel cell and hydrogen technologies in aviation.* Springer (2022) pg. 117-146.

[4] M. Marksel, S. Božičnik and A. Prapotnik Brdnik, delo v teku, načrtovana odaja v Sustainability.

Economical feasibility of fuel cell aircraft

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In many cases flying it is a faster and more convenient way to travel than by road or rail. Today, aviation contributes to 2% of global and 3% of European greenhouse gases, but due to fast growth of aircraft travel services, this will lead to a 300% increase in CO_2 emissions by 2050 if cleaner propulsion technologies are not introduced. Therefore, many new studies and projects are being conducted to find suitable alternatives to fossil fuels in aviation. A very interesting solution is the hydrogen fuel cell aircraft. In fuel cell aircraft, hydrogen is used in fuel cells to generate electricity. The electricity is then consumed by an electric motor that drives a propeller. Since the only by-product in fuel cell aircraft is water, fuel cell aircraft can be environmentally friendly aircraft with zero CO_2 emissions if the hydrogen used as fuel is produced by electrolysis with electricity from renewable energy sources (green hydrogen).

However, any kind of investment in a new aircraft, especially new propulsion technologies such as hydrogen fuel cell aircraft, is a risky investment, and no manufacturer will be willing to take such a risk if there are no airlines willing to buy the aircraft. Airlines, in turn, will not be willing to buy an aircraft whose seating capacity, range, price, and operating costs are not adequate. The aim of this talk is present a model that compares the direct operating costs of a conventional 19-seat aircraft with those of a fuel cell aircraft, and to provide an understanding of which cost categories might be important in the implementation of such an aircraft for commercial air services and where the opportunities and drawbacks lie in terms of economic viability. The 19-seat aircraft was selected because it is the largest certified passenger aircraft that falls under the regulations of FAR–23. Therefore, it should be both easier to register than larger aircraft and have a more favorable maximal takeoff mass and consequently operating costs compared to lighter FAR-23 aircraft.

References

[1] M. Marksel and A. Prapotnik Brdnik, *Sustainability* **14** (2022) 8392.

[2] A. Prapotnik Brdnik, R. Kamnik, M. Marksel, S. Božičnik, *Energies* **12** (2019) 1864.

[3] M. Marksel, R. Kamnik, S. Božičnik, A. Prapotnik Brdnik in: C.O. Colpan (ed.), A. Kovač (ed.) *Fuel cell and hydrogen technologies in aviation.* Springer (2022) pg. 117-146.

[4] M. Marksel, S. Božičnik and A. Prapotnik Brdnik, work in progress to be submitted to Sustainability.

Večdelčna lokalizacija: živa ali mrtva?

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V enodimenzionalnih spinskih verigah, oz. ekvivaletno v sklopljenih fermionskih sistemih, se opazi pri dodajanju velikih slučajnih ali kvaziperidičnih potencialiov pojav večdelčne lokalizacije (VDL), ki se izkazuje v večih lastnostih: z odsotnostjo termalizacije, v spektralnih lastnostih in v odsotnosti enosmernega transporta. Kljub intenzivnim teoretičnim in eksperimentalnih raziskavam v zadnjih 15 letih, je striktni obstoj VDL in povezanega faznega prehoda vprašljiv. V svojem predavanju bom obravnaval transportne lastnosti modelov VDL [1], zlasti spinskega in energijskega transporta. V primeru slučajnih potencialov kažejo te lastnosti velike fluktuacije glede na realizacijo potencialov, kar pa ni slučaj za kvaziperiodične potenciale. Prikazal bom rezultate, ki kažejo tudi v tem primeru eksponentno odvisnost prevodnosti od moči potenciala brez znakov dobro definiranega faznega prehoda. Poleg tega zamenjava kvaziperiodičnega potenciala s periodičnim daje podobno obnašanje, vsaj pri zmernih potencialih, kar nakazuje novo pot k razumevanju problema VDL.

Reference

[1] P. Prelovšek, M. Mierzejewski, O. Barišič, and J. Herbrych, *Annalen der Physik* **529** (2017) 1600362.

[2] J. Herbrych, M. Mierzejewski, and P. Prelovšek, *Physical Review B* **105** (2022) L081105.

Many - body localization: wanted dead or alive

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It is general observation that one-dimensional spin chains, and equivalently interacting fermionic chains, reveal a transition/crossover to many-body localization (MBL) when subjected to large random or quasiperiodic potentials. The MBL phase should be manifested by several features as the absence of thermalization, change of spectral properties and the absence of d.c. transport. In spite of intensive theoretical as well as experimental efforts over last 15 years, the question of the strict existence of MBL and of corresponding phase transition is at present controversial. I will focus on the perspective of transport quantities [1], i.e. the spin and energy diffusion. In random systems numerical results show large sample-sample fluctuations [2], while in quasiperiodic systems this is not the case. We present results for the high-temperature spin conductivity, which reveal an exponential-like dependence on potential strength over several decades, without any clear indication of a well-defined transition to MBL. Moreover, replacing the quasiperiodc potential with a simpler periodic one, the variation remains qualitatively similar up to large potential strength, which offers a new route to the MBL problem.

References

[1] P. Prelovšek, M. Mierzejewski, O. Barišič, and J. Herbrych, *Annalen der Physik* **529** (2017) 1600362.

[2] J. Herbrych, M. Mierzejewski, and P. Prelovšek, *Physical Review B* **105** (2022) L081105.

Nenavadna štirikvarkovska stanja

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V zadnjem desetletju so eksperimenti nepričakovano odkrili precej eksotičnih hadronov - to so stanja sestavljena iz več kot treh valenčnih kvarkov. Najbolj dolgoživ eksotičen hadron doslej je bil lani odkrit v CERNu in vsebuje štiri kvarke $cc\bar{u}\bar{d}$. V predavanju bom predstavila prvo teoretično študijo s kromodinamiko na mreži, ki kaže na obstoj tega zanimivega stanja. Večina doslej odkritih eksotičnih stanj vsebuje par $\bar{c}c$ ter dodatne lahke kvarke. Naša raziskava tovrstnih stanj je pravilno opisala lastnosti običajnih čarmonijev ter napovedala obstoj dveh nenavadnih hadronov, ki so ju letos eksperimentalno potrdili.

