International Workshop in memory of

Prof. Dr. Konstantin B. Efetov (1950-2021)

„Universalities, symmetries and correlations in low-dimensional electronic systems“

Bochum, Germany, September 23-27, 2024

PROGRAM AND ABSTRACTS

Organizing Committee

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Theoretische Physik III, Ruhr- Universität Bochum

LOCATION AND DATES

The workshop will be held from September 23 – 27, 2024 in the campus of Ruhr University Bochum, Germany.

REGISTRATION

The registration desk will be open on Monday, September 23rd, from 15:00 to 17:00. Tuesday-Friday, September 24th-September27, from 08:30 to 10:00.

TRAVEL INFORMATION

The workshop will take place at the International Convention Centre, Hall 3 of the Ruhr-Universität Bochum,

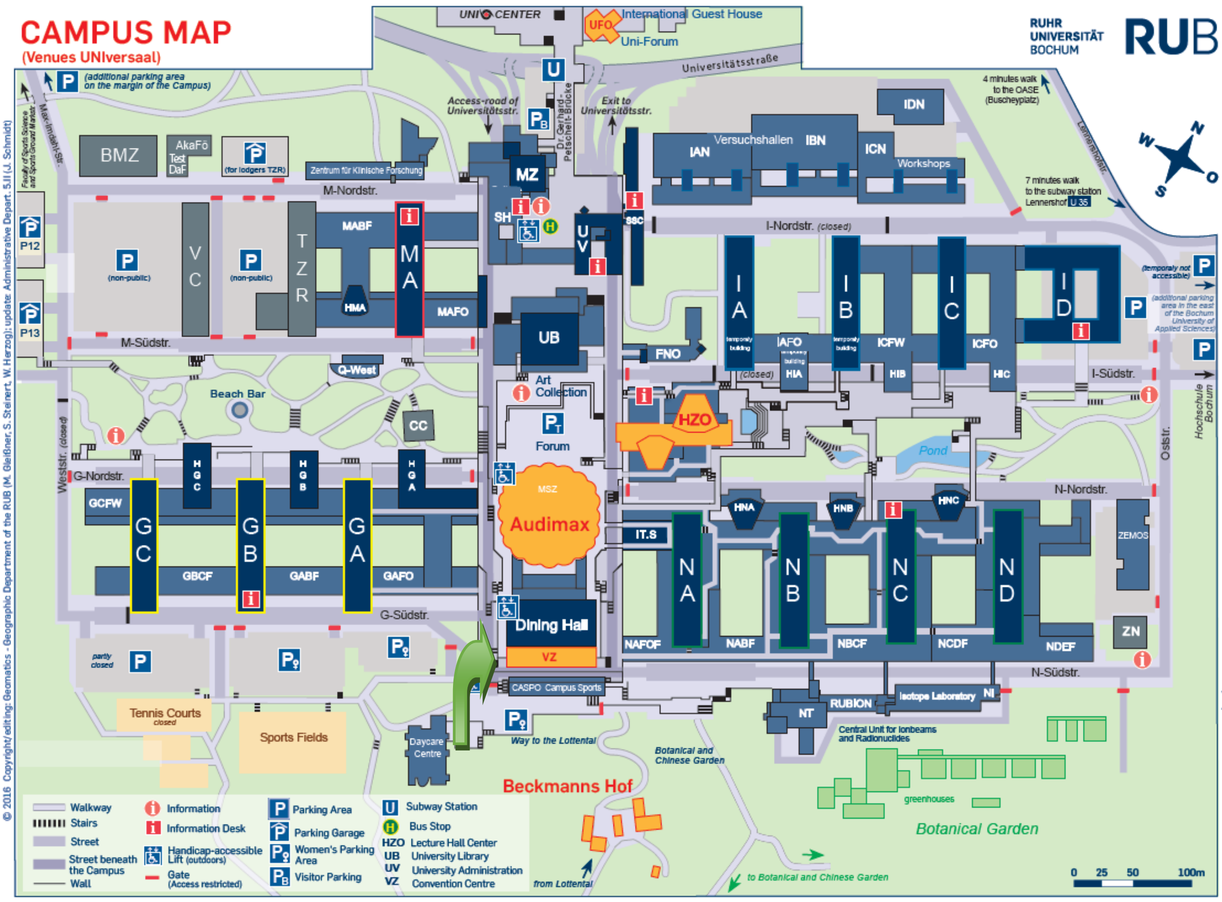
https://www.ruhr-uni-bochum.de/universaal/raumuebersicht/veranstaltungszentrum.html.en

The center is located on the southern edge of the campus. The conference halls are situated on the first floor.

The easiest way to reach Convention Center is to use line U35 from the Bochum Hbf (main station) (or from Rathaus Nord, depends which one is closer to your accommodation) in the direction of Hustadt till the station 'Ruhr-Universität'.

The campus will be located on your right (do not be confused with Uni Center, which is on the left). Once you reach the campus just continue straight through the campus (passing by the Audimax, you should also see the big construction hole on your left) and then enter the Dining Hall (**Mensa**), there take the elevator or stairs towards the **floor 04** (Veranstaltungzentrum). Once on the 04 floor just look for the **Hörsaal 3**.

Map of the Ruhr-Universität Campus



CONTACT INFORMATION

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For any questions please do not hesitate to contact us by email at:

office@tp3.rub.de

SCIENTIFIC PROGRAM

The speakers will be allotted 40 minutes including questions.