Reference

[1] M. Padmanath in S. Prelovšek, *Signature of a doubly charm tetraquark pole in DD^* scattering on the lattice*, Physical Review Letters 129 (2022) 032002.

[2] S. Prelovšek, S. Collins, D. Mohler, M. Padmanath, S. Piemonte, *Charmonium-like resonances with $J^{PC} = 0^{++}, 2^{++}$ in coupled $\bar{D} - \bar{D}_s\bar{D}_s$ scattering on the lattice*, Journal of High Energy Physics 06 (2021) 035.

Exotic tetraquark states

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Experiments have recently discovered several exotic hadrons that consist of more than three valence quarks/antiquarks. Among these, the longest-lived state $cc\bar{u}\bar{d}$ was discovered at CERN in 2021. I will present the first lattice QCD study that determines the underlying scattering amplitude and finds a pole that is likely related to this state. Most of the exotic hadrons contain $\bar{c}c$ and additional light quarks. Our recent study of such states features the expected conventional charmonia $\bar{c}c$ and predicts also two unexpected exotic tetraquark states, which have been discovered in experiment this year.

References

[1] M. Padmanath in S. Prelovšek, *Signature of a doubly charm tetraquark pole in DD^* scattering on the lattice*, Physical Review Letters 129 (2022) 032002.

[2] S. Prelovšek, S. Collins, D. Mohler, M. Padmanath, S. Piemonte, *Charmonium-like resonances with $J^{PC} = 0^{++}, 2^{++}$ in coupled $\bar{D} - \bar{D}_s\bar{D}_s$ scattering on the lattice*, Journal of High Energy Physics 06 (2021) 035.

Prehod kvantne prepletenosti od temeljev kvantne mahanike v uporabno tehnologijo

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Einstein, Podolsky in Rosen so se v svojem članku iz leta 1935 spraševali, ali je opis realnosti v okviru kvantne mehanike in valovnih funkcij res kompleten [1]. Danes je omenjeni članek sicer najbolj citirano Einsteinovo delo, a kvantne prepletenosti – ki je bila razlog za takratne dvome – ne obravnavamo več kot paradoks, ampak kot eno od osnovnih sestavin kvantne obravnave informacij. V predavanju bomo na kratko predstavili fizikalne osnove kvantne prepletenosti in nato prikazali primer uporabe kvantne izmenjave ključa, ki je bila pred kratkim realizirana med Ljubljano, Trstom in Rijeko [2]. Nakazali bom tudi, kakšno vlogo bo pri tej tehnologiji v prihodnosti imela kvantna prepletenost.

Reference

[1] *Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?*, A. Einstein, B. Podolsky, and N. Rosen, Phys. Rev. **47**, 777 (1935).

[2] *Deploying an inter-European quantum network*, D. Ribezzo, M. Zahidy, I. Vagniluca, N. Biagi, S. Francesconi, T. Occhipinti, Leif K. Oxenløwe, M. Lončaric, I. Cvitić, M. Stipčević, Ž. Pušavec, R. Kaltenbaek, A. Ramšak, F. Cesa, G. Giorgetti, F. Scazza, A. Bassi, P. De Natale, F. S. Cataliotti, M. Inguscio, D. Bacco, and A. Zavatta, to appear in Adv. Quantum Technol. (2022); arXiv:2203.11359.

The transition of quantum entanglement from the foundations of quantum mechanics to applied technology

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In their 1935 article, Einstein, Podolsky and Rosen questioned whether the description of reality within the framework of quantum mechanics and wave functions is really complete [1]. Today, the aforementioned article is not only Einstein's most cited work, but quantum entanglement - which gave rise to doubts at that time - is no longer treated as a paradox, but as one of the fundamental components of quantum information manipulation. We will briefly present the physical foundations of quantum entanglement and then show an example of the application of quantum key distribution, recently realized between Ljubljana, Trieste and Rijeka [2]. It will also be shown what role quantum entanglement will play in this technology in the near future.

References

[1] *Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?*, A. Einstein, B. Podolsky, and N. Rosen, Phys. Rev. **47**, 777 (1935).

[2] *Deploying an inter-European quantum network*, D. Ribezzo, M. Zahidy, I. Vagniluca, N. Biagi, S. Francesconi, T. Occhipinti, Leif K. Oxenløwe, M. Lončaric, I. Cvitić, M. Stipčević, Ž. Pušavec, R. Kaltenbaek, A. Ramšak, F. Cesa, G. Giorgetti, F. Scazza, A. Bassi, P. De Natale, F. S. Cataliotti, M. Inguscio, D. Bacco, and A. Zavatta, to appear in Adv. Quantum Technol. (2022); arXiv:2203.11359.

Pasivna in aktivna topološka mehka snov

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Topološka mehka snov predstavlja poseben primer materialov, ki so zmožni različnih materialnih mehanizmov in značilnosti, od notranjega reda, samosestavljanja, topologije, topoloških defektov in zlasti aktivnosti. Tukaj bom podal izbran pregled nedavnih in nastajajočih smeri v pasivni in aktivni topološki mehki snovi, s posebnim poudarkom na strukturah v pasivnih in aktivnih nematikih in njihovi sposobnosti, da delujejo kot fotonski ali mikroelektronski elementi. Izkazalo se je, da posebej singularni in nesingularni topološki defekti delujejo kot objekti, ki lahko vplivajo ali celo nadzorujejo zmogljivost in odziv materiala, tako v pasivnih kot aktivnih sistemih.

Passive and active topological soft matter

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Topological soft matter presents distinct class of materials capable of diverse material mechanisms and characteristics, ranging from internal order, self-assembly, topology, defects and notably, activity. Here, I will give a selected overview of recent and emergent directions in passive and active topological soft matter, with particular emphasis on structures in passive and active nematics and their capability to perform as photonic or microelectronic elements. Singular and nonsingular topological defects are shown to perform as objects that can affect or even control the material performance and response, both in passive and active systems.

Parametrično periodično vzbujanje klasičnega in kvantnega linearnega oscilatorja

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Proučujemo, teoretično in numerično, vedenje klasičnega in kvantnega parametrično periodično vzbujanega linearnega oscilatorja. Kot osnovno paradigmo takšnega Floquetovega sistema obravnavamo primer harmonične oscilacije oscilatorjeve frekvence, ki je priročen za teoretično in numerično obravnavo, a ohranja vse splošne lastnosti. Izpeljemo eksplicitno analitično formulo za kvantni propagator s pomočjo klasičnega propagatorja. Uporabljajoč to izpeljemo eksplicitno eksaktno formulo za razvoj pričakovane vrednosti energije, za poljubno normirano začetno stanje. V primeru, ko je začetno stanje stacionarno lastno stanje, je razvoj natančno enak kot za klasični mikrokanonični ansambel začetnih pogojev z isto začetno energijo. Izvedemo popolno numerično analizo vedenja sistema v območjih nestabilnosti (lacunae), kjer se energija oscilatorja eksponentno povečuje, kakor tudi v območjih stabilnosti, še posebej na meji med stabilnostnim ter nestabilnostnim območjem. Numerično potrdimo s popolno zanesljivostjo, da meji med stabilnim in nestabilnim območjem klasično in kvantno *eksaktno* sovpadata, v skladu s teorijo, in dobimo vrsto pomembnih empiričnih rezultatov, še prav posebej enačbo eliptičnega tipa, s katero izrazimo hitrost eksponentnega naraščanja energije v lacunah kot funkcijo drugih sistemskih parametrov. Verjamemo, da so naš pristop in rezultati generičnega tipa, t.j. uporabni v večini tovrstnih linearnih Floquetovih sistemov, in predstavimo motivacijo za splošno teorijo, klasično in kvantno. Ob zaključku omenimo vedenje nelinearnih parametrično vzbujanih oscilatorjev.

Reference

[1] V. Grubelnik, M. Logar, M. Robnik and Y. Xia, *Physical Review E* **99** No.2 (2019) 022209.

[2] G. Papamikos and M. Robnik, *J. Phys. A: Math. Theor.* **45** (2012) 015206

[3] G. Papamikos and M. Robnik, *J. Phys. A: Math. Theor.* **44** (2011) 315102

[4] G. Papamikos, B. C. Sowden and M. Robnik, *Nonlinear Phenomena in Complex Systems (Minsk)* **15** No. 3 (2012) 227

Parametric periodic driving of the classical and quantum linear oscillator

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We study theoretically and computationally the behaviour of the classical and quantum parametrically periodically driven linear oscillator. As a basic paradigm of such a Floquet system we consider the case of the harmonic oscillation of the oscillator frequency, which is convenient to handle theoretically and computationally, while keeping the general features. We derive explicit analytic formula for the quantum propagator in terms of the classical propagator. Using this, we derive the explicit exact formula for the evolution of the expectation value of the energy starting from an arbitrary normalizable initial state. In the case of the starting pure stationary eigenstate the evolution is exactly the same as for the classical microcanonical ensemble of initial conditions of the same starting energy. We perform a rather complete computational analysis of the system's behaviour inside the instability regions (lacunae), where the energy of the oscillator increases exponentially, as well as in the stability regions, and in particular in the vicinity of the (in)stability borders. We confirm also numerically with absolute certainty that the borders of (in)stability regions classically and quantally coincide *exactly*, in accordance with the theory, and find a number of important empirical results, especially an equation of the elliptic type describing the rate of exponential energy growth inside the lacunae in terms of other system's quantities. We believe that our approach and findings are of generic linear type, i.e. applicable in most such linear Floquet systems, and present a strong motivation for a general theory, classically and quantally. In closing we discuss the behavior of parametrically driven nonlinear oscillators.

References

[1] V. Grubelnik, M. Logar, M. Robnik and Y. Xia, *Physical Review E* **99** No.2 (2019) 022209.

[2] G. Papamikos and M. Robnik, *J. Phys. A: Math. Theor.* **45** (2012) 015206

[3] G. Papamikos and M. Robnik, *J. Phys. A: Math. Theor.* **44** (2011) 315102

[4] G. Papamikos, B. C. Sowden and M. Robnik, *Nonlinear Phenomena in Complex Systems (Minsk)* **15** No. 3 (2012) 227

Funkcije Ljapunova in limitni cikli v modelu rasti tumorja

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Predstavil bom kvalitativno analizo rasti modela tumorja, ki je opisana preko sistema navadnih diferencialnih enačb. Pokazali bomo, da ima sistem pozitivno ravnovesno točko in njegova stabilnost je neodvisna od povratne informacije. Z metodo funkcij Lyapunova dokažemo, da obstajajo realistične vrednosti parametrov za katere v sistemu obstajo periodična nihanja, ki se pojavio zaradi superkritične Hopfove bifurkacije. Predstavljena je tudi časovna evolucija faznih spremenljivk.

To je skupna študija z Danielom Drexlerjem in Ilono Nagy.

Reference

[1] D. A. Drexler, I. Nagy and V. Romanovski, Bifurcations in a closed-loop model of tumor growth control. In: 21th IEEE International Symposium on Computational Intelligence and Informatics, November 18-20 2021, Budapest, Hungary. PP. 37-42. DOI: 10.1109/CINTI53070.2021.9668407.

[2] Y. N. Bibikov, Local Theory of Nonlinear Analytic Ordinary Differential Equations. Berlin, Heidelberg, New York: Springer-Verlag, 1979

Lyapunov functions and limit cycles in a tumor growth model

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We carry out qualitative analysis of a fourth-order tumor growth control model, using ordinary differential equations. We show that the system has one positive equilibrium point and its stability is independent of the feedback gain. Using a Lyapunov method we prove that there exist realistic parameter values for which the systems admits limit cycle oscillations due to a supercritical Hopf bifurcation. The time evolution of the state variables is also represented.

This is a joint study with Daniel Drexler and Ilona Nagy.