SOCIAL PROGRAM

Excursion

An excursion to the Deutsches Bergbau Museum will be arranged on Friday afternoon. The excursion will start at 15:00 and the participants are expected to meet at the entrance Hall of the Museum. The museum can be easily reached from the University Campus by U35 metro line (U-Bahn Station "Deutsche Bergbau Museum"), the trip takes approximately 20 mins. The link of the museum is given below

http://www.bergbaumuseum.de/index.php?page=1

Welcome Dinner and Social Dinner

The welcome dinner of the workshop will take place on Monday at 18:00 in the restaurant B-im-Beckmanshof, which is about 5 mins walk from the Convention Center

https://b-im-beckmannshof.de/

The social dinner of the workshop will take place on Thursday evening at 18:00 hours in the Restaurant Yamas. It is only 10 minutes' walk from the Bochum main station by foot.

https://yam.as/

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Program

Monday, September 23rd

13:00-15:00 Arrival, Registration, Lunch & Opening (Ilya Eremin, Igor Beloborodov and Sebastian Bergeret)

Session 1: Solid State Physics in Bochum from late 90ies till 2020
Chairperson: Ilya Eremin

15:00-15:20 **Hartmut Zabel (Experimentalphysik IV, Ruhr-University Bochum)** *"Memories of a Fruitful Collaboration"*

15:20-15:40 **Igor Beloborodov (California State University, Northridge)** *"My Teacher - Konstantin Efetov around 1997-99"*
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15:40-16:00 **Sebastian Bergeret (Centro de Fisica de Materiales, San-Sebastian),** *"Memories of a journey towards the prediction of odd-triplet superconductivity in proximitized ferromagnets. In memory of Konstantin Efetov"*

16:00-16:30 **Dmitri K. Efetov (Ludwig-Maximilians University, München),** *"A very personal perspective from the Efetov family"*

17:00 Welcome Dinner in Beckmanshof

Tuesday, September 24th of 2024

Session 2 Proximity Effects
Chairperson: Sebastian Bergeret

09:00-09:40 **Norman Birge (Michigan State University),** *"Spin-triplet supercurrent in ferromagnetic Josephson junctions"*

09:40-10:20 **Davide Massarotti (Università Federico II di Napoli),** *"Tunnel-ferromagnetic Josephson junctions for novel quantum hardware and detection schemes."*

10:20-11:00 Coffee break

Chairperson: Sebastian Bergeret

11:00-11:40 **Pauli Virtanen (University of Jyväskylä)** *"Magnetoelectric effects in diffusive superconductor transport theory"*

11:40-12:20 **Tomas Löfwander (Chalmers University of Technology),** *"Interplay of superconductivity and magnetism in unconventional superconductors and in superconductor-ferromagnet hybrids"*

12:20-14:00 Lunch

Session 3 Long-range interactions
Chairperson: Igor Beloborodov

14:00-14:40 **Mikhail Fistul (Ruhr-University Bochum),** *"Long-range interacting spins models emerging from qubits networks"*

14:40-15:20 **Stefan Kettemann (Constructor University Bremen)**, *"Quantum critical growth of entanglement entropy in disordered spin chains with long range interactions: Strong Disorder Renormalization Group and Quantum Simulations"*

15:20-15:50 Coffee break

Session 4 Spin chains
Chairperson: Stefan Kettemann

15:50-16:30 **Tigran Sedrakyan" (University of Massachusetts, Amherst),** *"Unveiling chiral states in the XXZ chain "*

16:30-17:10 **Grigory Starkov (Würzburg University),** *"Formation of Exceptional Points in Non-Hermitian systems with Pseudo-Hermitian symmetry "*

Wednesday, September 25th of 2024

Session 4 Quantum Magnetism
Chairperson: Flavio Nogueira

09:00-09:40 **Götz Uhrig (TU Dortmund),** *"Continuously and periodically driven quantum magnetic systems"*

09:40-10:20 **Benedikt Fauseweh (TU Dortmund)**, *" Three-body bound states in antiferromagnetic spin ladders "*

10:20-11:00 Coffee break

Session 5 Mesoscopic Systems II
Chairperson Mikhail Fistul

11:00-11:40 **Jürgen König (University of Duisburg Essen),** "Charge-Carrier Dynamics in Nanostructures: What can we learn from Real-Time Measurements of Electron Tunneling in Quantum Dots?*"*

11:40-12:20 **Daniel Hägele (Ruhr-University Bochum),** *"Higher order spectra of continuous quantum measurements - overcoming limitations of full counting statistics"*

12:20-14:00 Lunch

Session 6 Unconventional Superconductors I
Chairperson: Dmitrii Maslov

14:00-14:40 **Catherine Pepin (CEA, Paris),** *"Surface bands and the Order Parameter of* UTe_2*"*

14:40-15:20 **Pavel A. Volkov (ZOOM) (Connecticut University),** *"Topology and phase transitions in twisted nodal superconductors* "

15:20-15:50 Coffee break

Session 4 Unconventional Superconductors II
Chairperson: Catherine Pepin

15:50-16:30 **Sergey I. Mukhin(ZOOM) (National University of Science and Thechnology, MISiS),** *"Possible manifestations of Q-ball mechanism of high-Tc superconductivity in temperature dependences of pseudogap, diamagnetic response, X-ray diffraction"*

16:30-17:10 **Flavio S. Nogueira (IFW Dresden),** *"Anomalous Meissner state in Weyl superconductors*

Thursday, September 26th of 2024

Session 7 2D electron gas, Fermi-liquids, and disorder I
Chairperson: Flavio Nogueira

09:00-09:40 **Dmitrii Maslov (University of Florida in Gainesville),** *"Conductivity of a Fermi liquid near an Ising-nematic quantum critical point"*

09:40-10:20 **Andrey Chubukov (University of Minnesota)**, *"Unconventional discontinuous transitions in a 2D system with spin and valley degrees of freedom"*

10:20-11:00 **Coffee break**

Chairperson Mikhail Fistul
Session 8: 2D electron gas, Fermi-liquids, and disorder II

11:00-11:40 **George Schwiete (University of Alabama in Tuscaloosa),** "*Thermal and thermoelectric transport in the disordered 2d electron gas"*

11:40-12:20 **Keith Slevin (Osaka University),** *"Time evolution of coherent wave propagation and spin relaxation in spin-orbit-coupled systems"*

12:20-14:00 **Lunch**

Session 9 CDW/SDW
Chairperson: G. Schwiete

14:00-14:40 **N. Kirova (LPS, CNRS & Université Paris-Saclay),** *"Fractional charge-spin vortices in spin density waves"*

14:40-15:20 **Sergei Brazovskii (LPTMS, CNRS, Université Paris–Saclay),** *"From Chiral Anomaly to Two-fluid Hydrodynamics for Electronic Vortices in Charge Density Waves* "