References

[1] D. A. Drexler, I. Nagy and V. Romanovski, Bifurcations in a closed-loop model of tumor growth control. In: 21th IEEE International Symposium on Computational Intelligence and Informatics, November 18-20 2021, Budapest, Hungary. PP. 37-42. DOI: 10.1109/CINTI53070.2021.9668407.

[2] Y. N. Bibikov, Local Theory of Nonlinear Analytic Ordinary Differential Equations. Berlin, Heidelberg, New York: Springer-Verlag, 1979

Ultralong-Range Molecules

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Ultralong-Range Molecules provide a new type of highly excited Rydberg molecules with a novel binding mechanisms different from the 'traditional' covalent or ionic binding. They combine Rydberg atoms with ground state atoms in a single molecule thereby leading to molecular properties inherited from the Rydberg component. Huge bond lengths and corresponding dipole moments belong to the peculiar features of this species. They have been observed spectroscopically approximately a decade ago and are now under intense investigation in several ultracold atom groups worldwide. Due to their small binding energies they are extremely sensitive even to weak external electric and magnetic fields, as we shall demonstrate in this presentation [1,2,3]. Bond lengths, local equilibria, orientation and aligment can be controlled using fields and vary largely with the degree of excitation of the Rydberg atom(s). We compare experimental results with theory [2] and demonstrate isotropic as well as anisotropic interaction effects with a rich structure of the resulting vibrational dynamics and states. More recently high resolution spectroscopy has even seen the spin structure of those states - and we demonstrate what is necessary in order to describe the latter and combine it with the external field effects [4]. Moving from diatomic to triatomic systems [5,6] the first evidence for three-body interactions has been demonstrated in theory and experiment opening-up the possibility of a full control of chemical reaction dynamics in these highly excited Rydberg molecules.

References

[1] M. Kurz and P. Schmelcher, *Physical Review A* **88**, 022501 (2013).

[2] A.T. Krupp, A. Gaj, J.B. Balewski, S. Hofferberth, R. Löw, T. Pfau, M. Kurz and P. Schmelcher, *Physical Review Letters* **112**, 143008 (2014).

[3] M. Kurz and P. Schmelcher, *Journal of Physics B* **47**, 165101 (2014).

[4] F. Hummel, C. Fey and P. Schmelcher, *Physical Review A* **97**, 043422 (2018).

[5] C. Fey, M. Kurz and P. Schmelcher, *Physical Review A* **94**, 012516 (2016).

[6] C. Fey, J. Yang, S.T. Rittenhouse, F. Munkes, M. Baluktsian, P. Schmelcher, H.R. Sadeghpour, J.P. Shaffer, arXiv:1803:09781.

A spectral duality in graphs and microwave networks

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Quantum graphs and their experimental counterparts, microwave networks, are ideally suited to study the spectral statistics of chaotic systems. The graph spectrum is obtained from the zeros of a secular determinant derived from energy and charge conservation [1]. Depending on the boundary conditions at the vertices there are Neumann and Dirichlet graphs [2]. The first ones are realized in experiments, since the standard junctions connecting the bonds obey Neumann boundary conditions due to current conservation. On average the corresponding Neumann and Dirichlet eigenvalues alternate as a function of the wave number, with the consequence that the Neumann spectrum is described by random matrix theory only locally, but adopts features of the interlacing Dirichlet spectrum for long-range correlations. Another spectral interlacing is found for the Green function which in contrast to the secular determinant is experimentally accessible. This is illustrated by microwave studies and numerics.

This is a joint work together with Tobias Hofmann, Philipps University of Marburg, and Junjie Lu, Ulrich Kuhl, Université Côte d'Azur of Nice [3].

References

[1] T. Kottos and U. Smilansky, Ann. Phys. (NY) 274, 76 (1999).

[2] G. Berkolaiko and P. Kuchment, Introduction to Quantum Graphs, Mathematical Surveys and Monographs, Vol. 186, American Mathematical Society (2013).

[3] T. Hofmann, J. Lu, U. Kuhl , and H.-J. Stöckmann, Phys. Rev. E 104, 045211 (2021).

Vzorci kalcijeve aktivnosti, medceličnih valov in funkcionalne povezanosti v normalnih in diabetičnih človeških Langerhansovih otočkih

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Langerhansovi otočki so sestavljeni iz velikega funkcionalnega sincicija celic beta, ki proizvajajo pulze inzulina, pri čemer naraščajoča raven tega hormona nadzoruje postprandialno skladiščenje in zmanjšana raven inzulina spodbuja interprandialno sproščanje energijsko bogatih hranil. Kalcijevi ioni so osrednji sekundarni sporočevalec v znotrajcelični sklopitvi stimulacije in izločanja ter pri usklajenem medceličnem delovanju. Pri sladkorni bolezni tipa 2 (T2D) sta tako znotrajcelična kot medcelična signalizacija moteni, vendar pa ni povsem jasno, ali in kako glukoza nadzira kalcijeve oscilacije v normalnih človeških otočkih, ali in v kolikšni meri so oscilacije sinhronizirane v različnih celicah beta in ali otočki kažejo funkcionalne lastnosti majhnega sveta ali kakšno drugo vrsto funkcionalne mrežne povezanosti. Najpomembneje je, da ni povsem jasno, kateri od teh parametrov se spremenijo pri sladkorni bolezni in kako. Da bi odpravili zgornje vrzeli v našem znanju o normalni in patološki biologiji otočkov, smo združili snemanje kalcijevih oscilacij v izoliranih človeških otočkih s pomočjo CCD kamere s klasičnimi fiziološkimi in naprednimi mrežnimi analizami. Človeški otočki so se odzvali na stimulacijo z glukozo, ki je najpomembnejši sekretagog, z regularnimi kalcijevimi oscilacijami, ki so bile sinhronizirane v različnih regijah preko kalcijevih valov, ki so bili večinoma lokalni in so le redko vključevali večino celic beta znotraj otočka. Zviševanje koncentracije glukoze je povečalo tako število aktivnih celic beta kot stopnjo njihove aktivnosti, izzvalo večji delež večjih medceličnih kalcijevih valov, območja, ki so sprožila te valove, pa so postala časovno stabilnejša. Funkcionalne mreže, izgrajene na podlagi kalcijevih oscilacij, so pri višji koncentraciji glukoze postale gostejše in manj razdrobljene. Prav tako smo opazili vozliščna območja z veliko povezavami, ki so se ujemala z območji ki so imela najdaljše aktivne čase. Diabetični otočki so bili manj aktivni v smislu aktivnega časa, izkazovali so večji delež bolj lokalnih valov, manj stabilna iniciatorska območja in bolj razdrobljene funkcionalne mreže. Pomemben rezultat je, da so vozliščne regije med razvojem sladkorne bolezni bile najbolj prizadete, saj so izgubile nesorazmerno veliko povezav. Nazadnje je treba izpostaviti, da so imeli nekateri diabetični otočki precej normalne aktivne čase, medcelične valove in funkcionalne mreže, kar kaže na to, da so različni otočki različno dovzetni za diabetogene poškodbe. Naša študija, ki združuje klasične in mrežne analize v človeških otočkih, pojasnjuje in usklajuje praktično vse značilnosti otočkov, ki so jih opisovali v prejšnjih študijah, ki so obravnavale različne vidike kalcijeve signalizacije s pogosto navidezno nasprotujočimi