15:20-15:50 **Coffee break and discussions**

Session 10 Quantum Magnetism
Chairperson: I. Eremin

15:50-16:30 **Sergey Syzranov (ZOOM) (University of California, Santa Cruz)**, *"Effect of Quenched Disorder on Quantum Spin Liquids and Geometrically Frustrated Magnets"*

18:00 **Dinner at Yamas (downtown Bochum)**

Friday, September 27th of 2024

Session 11
Chairperson: Andrey Chubukov

09:00-09:40 **Vladimir Kravtsov (ICTP, Trieste),** *"Numerical renormalization group in finite and infinite dimensions "*

09:40-10:20 **Alvaro Ferraz (International Institute of Physics, Natal),** "*Non-trivial topologies in strongly correlated electron systems"*

10:20-11:00 Coffee break

Chairperson: Ilya Eremin

11:00-11:40 **Andreas Wieck (Ruhr-University Bochum)**, *"Kostya and me: Filling the gap between tough theory and preparative, applied solid-state physics with russian-german friendship and respect"*

11:40-12:00 Closing remarks

12:00-14:00 Lunch

15:00 Guided excursion to Bergbaumuseum

Abstracts

Spin-triplet supercurrent in ferromagnetic Josephson junctions

Norman O. Birge

Michigan State University, East Lansing, MI, USA

The theoretical prediction by Bergeret, Volkov, and Efetov [1] of long-range spin-triplet pair correlations in hybrid superconducting/ferromagnetic (S/F) systems launched a new field of condensed matter physics called "superconducting spintronics." Our group was one of several that confirmed the predictions by demonstrating long-range supercurrents in Josephson junctions containing a trio of strong F materials [2,3]. One can turn the spin-triplet supercurrent on and off by rotating one of the F layers by 90° [4], or toggle the ground-state phase across the junction between 0 and π by rotating one of the F layers by 180° [5]. Other theoretical predictions have not yet been verified experimentally. If the magnetizations of the three F layers in the junction are non-coplanar, then one should be able to create a so-called "φ_0-junction" with an arbitrary ground-state phase difference [6]. Due to the coupling between the magnetizations and the supercurrent, it should be possible to induce magnetization switching by applying a supercurrent through the junction or by applying a static phase difference across the junction. I will discuss our progress toward making a φ_0-junction [7] and discuss some of the difficulties associated with induced magnetization switching. Finally, if there is time, I may mention our work on simpler junctions containing only two F layers, which also exhibit a controllable ground-state phase difference of 0 or π but cannot produce arbitrary phase states [8].

[1] F.S. Bergeret, A.F. Volkov, and K.B. Efetov, Phys. Rev. Lett., 86, 4096 (2001).

[2] T.S. Khaire, M.A. Khasawneh, W.P. Pratt, Jr., and N.O. Birge, Phys. Rev. Lett. 104, 137002 (2010); C. Klose et al, Phys. Rev. Lett. 108, 127002 (2012).

[3] M. Houzet and A.I. Buzdin, Phys. Rev. B 76, 060504(R) (2007).

[4] W. Martinez, W.P. Pratt, Jr., and N.O. Birge, Phys. Rev. Lett. 116, 077001 (2016).

[5] J.A. Glick, V. Aguilar, A. Gougam, B.M. Niedzielski, E.C. Gingrich, R. Loloee, W.P. Pratt, Jr. and N.O. Birge, Science Advances **4**, eaat9457 (2018).

[6] M.A. Silaev, I.V. Tokatly, and F.S. Bergeret, Phys. Rev. B 95, 184508 (2017).

[7] V. Aguilar, D. Korucu, J.A. Glick, R. Loloee, W. P. Pratt, Jr. , and N.O. Birge, Phys. Rev. B **102**, 024518 (2020).

[8] E.C. Gingrich, B.M. Niedzielski, J.A. Glick, Y. Wang, D.L. Miller, R. Loloee, W.P. Pratt, Jr., and N.O. Birge, Nature Phys. 12, 564 (2016).

Tunnel-ferromagnetic Josephson junctions for novel quantum hardware and detection schemes

D. Massarotti[1], H. G. Ahmad[2], R. Satariano[2], R. Ferraiuolo[2], G. Serpico[2], P. Mastrovito[2], L. Parlato[2], G. Ausanio[2], P. Lucignano[2], V. Brosco[3], D. Montemurro[2], A. Vettoliere[4], C. Granata[4], R. Fazio[5,1], G. P. Pepe[2], F. Tafuri[2]

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[2]*Università Federico II di Napoli, Dipartimento di Fisica "E. Pancini", Napoli, Italy*

[3]*Institute for Complex Systems, National Research Council and Dipartimento di Fisica, Università "La Sapienza", P.le A. Moro 2, Rome, Italy*

[4]*Consiglio Nazionale delle Ricerche, ISASI, Via Campi Flegrei 34, Pozzuoli, Italy*

[5]*Abdus Salam ICTP, Strada Costiera 11, Trieste, Italy*

Progress in material science and nanofabrication gives opportunities to create unique hybrid Josephson junctions (JJs), thus providing advanced functionalities in superconducting quantum technologies. Therefore, novel hybrid paradigms have been introduced demonstrating that devices integrating superconductors and exotic barriers can provide alternative architectures in quantum circuits.

We will report on special properties of hybrid tunnel-ferromagnetic JJs [1-3], which make possible alternative layouts for the superconducting modules inside a more general 3D-architecture for quantum hardware. The capability to have low dissipative and high-quality tunnel ferromagnetic JJs [1-2, 4-5], also employing Al-based technology [6], have promoted the notion of a novel type of superconducting qubit: the ferro-transmon [7]. This type of device allows for an innovative protocol for the tuning of the qubit frequency by means of magnetic field pulses, which is not susceptible to specific noise sources in a transmon configuration: the memory properties of tunnel ferromagnetic JJs enable them to retain their state at the end of the pulse, thus eliminating the need for a static field during the qubit operation that can be detrimental for coherence.

Moreover, we will classify some significant behaviors of tunnel-ferromagnetic JJs through a comparative study of fluctuations and of electro-dynamical properties [2,8] at the nanoscale. Finally, this kind of architecture offers novel experimental tools to probe the rich phenomenology of superconductor/ferromagnet interfaces [5].