si rezultati. V prihodnosti želimo nadgraditi naš pristop z boljšo časovno in prostorsko ločljivostjo, z uporabo dodatnih fizioloških in farmakoloških dražljajev ter se osredotočiti na otočke bolnikov, ki so dosegli remisijo sladkorne bolezni, da bi pomembno poglobili naše patofiziološko razumevanje sladkorne bolezni tipa 2.

Reference

[1] V. Tokarz, P.E. MacDonald, A. Klip, *The Journal of Cell Biology* **217** (2018) 2273-2289.

[2] M. Skelin Klemen et al., *Islets* **9** (2017) 109-139.

[3] M. Gosak, R. Yan-Do, H. Lin, P.E. MacDonald, in A. Stožer, *Diabetes* (2022) accepted.

Patterns of Calcium Activity, Intercellular Wave Propagation, and Functional Connectivity in Normal and Diabetic Human Islets of Langerhans

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Islets of Langerhans consist of a large functional syncytium of beta cells that produce pulses of insulin, with increasing levels of this hormone controlling postprandial storage and decreased levels of insulin stimulating interprandial release of energy-rich nutrients. Calcium ions are the central secondary messenger in intracellular stimulus-secretion coupling and coordinated intercellular activity. Importantly, both intra- and intercellular coupling are deranged in type 2 diabetes mellitus (T2D), but it is not entirely clear whether and how glucose controls calcium oscillations in normal human islets, if and to what extent they are synchronized in different beta cells, and whether the islets display small-world or some other type of functional network features. Most importantly, it is not entirely clear which of these parameters change in diabetes and how. To address the above gaps in our knowledge of normal and pathological islet biology, we combined CCD camera-based calcium imaging of isolated human islets with classical physiological and advanced network analyses. Human islets responded to stimulation with glucose, the most important secretagogue, with regular calcium oscillations that were synchronized in different regions through calcium waves, that were mostly local and only rarely invoked most of the beta cells within an islet. Increasing glucose increased both the number of active beta cells and the frequency of their oscillations, elicited a greater proportion of larger intercellular calcium waves, and the initiator regions of these waves became more stable in time. The functional networks constructed on the basis of calcium oscillation became denser and less fragmented in higher glucose. We also observed hub regions with many connections, and they corresponded with regions that had the longest active times. Diabetic islets were less active in terms of active time, displayed a greater proportion of more local waves, less stable initiator regions, and more segregated functional networks. Strikingly, hub regions seemed to suffered the most during diabetes development by losing a disproportionately large fraction of connections. Finally, some diabetic islets had rather normal active times, intercellular waves, and functional networks, which suggests that different islets are not equally susceptible to diabetogenic insults. Our study combining classical and network measures in human islets accounts for and reconciles practically all of the features observed in previous studies addressing different aspects of calcium signaling with seemingly contradictory results. In the future, we wish to upgrade our approach by a better temporal and spatial resolution, using additional physiological and pharmacological stimuli, and

focusing on islets from patients achieving remission of diabetes, to importantly deepen our pathophysiological understanding of type 2 diabetes.

References

[1] V. Tokarz, P.E. MacDonald, A. Klip, *The Journal of Cell Biology* **217** (2018) 2273-2289.

[2] M. Skelin Klemen et al., *Islets* **9** (2017) 109-139.

[3] M. Gosak, R. Yan-Do, H. Lin, P.E. MacDonald, and A. Stožer, *Diabetes* (2022) accepted.

Anomalije v fiziki mezonov B

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Ena izmed osnovnih predpostavk Standardnega modela je enaka sklopitev elektro-šibkih bozonov z vsemi leptoni (e, μ, τ), t.i. leptonska univerzalnost. Eksperimentalno je leptonska univerzalnost zelo dobro potrjena v meritvah razpadov leptonov τ, bozonov Z, in razpadov lahkih mezonov. V zadnjih nekaj letih so z velikim številom zbranih razpadov mezonov B postali možni tudi testi leptonske univerzalnosti v sistemu teh težkih mezonov. Čeprav rezultati teh meritev še niso statistično dovolj signifikantni, jih kar nekaj kaže na to, da je leptonska univerzalnost v teh razpadih kršena. Če bi se v naslednjih letih potrdilo, da je temu res tako, bi to predstavljalo prvi nedvoumen dokaz o obstoju nove fizike. V predavanju bom povzel zadnje rezultate na področju teh meritev, predvsem pri eksperimentih Belle in Belle II, opisal nekaj možnih teoretičnih razlag opaženih pojavov, ter zaključil s pogledom v prihodnost.

Reference

[1] G. Caria et al. (Belle Collaboration) *Phys. Rev. Lett.* **124**, 161803 (2020)

[2] S. Wehle et al. (Belle Collaboration) *Phys. Rev. Lett.* **126**, *161801 (2021)*

[3] F. Abudinén et al. (Belle II Collaboration) *Phys. Rev. Lett.* **127**, 181802 (2021)

[4] Buttazzo, D., Greljo, A., Isidori, G. et al. *Journal of High Energy Physics* **2017**, 44 (2017)

Anomalies in physics of B mesons

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One of the cornerstones of the Standard model is the equal coupling of electroweak gauge bosons to all leptons (e, μ, τ), the so-called lepton flavor universality. Experimentally this is very well confirmed for example in τ decays, Z boson decay widths, and decays of light mesons. In the last few years, however, several studies of B meson decays seem to indicate that the lepton flavor universality is violated. While these measurements are so far inconclusive, if confirmed when larger data samples become available, they would represent unambiguous evidence of new physics. In the lecture I will summarize recent measurements in this field, with the focus on results from Belle and Belle II experiments. I will describe some of the possible theoretical explanations of observed phenomena, and conclude with look into the future.

References

[1] G. Caria et al. (Belle Collaboration) *Phys. Rev. Lett.* **124**, 161803 (2020)

[2] S. Wehle et al. (Belle Collaboration) *Phys. Rev. Lett.* **126**, *161801 (2021)*

[3] F. Abudinén et al. (Belle II Collaboration) *Phys. Rev. Lett.* **127**, 181802 (2021)

[4] Buttazzo, D., Greljo, A., Isidori, G. et al. *Journal of High Energy Physics* **2017**, 44 (2017)

Brezmrežne simulacije večfizikalnih in večnivojskih problemov s strjevanjem

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V prispevku najprej predstavimo koncept povezanih simulacij strjevanja večsestavinskih sistemov na več merilih ob prisotnosti zunanjih polj. Pri tem so makroskopski modeli formulirani na podlagi teorije idealne mešanice, mezoskopski na podlagi celičnih avtomatov in mikroskopski na podlagi faznega polja. V modelih upoštevamo prenos mase, energije, gibalne količine in sestavin. Fazni diagram je vključen na podlagi vzvodnega pravila, kašasto področje pa s porozno plastjo. Predstavimo inovativne brezmrežne rešitve na vseh treh nivojih, ki temeljijo na konceptu močne formulacije, razdelitve področja na poddomene in uporabo različnih avtomatskih prilagoditvenih strategij. Na koncu predstavimo uporabo nekaterih razvitih modelov pri snovanju vodilnih tehnologij.

Reference

[1] T. Dobravec, B. Mavrič and B. Šarler, *Computers & Mathematics with Applications* **126** (2022) L77-L99.

[2] K. Mramor, R. Vertnik and B. Šarler, *Engineering Analysis with Boundary Elements* **138** (2022) L319-L338.

[3] V. Hatič, B. Mavrič, N. Košnik and B. Šarler, *Applied Mathematical Modelling* **54** (2018) L170-L188.

Meshless simulation of multiphysics and multiscale solidification problems

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In this paper, we first present the concept of coupled simulations of solidification of multi-component systems at multiple scales in the presence of external fields. The macroscopic models are formulated on the basis of the ideal mixture theory, mesoscopic models on the basis of cellular automata and microscopic models on the basis of the phase field. The models take into account the transfer of mass, energy, momentum and species. The phase diagram is included based on the lever rule, and the mushy zone with the porous layer. We present innovative meshless solutions at all three levels based on the concept of strong formulation, partitioning the domain into subdomains, and use of different automatic adaptation strategies. Finally, we present the use of some developed models in the creation of leading technologies.

References

[1] T. Dobravec, B. Mavrič and B. Šarler, *Computers & Mathematics with Applications* **126** (2022) L77-L99.

[2] K. Mramor, R. Vertnik and B. Šarler, *Engineering Analysis with Boundary Elements* **138** (2022) L319-L338.

[3] V. Hatič, B. Mavrič, N. Košnik and B. Šarler, *Applied Mathematical Modelling* **54** (2018) L170-L188.

Razkrivanje struktur kompleksnih tekočekristalnih faz

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Kombinacija eksperimenta in teoretičnega modeliranja je ključna pri določevanju ureditve molekul v tekočekristalnih fazah. Simetrijo tekočekristalnih faz razberemo iz rentgenskih spektrov, kjer je lega interferenčnih vrhov odvisna od tega, kako se v preiskovani snovi s krajem spreminja elektronska gostota. Vendar se v številnih fazah elektronska gostota s krajem ne spreminja, čeprav so v njih molekule urejene. Možne pa so tudi različne ureditve molekul, za katere je krajevno spreminjanje elektronske gostote enako. Simetrijo tekočekristalnih faz in hkrati prostorsko ureditev molekul lahko ugotovimo z resonančno rentgensko spektroskopijo [1], ki je občutljiva tudi na smeri kemijskih vezi. Na predavanju bom predstavila raziskovalno delo, ki je bilo izvedeno v sodelovanju z raziskovalci iz Univerze v Varšavi, Univerze v Aberdeenu in nacionalnega laboratorija Lawrence Berkeley. Odkrili in opisali smo večnivojske vijačne strukture v smektičnih fazah iz ukrivljenih molekul [2] in na tej osnovi nekiralne faze s fotonsko režo [3]. Pojasnili smo ureditev molekul v kubičnih fazah, kjer so nekiralne molekule urejene v povezane kanalčke, ki tvorijo zvezne in med seboj prepletene mreže, osnovne kristalografske celice pa so nekiralne [4] ali kiralne [5] in vsebujejo več tisoč molekul.

Reference

[1] W. Lewandowski et al, *Adv. Mater.* **32** (2020) 1905591.
[2] M. Salamonczyk et al, *Nat. Commun.* **10** (2019) 1922.
[3] D. Pociecha et al, *Adv. Mater.* **33** (2021) 2103288.
[4] Y. Cao et al, *Phys. Rev. Lett.* **125** (2020) 027801.
[5] T. Grabovac et al, *Soft Matter* **35** (2022) 8194.