[1] D. Massarotti et al. Nat. Commun. 6, 7376 (2015).

[2] H. G. Ahmad et al., Phys. Rev. Applied 13, 014017 (2020).

[3] H. G. Ahmad et al. Comms. Phys. 5, 2 (2022).

[4] R. Satariano et al. Phys. Rev. B 103 224521 (2021).

[5] R. Satariano et al. Communications Materials 5, 67 (2024).

[6] A. Vettoliere et al. Appl. Phys. Letter. 120, 262601 (2022).

[7] H. G. Ahmad et al., Phys. Rev. B 105, 214522 (2022).

[8] H. G. Ahmad et al., Appl. Phys. Letter. 124, 232601 (2024).

Magnetoelectric effects in diffusive superconductor transport theory

P. Virtanen[1]
1-University of Jyväskylä, Finland

Breaking the inversion and time-reversal symmetries in a superconductor allows for several magnetoelectric effects, such as the spin-galvanic and supercurrent diode effects. We have formulated one description of such effects generated from weak spin-orbit coupling (SOC) for dirty superconductors, [1] in the form of additional parts in the free energy/action of a σ-model. We considered the supercurrent diode [2] and other magnetoelectric effects [3,4] in superconductors and superconducting junctions within this model, and outlined a numerical method for models of this type at equilibrium [3]. In this talk, I will discuss these works and some similar models including gyrotropy in the opposite strong-SOC limit.

[1] P. Virtanen, F.S. Bergeret, I.V. Tokatly. Phys. Rev. B 105, 224517 (2022).
[2] S. Ilic, P. Virtanen, D. Crawford, T. T. Heikkilä, F. S. Bergeret, arXiv:2406.17046 (2024).
[3] P. Virtanen, arXiv:2406.19894 (2024).
[4] A. Hijano, S. Vosoughi-nia, F. S. Bergeret, P. Virtanen, T. T. Heikkilä, Phys. Rev. B 108, 104506 (2023).

Interplay of superconductivity and magnetism in unconventional superconductors and in superconductor-ferromagnet hybrids

T. Löfwander

Department of Microtechnology and Nanoscience – MC2,
Chalmers University of Technology, SE-41296 Göteborg, Sweden

During numerical simulations of *d*-wave superconducting grains [1], a phase transition into an unusual phase now called phase crystal was serendipitously discovered [1-4]. Below the transition temperature T*, roughly a fifth of the superconducting transition temperature T_c, time-reversal symmetry as well as translational invariance are broken along edges that are misaligned with respect to the main crystallographic *ab*-axes. The mechanism behind the phase transition is a lowering of the free energy through Doppler shifts of zero-energy Andreev surface states when a superflow pattern with alternating superflow on the scale of a few coherence lengths appears along the edge. However, taking into account electron interactions within Fermi liquid theory, a competing ferromagnetic phase may appear with spin-split Andreev states [5]. We will give an overview of this interesting example of competing order in unconventional superconductors and also briefly discuss the simulation tools developed the last few years to solve the Eilenberger equations, including a recently released open source GPU-code [6], as well as a new solution strategy based on finite element methods [7].

In the 2nd part of the presentation, we will go back to earlier work on superconductor-ferromagnetic hybrids and discuss the induction of triplet odd-frequency superconducting correlations that influence the physics of such devices. Going from the ballistic to the diffusive limit, these correlations may have different orbital symmetries [8]. In the diffusive limit, for FSFSF Josephson junctions, long-range triplet correlations may stabilize either a 0- or a pi-junction depending on device parameters [9]. Some of this theoretical work was used to fit experimental data for the transition temperature of such multilayer Josephson junctions and extract information about the exchange field in the ferromagnet Ni. The results correlated well with critical Josephson current experiments presented in the same paper [10].

[1] M. Håkansson, T. Löfwander, and M. Fogelström, Nature Physics **11**, 755 (2015).

[2] P. Holmvall, A.B. Vorontsov, M. Fogelström, and T. Löfwander, Nature Communications **9**, 2190 (2018).

[3] P. Holmvall, M. Fogelström, T. Löfwander, and A. B. Vorontsov, Phys. Rev. Research **2**, 013104 (2020).

[4] D. Chakraborty, T. Löfwander, M. Fogelström, and A. M. Black-Schaffer, npj Quantum Materials **7**, 44 (2022).

[5] K. M. Seja, N. Wall Wennerdal, T. Löfwander, and M. Fogelström, Phys. Rev. B **110**, 064502 (2024).

[6] P. Holmvall, N. Wall Wennerdal, M. Håkansson, P. Stadler, O. Shevtsov, T. Löfwander, and M Fogelström, Appl. Phys. Rev. **10**, 011317 (2023).

[7] K. M. Seja and T. Löfwander, Phys. Rev. B **106**, 144511 (2022).

[8] M. Eschrig and T. Löfwander, Nature Physics **4**, 138 (2008).

[9] T. Löfwander, T. Champel, and M. Eschrig, Phys. Rev. B **75**, 014512 (2007).

[10] V. Shelukhin, A. Tsukernik, M. Karpovski, Y. Blum, K. B. Efetov, A. F. Volkov, T. Champel, M. Eschrig,T. Löfwander, G. Schön, and A. Palevski, Phys. Rev. B **73**, 174506 (2006)

Long-range interacting spins models emerging from qubits networks

Mikhail V. Fistul

Theoretische Physik III, Ruhr-University Bochum, 44801 Bochum, Germany

Geometrical frustration in correlated systems can give rise to a plethora of ordered/disordered states and intriguing quantum phases. In this talk I will discuss a variety of collective phases identified in low-dimensional vertex-sharing frustrated networks of Josephson junctions. The frustration is provided by periodically arranged *0-* and p-Josephson junctions. The basic element of a system, i.e., the triangular superconducting cell, contains two *0-* and one p-Josephson junctions, and in the frustrated regime the low energy quantum dynamics of a single cell is determined by anticlockwise or clockwise flowing persistent currents (vortex/antivortex), i.e., a single flux qubit [1,2].

I will focus on two types of qubits networks: saw-tooth chains [1] and Kagome lattices [2]. In the first case the direct embedding of p-Josephson junctions in a low-dissipative transmission line allows to establish a short/long-range interaction between (anti)vortices of well separated cells. By making use of the variational approach, we map the superconducting circuit Hamiltonian to an *effective XX spin model* with an exchange spin-spin interaction decaying with the distance x as x^{-b} and the local transverse magnetic field corresponding to the coherent quantum beats between vortex and antivortex in a single cell. By means of exact numerical diagonalization, we study the interplay between the coherent quantum beats and the exchange spin-spin interaction leading to the appearance of various collective quantum phases such as the paramagnetic (*P*), compressible superfluid (*CS*) and weakly compressible superfluid (*w-CS*) states.

For qubits networks arranged in the Kagome lattice we obtain that numerous topological constraints, related to the flux quantization in any hexagon loop, lead to highly anisotropic and long-range interaction between well separated vortices/antivortices. Considering this interaction and a possibility of macroscopic tunneling between vortex and antivortex in single superconducting triangles, we derive *an effective Ising-type spin Hamiltonian* with strongly anisotropic long-range interaction. In the classically frustrated regime, we numerically calculate the temperature-dependent spatially averaged spin polarization characterizing the crossover between the ordered and disordered vortex/antivortex states. In the coherent quantum regime, we analyse the lifting of the degeneracy of the ground state and the appearance of the highly entangled states.

References.

[1] B. J.P. Pernack, M. V. Fistul, and I. M. Eremin, "*Quantum dynamics of frustrated Josephson junction arrays embedded in a transmission line: an effective XX spin chain with long-range interaction*", quant-phys: arXiv:2407.03928.

[2] O. Neyenhuys, M. V. Fistul, and I. M. Eremin, "*Long-range Ising spins models emerging from frustrated Josephson junctions arrays with topological constraints*", Phys. Rev. B 108, 165413 (2023).

Quantum critical growth of entanglement entropy in disordered spin chains with long range interactions: Strong Disorder Renormalization Group and Quantum Simulations

Stefan Kettemann

Constructor University Bremen gGmbH Germany

The nonequilibrium dynamics of disordered many-body quantum systems after a quantum quench unveils important insights about the competition between interactions and disorder. We examine the entanglement entropy growth after a global quench in a quantum spin chain with randomly placed spins and long-range tunable interactions decaying with distance with power α. Using a dynamical version of the strong disorder renormalization group we find for $\alpha > \alpha c$ that the entanglement entropy grows logarithmically with time as in a quantum critical glass. It is found to become smaller with larger α as $S(t) = Sp \ln(t)/(2\alpha)$. For $\alpha < \alpha c$, we find that the entanglement entropy grows as a power law with time, $S(t) \sim t\gamma(\alpha)$ with $0 < \gamma(\alpha) < 1$ a decaying function of the interaction exponent α [1].This work builds on previous work, which showed that the is a strong disorder fixed point for disordered spin chains with long range interactions both for the groound state[2] and excited states [3] for sufficiently large α, as confirmed with numerical exact diagonalization and a tensor network extension of DMRG[2].

[1] Y. Mohdeb, J. Vahedi, S. Haas, R. N. Bhatt, S. Kettemann, Global Quench Dynamics and the Growth of Entanglement Entropy in Disordered Spin Chains with Tunable Range Interactions, Phys. Rev. B 108 L140203 (2023).

[2] Y. Mohdeb, J. Vahedi, N. Moure, A. Roshani, H.Y. Lee, R. N. Bhatt, S. Haas, S. Kettemann, Entanglement Properties of Disordered Quantum Spin Chains with Long-Range Antiferromagnetic Interactions, Phys. Rev. B 102, 214201 (2020).

[3] Y. Mohdeb, J. Vahedi, S. Kettemann, Excited-Eigenstate Entanglement Pro- perties of XX Spin Chains with Random Long-Range Interactions, Phys. Rev. B 106, 104201 (2022).

Unveiling chiral states in the XXZ chain

Tigran Sedrakyan

University of Massachusetts, Amherst, USA

In this talk, I will present a detailed study of the low-energy properties of the one-dimensional spin-1/2 XXZ chain with time-reversal symmetry-breaking pseudo-scalar chiral interaction. I will propose a phase diagram for the model, focusing on the integrable case of the isotropic Heisenberg model with the chiral interaction. By employing the thermodynamic Bethe ansatz, I will discuss the concept of "chiralization"—the response of the ground state to the strength of the pseudo-scalar chiral interaction in a chiral Heisenberg chain. Notably, the chirality of the ground state remains zero until a critical coupling, $\alpha_c = (2/\pi)J$, is reached, where J denotes the antiferromagnetic spin-exchange interaction. The two distinct phases, characterized by zero and finite chirality, are described by central-charge c = 1 conformal field theories (CFTs). Despite having identical central charges, I will argue that the difference between these emergent CFTs lies in the symmetry of their ground-state primary fields, leading to symmetry-enriched CFTs. Furthermore, at finite but small temperatures, the non-chiral Heisenberg phase acquires a finite chirality that scales quadratically with temperature. Finally, I will discuss how finite-size effects near the transition point provide a sensitive probe of the phase transition, offering insights into the underlying physics.

[1] Chenan Wei, Vagharsh V. Mkhitaryan, and Tigran A. Sedrakyan, *Unveiling chiral states in the XXZ chain: finite-size scaling probing symmetry-enriched c = 1 conformal field theories,* J. High Energ. Phys.2024, 125 (2024). https://doi.org/10.1007/JHEP06(2024)125

Formation of Exceptional Points in Non-Hermitian systems with Pseudo-Hermitian symmetry

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Non-Hermitian Hamiltonians can be regarded as the natural approximation of open systems. Their ubiquitous feature is the presence of the so-called Exceptional Points (EPs): special degeneracies in the eigenspectrum, associated with the simultaneous overlapping of two or more eigenvalues and corresponding eigenvectors. These special degeneracies can be utilized, for example, to increase the sensitivity of quantum sensors and for adiabatic state conversion, which has drawn much attention to non-Hermitian systems in recent years. The experimental realization of devices based on EPs is complicated by the need to tune the system to the vicinity of an EP. At the same time, the number of independent parameters required for tuning is diminished in the presence of symmetries.