Unmasking structures of complex liquid crystalline phases

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Combination of experiment and modelling is essential to determine molecular packing in liquid crystalline phases. Symmetries of phases can be obtained from classical X-ray diffraction spectra because positions of diffraction peaks depend on the spatial variation of the electron density. However, in several phases, there is no measurable electron density variation even though they contain some (periodic) arrangement of molecules. On the other hand, several different packings of molecules can result in the same electron density modulation. Information on both the symmetry of the phase as well as packing of molecules can be obtained by the resonant X-ray diffraction [1], which is sensitive also to the orientation of chemical bonds. I will present the research that was performed in collaboration with researchers from University of Warsaw, University of Aberdeen, and Lawrence Berkeley National Laboratory. We discovered multilevel chirality in smectic phases formed from achiral bent-core molecules [2] and based on this achiral phases with a photonic bandgap [3]. We have also unmasked the molecular packing in cubic phases in which achiral molecules are packed in continuous grids of channels. The crystallographic unit cells, which contain several thousand molecules, can be either achiral [4] or chiral [5].

References

[1] W. Lewandowski et al, *Adv. Mater.***32** (2020) 1905591.
[2] M. Salamonczyk et al, *Nat. Commun.* **10** (2019) 1922.
[3] D. Pociecha et al, *Adv. Mater.* **33** (2021) 2103288.
[4] Y. Cao et al, *Phys. Rev. Lett.* **125** (2020) 027801.
[5] T. Grabovac et al, *Soft Matter* **35** (2022) 8194.

Medzvezdni absorpcijski pasovi v velikih spektroskopskih pregledih neba

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Medzvezdni absorpcijski pasovi (MAP) so pogoste absorpcije v spektrih zvezd, katerih izvor pa ostaja nejasen. Igrajo pomembno vlogo v življenjskem ciklu medzvezdnega prostora in nam tudi pomagajo slediti strukturi Galaksije. Predstavil bom rezultate, ki temeljijo na več kot milijonu spektrov zvezd razporejenih po vsem nebu, ki sta jih zbrala satelit Gaia Evropske vesoljske agencije in zemeljski spektroskopski pregled neba Galah. Primerjal bom tudi prostorsko porazdelitev MAP absorpcij s porazdelitvami medzvezdnega atomarnega plina in medzvezdnega prahu.

Reference

[1] Gaia Collaboration, A. Vallenari, A.G.A. Brown, T. Prusti, et al., *Astronomy and Astrophysics*, accepted, (2022) arXiv:2208.00211.

[2] Gaia Collaboration, M. Schultheis, H. Zhao, T. Zwitter, et al., *Astronomy and Astrophysics*, accepted, (2022) arXiv:2206.05536.

[3] H. Zhao, M. Schultheis, T. Zwitter, et al., *Astronomy and Astrophysics*, **666**, (2022) L12.

Diffuse interstellar bands in large spectroscopic sky surveys

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Diffuse interstellar bands (DIBs) are common interstellar absorption features in spectroscopic observations of stars but their origins remain unclear. DIBs play an important role in the life cycle of the interstellar medium and can also be used to trace Galactic structure. I shall discuss results from over a million spectra of stars well distributed over the whole sky which were collected by the Gaia satellite of ESA and by the Galah ground-based spectroscopic survey. In particular, the spatial distribution of DIB absorptions can be compared to distributions of insterstellar atomic gas and dust.

References

[1] Gaia Collaboration, A. Vallenari, A.G.A. Brown, T. Prusti, et al., *Astronomy and Astrophysics*, accepted, (2022) arXiv:2208.00211.

[2] Gaia Collaboration, M. Schultheis, H. Zhao, T. Zwitter, et al., *Astronomy and Astrophysics*, accepted, (2022) arXiv:2206.05536.

[3] H. Zhao, M. Schultheis, T. Zwitter, et al., *Astronomy and Astrophysics*, **666**, (2022) L12.

Fermijeve tekočine, Luttingerjevi integrali, topološke invariante ... in magnetne molekule

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Osnovno stanje sistema interagirajočih fermionov je pogosto Fermijeva tekočina, katere osnovne vzbuditve enolično ustrezajo vzbuditvam neinteragirajočega Fermijevega plina. Bistvena ideja Landauove teorije je adiabatična povezava med interagirajočim in neinteragirajočim sistemom. Adiabatska povezava pa ne obstaja vedno. Poznamo nekaj problemov nečistoč z osnovnim stanjem, ki je Fermijeva tekočina, vendar ne Landauovega tipa. Predstavil bom primer dvokanalnega Kondovega modela s spinom 1 in z magnetno anizotropijo, v katerem topološki kvantni fazni prehod loči dve različni fazi, ki sta obe Fermijevi tekočini. Opisal bom, kako ohranitveni zakoni omejijo Luttingerjeve integrale, tako da njihove linearne kombinacije postanejo topološke invariante, in kako popravljena Friedelova vsotna pravila vodijo k neobičajnemu obnašanju spektralne funkcije nečistoče. Potem bom pokazal, da lahko tunelske spektre molekul železovega ftalocianina na površini Au(111) in molekul nikelocena na površini Cu(100) konsistentno pojasnimo v okviru teorije ne-Landauovih Fermijevih tekočin.

Reference

[1] R. Žitko, G. G. Blesio, L. O. Manuel, A. A. Aligia, *Nat. Commun.* **12** (2021) 6027.

[2] G. G. Blesio, R. Žitko, L. O. Manuel, A. A. Aligia, *arXiv:2205.10476* (2022).

Fermi liquids, Luttinger integrals, topological invariants ... and magnetic molecules

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The ground state of a system of interacting fermions is often a Fermi liquid with elementary excitations that are in a one-to-one correspondence with those of a non-interacting Fermi gas. A key idea in Landau's theory is the adiabatic connection between the interacting and the non-interacting system. The adiabatic connection does not, however, always exist and there are several impurity problems where the ground state is known to be a Fermi liquid that is not of the Landau type. I will present the case of the two-channel S=1 Kondo model with single-ion magnetic anisotropy which has a topological quantum phase transition separating two different Fermi-liquid phases. I will discuss how the conservation laws constrain the Luttinger integrals so that their linear combinations become topological invariants, and how the modified Friedel sum rules lead to a peculiar variation of the impurity spectral function. I will then show that the tunneling spectra of iron phthalocyanine molecules on Au(111) surface and of nickelocene molecules on Cu(100) surface can be consistently interpreted in the framework of non-Landau Fermi liquid theory.