In my talk, I focus on systems with pseudo-Hermitian symmetry, which is naturally associated with the balancing of gains and losses in the systems. In this case, I show that all the levels can be characterized by a topological Z2 index, which governs the formation of EPs: they can only be formed by the levels with opposite signs of the topological index. Moreover, an interplay between several pseudo-Hermitian symmetries is possible and can lead to interesting features of the eigenspectrum.

To demonstrate the approach, I consider a transverse-field Ising chain with longitudinal staggered gain and loss, which is pseudo-Hermitian with respect to parity. Using the integrability of the model in the absence of Hermiticity-breaking terms, I compute all the topological indices analytically and then use them to analyze the formation of second- and third-order Exceptional points. As a side note, I also consider how the EPs can be directly studied with the help of the non-Hermitian Schrieffer-Wolff transformation.

[1] G. Starkov, M. Fistul, I. Eremin, PRA 108, 022206 (2023)

[2] G. Starkov, arXiv:240207690, (2024).

[3] G. Starkov, M. Fistul, I. Eremin, PRB 108, 235417 (2023)

[4] G. Starkov, M. Fistul, I. Eremin, Ann. Phys. (NY), 169268 (2023)

Continuously and periodically driven quantum magnetic systems

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Non-equilibrium physics is a particularly fascinating field of current research. Generically, driven systems are gradually heated up so that quantum effects die out. In contrast, we show that weak periodic pulsing can lead to peculiar non-equilibrium states with reduced entropy compared to the initial state. The key aspect is the commensurability of the external driving with internal frequencies in combination with a certain degree of dissipation to an external bath.

A first example is a central spin model driven by light pulses via the intermediate excitation of trion states. A controlled dissipation in a highly excited state is included which allows us to distill quantum coherent states. A second example is an extended spin system driven by light pulses in the THz regime mediated by an infrared active phonon. Conventional superconductors represent a third example in which trains of optical light pulses can induce uncommon distributions of Cooper pairs.

Three-body bound states in antiferromagnetic spin ladders

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Stable bound quantum states are ubiquitous in nature. Mostly, they result from the interaction of only pairs of particles, so called two-body interactions, even when large complex many-particle structures are formed. We show that three-particle bound states occur in a generic, experimentally accessible solid-state system: antiferromagnetic spin ladders, related to high-temperature superconductors. This binding is induced by genuine three-particle interactions; without them there is no bound state. We discuss how these three-body interactions arise using continuous unitary transformations and we compute the dynamic exchange structure factor required for the experimental detection of the predicted state by resonant inelastic X-ray scattering for realistic material parameters. Our work enables us to quantify these elusive interactions and unambiguously establishes their effect on the dynamics of the quantum many-particle state.

[1] G. Schmiedinghoff, et al., *Comm. Phys.* **5**, 218 (2022).

Charge-Carrier Dynamics in Nanostructures: What can we learn from Real-Time Measurements of Electron Tunneling in Quantum Dots?

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Time-resolved studies of quantum systems are the key to understanding quantum dynamics at its core. The real-time measurement of individual quantum numbers as they switch between certain discrete values, well known as a “random telegraph signal,” is expected to yield maximal physical insight. An example is electron tunneling in quantum dots, for which recent progress in nanotechnology has made it possible to monitor individual tunneling events in real time. This raises the question of how to extract from the measured time traces useful information about the underlying quantum dynamics. I will demonstrate the usefulness of so-called factorial cumulants as a tool to access in recently measured data phenomena such as spin relaxation [1], Auger and spin-flip Raman processes [2] as well as stochastic resonance in quantum dots or magnetic switching in spin-cross over complexes [3,4]. This includes a discussion of the error resilience of factorial cumulants [5], which makes them superior to ordinary ones usually employed in the literature.

[1] A. Kurzmann, P. Stegmann, et al., Phys. Rev. Lett. 122, 247403 (2019).

[2] E. Kleinherbers, H. Mannel, et al., Phys. Rev. Research 5, 043103 (2023).

[3] P. Stegmann, A. Gee, et al., Phys. Rev. B 104, 125431 (2021).

[4] C. Besson, P. Stegmann, et al., Phys. Rev. B 107, 245414 (2023).

[5] E. Kleinherbers, P. Stegmann, et al., Phys. Rev. Lett. 128, 087701 (2022).

A unifying framework for continuous quantum measurements

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We show that higher order spectra of continuous quantum measurements, so-called quantum polyspectra, provide a unifying framework for modeling and evaluating different classes of quantum measurements [1]. The framework covers, e.g., all measurements that were traditionally treated by the full counting statistics (FCS) or waiting-time distributions. Even in the case of background noise, the framework still yields sensible results, while the FCS can no longer be applied as quantum jumps may no longer be identified from the noise. We successfully apply quantum polyspectra also to the blinking statistics of quantum dots where we show that the blinking statistics can be recovered from single photon data without the need for photon-binning. Even in the case of extreme photon loss the blinking statistics can be recovered [2,3].

Experimental polyspectra up to fourth order are calculated from measurement traces $z(t)$ without preprocessing. Their model-counterparts follow from analytic expressions that we derived from the general stochastic master equation [1]. The model-spectra depend on the system Liouvillian, the measurement operator, and the measurement strength and regard measurement induced damping. Spectra can be calculated for all quantum systems that can be described by the very general Lindblad equation. Applications therefore include diverse experiments as transport experiments via quantum point contacts or laser probing of semiconductor spin systems at light levels that require single photon detection (spin noise spectroscopy) [2]. Prospects for treating simultaneous measurements of two, three, and more (non-commuting) observables will be given.

[1] D. Hägele and F. Schefczik, Phys. Rev. B 98, 205143 (2018).

[2] M. Sifft, D. Hägele, Phys. Rev. A 107, 052203 (2023).

[3] M. Sifft, A. Kurzmann, J. Kerski, R. Schott, A. Ludwig, A. D. Wieck, A. Lorke, M. Geller, D. Hägele, Phys. Rev. A 109, 062210 (2024).

Surface bands and the Order Parameter of UTe_2

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UTe_2 has been considered for many years as a leading candidate for topological superconductivity. A typical characteristic of such an intrinsic topological superconductor is a topological surface band of exotic fractionalized particles. Combining state of the art STM experiments with theoretical insight coming from impurity scattering simulations enabled us to visualize such exotic surface state and directly characterize the surface bands. Quantitative and highly consistent predictions are made possible if the bulk order parameter has a-axis nodal, time reversal conserving, odd-parity B3u symmetry. We believe this work sheds a very insightful light on the long-sought nature of the gap symmetry of this unconventional superconductor.

Topology and phase transitions in twisted nodal superconductors

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“Twistronics” paradigm has been tremendously successful in realizing strongly correlated and topological phases of electrons in two-dimensional semiconductors or semimetals. In my talk, I will show that twisted bilayers of nodal superconductors, such as cuprates, allow a similar degree of control over the neutral quasiparticles in superconductors.

I will demonstrate that the spectrum of the superconducting Dirac quasiparticles close to the gap nodes is strongly renormalized by twisting and can be further controlled externally [1]. In particular, the application of an interlayer current or magnetic field endows the system with topological properties at any nonzero twist angle [2]. Moreover, at large twist angles near 45° (for d-wave case), I will demonstrate that frustrated Josephson coupling can drive spontaneous time-reversal symmetry breaking. A promising platform to observe these effects is provided by the high-Tc cuprates, and I will discuss the theoretical description of the recent experimental results on twisted flakes of $Bi_2Sr_2CaCu_2O_{8+x}$ [3].

[1] P. A. Volkov, J. Wilson, K. Lucht & J. Pixley, Phys. Rev. B 107 , 174506 (2023).

[2] P. A. Volkov, J. Wilson, K. Lucht & J. Pixley, Phys. Rev. Lett. 130, 186001 (2023).

[3] SYF Zhao, X. Cui, P. A. Volkov et al., Science 382, 6677, 1422 (2023).

Possible manifestations of Q-ball mechanism of high-T_c superconductivity in temperature dependences of pseudogap, diamagnetic response, X-ray diffraction

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Recently proposed Q-ball mechanism of pseudogap state and high-Tc superconductivity in cuprates [1]-[3] has experimental manifestations [4]-[7], [9]. Conserved Q-ball charge Q gives the number of condensed elementary bosonic excitations [8] in a CDW/SDW fluctuation of finite amplitude and volume. It is found that attraction between elementary bosonic excitations inside the stable Euclidean Q-balls is triggered self-consistently by condensing Cooper/local pairs below pseudogap transition temperature T. Euclidean Q-balls charge Q is conserved in Matsubara time due to U(1) symmetry of the effective theory under global rotation of phases of the Fourier amplitudes of the CDW/SDW fluctuations. The Q scales as ~ TM^2V with temperature T, Q-ball's volume V and fluctuation amplitude M. Simultaneously, Q-ball energy E_Q scales as ~ QT. These leads to inverse proportionality between volume V and X-ray scattering intensity A ~ M^2 of the most probable Q-balls at a given temperature. Besides, the theory [1]-[3] predicts, that superconducting condensate forms at T* inside the Q-balls via second order phase transition starting from vanishingly small superconducting density, while amplitude M forms via first order phase transition. Hence, the most probable Q-ball volume should increase when temperature approaches T* from below, since according to Ginzburg-Landau theory the minimal radius of superconducting sphere increases in the vicinity of the transition temperature T_c, which for an individual Q-ball coincides with T*. These behaviors are found in micro X-ray scattering experiments [4]-[6]. Also, a diamagnetic moment of the Q-ball gas as function of magnetic field above T_c is calculated and favourably compares with experiment in cuprates [7]. The pseudogap temperature dependence below T* and starfish-shape of the Cooper-pairs also follow from the proposed theory [2] in qualitative correspondence with ARPES experiments [9].

[1] S.I. Mukhin, arXiv:2108.10372 (2021).

[2] S.I. Mukhin, Condens. Matter **7**, 31 (2022).

[3] S.I. Mukhin, Annals of Physics **447**, 169000 (2022).

[4] S. I. Mukhin, Condens. Matter **8**, 16 (2023).

[5] G. Campi, *et al*., Condens. Matter **8**, 15 (2023).

[6] G. Campi and A. Bianconi *et al*., Nature **525**, 359 (2015).

[7] L. Li *et al*., Phys. Rev. **B 81**, 054510 (2010).

[8] S.R. Coleman, Q-Balls. Nucl. Phys. B 1985, 262, 263–283.

[9] H. Li, X. Zhou *et al.* arxiv:1809.02194v2 (2019).

Anomalous Meissner state in Weyl superconductors

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Weyl semimetals have nodes in their electronic structure at which electrons attain a definite chirality.Due to the chiral anomaly, the non-conservation of charges with given chirality, the axion term appears in their effective electromagnetic action. We determine how this affects the properties of time-reversal invariant Weyl superconductors (SCs) in the London regime. For type II SCs the axion coupling generates magnetic B-fields transverse to vortices, which become unstable at a critical coupling so that a transition into type I SC ensues. In this regime an applied B-field not only decays inside the SC within the London penetration depth, but the axion coupling generates an additional perpendicular field. Consequently, when penetrating into the bulk the B-field starts to steadily rotate away from the applied field. At a critical coupling the screening of the magnetic field breaks down. The novel chiral superconducting state that emerges has a periodically divergent susceptibility that separates onsets of chiral Meissner regimes.The chiral anomaly thus leaves very crisp experimental signatures in structurally chiral Weyl SCs with an axion response [1].

[1] Vira Shyta, Jeroen van den Brink, and Flavio S. Nogueira, Phys. Rev. Research **6**, 013240 (2024).

Conductivity of a Fermi liquid near an Ising-nematic quantum critical point

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I will review both the optical and *dc* conductivities of a Fermi liquid (FL) near an Ising-nematic quantum critical point. It will be shown that the scaling forms of the conductivity is dramatically affected by the topology and geometry of the Fermi surface. The leading-order terms in the optical conductivity for both isotropic and convex Fermi surfaces in 2D vanish, while the remaining contribution scales as $\sigma(\omega) \sim \omega^2 \log|\omega|$ in the FL regime and as $\sigma(\omega) \sim |\omega|^{2/3}$ in the non-Fermi—liquid (NFL) one. Concomitantly, the correction to the residual *dc* resistivity scales as $T^4 \; logT$ (FL) and $T^{8/3}$ (NFL) at lower temperatures and saturates at higher temperatures. For convex and multi-valley Fermi surfaces, the conductivity recovers its expected scaling forms in the corresponding regimes.