References

[1] R. Žitko, G. G. Blesio, L. O. Manuel, A. A. Aligia, *Nat. Commun.* **12** (2021) 6027.

[2] G. G. Blesio, R. Žitko, L. O. Manuel, A. A. Aligia, *arXiv:2205.10476* (2022).

Interakcija optičnih in topoloških solitonov v frustriranih kiralnih nematikih

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Solitoni, pomembni na različnih področjih fizike, od osnovnih delcev do kondenzirane snovi in kozmologije, so fascinantne lokalizirane motnje relevantnih polj. Tukaj se osredotočamo na poravnane kiralne nematike. To so frustrirani sistemi, kjer omejitev na tanke plasti inducira odvijanje njihove intrinzične kiralne strukture in zagotavlja pogoje za nastanek topoloških solitonov toronov. Čeprav so ti topološko zaščiteni defekti že dalj časa podrobno poznani [1], smo šele pred kratkim pokazali, da ti frustrirani sistemi, zaradi s kiralnostjo ojačenega samo-fokusiranja, omogočajo nastanek in širjenje periodično odbijajočih se optičnih solitonov [2]. Naši teoretični in simulacijski pristopi so napovedali obstoj takih solitonov in omogočili podrobno razlago njihove realizacije, ki jo je izvedla sodelujoča eksperimentalna skupina v Boulderju. Uporaba frustriranih kiralnih nematikov nam je omogočila izvedbo prve študije opto-mehanske interakcije topoloških in optičnih solitonov [3]. Ta interakcija temelji na prenosu gibalne količine s svetlobe na snov in sile zaradi nelokalne orientacijske elastičnosti kiralnih tekočih kristalov. Občutljivo ravnovesje obeh sil omogoča dinamično kontrolo in prostorsko lokalizacijo topoloških solitonov. Identificiran je bil nenavaden vlečni učinek periodično odbijajočih se optičnih solitonov, ki vodi v nastanek svetlobno inducirane periodične razporeditve topoloških solitonov. Predstavljeni pojavi odpirajo nove možnosti za opto-mehanske in fotonske aplikacije, ki temeljijo na topološki mehki snovi.

Reference

[1] I. I. Smalyukh, Y. Lansac, N. A. Clark, R. P. Trivedi, *Nature Materials* **9** (2010) 139-145.

[2] G. Poy, A. J. Hess, I. I. Smalyukh, and S. Žumer, *Physical Review Letters* **125** (2020) 077801-1-6.

[3] G. Poy, A. J. Hess, A. J. Seracuse, M. Paul, S. Žumer, and I. I. Smalyukh, *Nature Photonics* **16** (2022) 454-461.

Interaction of optical and topological solitons in frustrated chiral nematics

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S olitons relevant in different areas of physics ranging from elementary particles to condensed matter and cosmology are fascinating localized perturbations of relevant fields. Here we focus our attention on unwinded chiral nematics that are frustrated systems where confinement to thin layers induces the unwinding of their intrinsic chiral structure and provides conditions for the formation of topological solitons torons. These are well-known [1] topologically protected defect structures. We show that these frustrated systems due to their chirality-enhanced self-focusing properties allow the formation and propagation of bouncing optical solitons [2]. Our theoretical and simulation approaches allow explaining the realization of these optically induced solitons by collaborating experimental group in Boulder. The use of frustrated chiral nematics enables us to realize the first study of the optomechanical interaction of topological and optical solitons [3]. This interaction is based on the light-to-matter transfer of momentum and the force due to the nonlocal orientation elasticity of chiral liquid crystals. The delicate balance of both forces enables dynamic control and spatial localization of topological solitons. An unusual traction effect of bouncing optical solitons that leads to the formation of a light-induced periodic arrangement of topological solitons was identified. The presented phenomena open up new possibilities for optomechanical and photonic applications based on topological soft matter.

References

[1] I. I. Smalyukh, Y. Lansac, N. A. Clark, R. P. Trivedi, *Nature Materials* **9** (2010) 139-145.

[2] G. Poy, A. J. Hess, I. I. Smalyukh, and S. Žumer, *Physical Review Letters* **125** (2020) 077801-1-6.

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Tenzorske mreže v strojnem učenju

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Predstavil bom tenzorske mreže in njihove nedavne aplikacije v strojnem učenju. Po splošnem uvodu se bom osredotočil na klasifikacijske probleme. Predstavil bom globoke tenzorske mreže [1] in pokazal, da predstavljajo posplošen mehanizem pozornosti. Potem bom tenzorske mreže uporabil za preučevanje faznih prehodov pri učenju pravil. Povezal bom standardno teorijo statističnega učenja z nedavnimi opažanji pri učenju globokih nevronskih mrež [2]. Na koncu bom predstavil še uporabo tenzorskih mrež pri pozitivnem neoznačenem učnenju [3].

Reference

[1] B. Žunkovič, *Quantum Machine Intelligence* **4** (2022) 1-12.

[2] B. Žunkovič, E. Ilievski *arXiv:2210.15435*

[3] B. Žunkovič *unpublished*

Tensor networks in machine learning

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I will review tensor network methods and discuss three recent applications in machine learning. After a general introduction to tensor network methods, I will focus on classification problems. First, I will discuss deep tensor networks introduced in [1] and show that a single tensor network layer implements a generalised attention layer. Second, I will use the tensor-network attention mechanism to study phase transitions in the rule-learning scenario and connect the standard statistical learning theory with recent observations in deep-neural-network training [2]. Finally, I will discuss the application of tensor networks to the positive unlabeled learning problem [3].

References

[1] B. Žunkovič, *Quantum Machine Intelligence* **4** (2022) 1-12.

[2] B. Žunkovič, E. Ilievski *arXiv:2210.15435*

[3] B. Žunkovič *unpublished*