[1] S. Li, P. Sharma, A. Levchenko, and D. L. Maslov, Phys. Rev. B **108**, 235125 (2023)

[2] Y. Gindikin, S.Li, A. Levchenko, A. Kamenev, A. V. Chubukov, and D. L. Maslov, Phys. Rev. B **110**, 085139

Unconventional discontinuous transitions in a 2D system with spin and valley degrees of freedom

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We analyze the transition into the most favorable ordered state for a system of 2D fermions with spin and valley degrees of freedom. We show that for short-ranged interactions and a range of rotationally invariant dispersions, the ordering transition is highly unconventional: the associated susceptibility diverges (or almost diverges) at the transition, yet immediately below it the system jumps discontinuously into a fully polarized state. We analyze the dispersion of longitudinal and transverse collective modes in different parameter regimes above and below the transition. Additionally, we consider ordering in a system with full SU(4) symmetry and show that there is a cascade of discontinuous transitions into a set of states, which includes a quarter-metal, a half-metal and a three-quarter metal. We compare our results with the data for biased bilayer graphene and AlAs.

* In collaboration with Z. Raines (UMN) and L.I. Glazman (Yale)

Thermal and thermoelectric transport in the disordered two-dimensional electron gas

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In this talk, I will discuss thermal and thermoelectric transport in the disordered electron gas. I will start out with the thermal conductivity and describe our analysis of the heat density-heat density correlation function, which follows a two-stage procedure: a renormalization group calculation based on the Keldysh nonlinear sigma model in the presence of Luttinger's gravitational potentials is supplemented with a perturbative study of scattering processes induced by the Coulomb interaction at low (sub-temperature) energies [1]. These scattering processes are at the origin of logarithmic corrections violating the Wiedemann-Franz law. In contrast to electric and thermal transport, thermoelectric transport is very sensitive to particle-hole asymmetry. Since this effect is not accounted for by the conventional sigma model approach, we derived a minimal extension of the Keldysh nonlinear sigma model tailored for two-dimensional interacting systems [2]. I will describe our perturbative analysis of the heat density-density correlation function based on this model, and the results for the thermoelectric transport coefficient that follow from it [3].

[1] G. Schwiete and A. M. Finkel'stein, *Theory of thermal conductivity in the disordered electron liquid*, JETP 122 (3), 567 (2016).

[2] G. Schwiete, *Non-linear sigma model with particle-hole asymmetry for the disordered two-dimensional electron gas*, Phys. Rev. B 103, 125422 (2021).

[3] Z. Jitu and G. Schwiete, *Interaction corrections to the thermopower of the disordered two-dimensional electron gas*, Phys. Rev. B 110, L041404 (2024).

Time evolution of coherent wave propagation and spin relaxation in spin-orbit-coupled systems

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We investigate, both numerically and analytically, the time evolution of a particle in an initial plane-wave state as it is subject to elastic scattering in a two-dimensional disordered system with Rashba spin-orbit coupling (SOC). In the analytic calculation, we treat the SOC nonperturbatively and the disorder perturbatively using the diffuson and the cooperon. We calculate the time dependence of coherent backscattering as a function of the strength of the SOC. We identify weak and strong SOC regimes and give the relevant time and energy scales in each case. By studying the time dependence of the anisotropy of the disorder-averaged momentum distribution, we identify the spin-relaxation time. We find a crossover from D'yakonov-Perel' spin relaxation for weak SOC to Elliot-Yafet-like behavior for strong SOC.

[1] Kakoi, M. and K. Slevin, Physical Review A 109(3): 033303 (2024).

Fractional charge-spin vortices in spin density waves

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As electronic crystals, the charge/spin density waves (CDW/SDW) possess such common topological defects as dislocations – the vortices of their displacements' phases which appear under the application of the electric field or other stresses. Less commonly, the density waves possess also the space-time vortices, the phase slip centers as a kind of instantons, which are necessary for the onset of the collective sliding and the conversion among the normal and condensed carriers. SDWs, as itinerate antiferromagnets, possess also the spin-rotation degree of freedom which can give rise to vorticity of their staggered magnetization. The rich multiplicative order parameter of SDWs allows for an unusual object of a complex nature: topologically bound half - integer dislocation combined with a semi - vortex of a staggered magnetization [1,2]. These objects become energetically favorable in comparison with conventional integer vortices due to the enhanced Coulomb interactions. Their generation affects the static vortex arrays and also the time-periodic phase slips responsible for the phenomenon of the so called narrow band noise.

[1] S. Brazovskii and N. Kirova, "Phase slips, dislocations, half-integer vortices, two-fluid hydrodynamics and the chiral anomaly in charge and spin density waves.", *I.E. Dzyaloshinskii 90 anniversary volume*, JETP, **159**, 806-814 (2021).

[2] S. Brazovskii and N. Kirova, "Simulations of dynamical electronic vortices in charge and spin density waves", *in* "Topological Objects in Correlated Electronic Systems", MDPI Symmetry, **15** (2023) 915.

From Chiral Anomaly to Two-fluid Hydrodynamics for Electronic Vortices in Charge Density Waves

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Many recent experiments addressed manifestations of electronic crystals, particularly the charge density waves, in nano-junctions, under electric field effect, at high magnetic fields, together with real space visualizations by STM and micro X-ray diffraction. This activity returns the interest to stationary or transient states with static and dynamic topologically nontrivial configurations: electronic vortices as dislocations, instantons as phase slip centers, and ensembles of microscopic solitons. Describing and modeling these states and processes calls for an efficient phenomenological theory which should take into account the degenerate order parameter, various kinds of normal carriers, and the electric field. Here we notice that the commonly employed time-depend Ginzburg-Landau approach suffers with violation of the charge conservation law resulting in unphysical generation of particles which is particularly strong for nucleating or moving electronic vortices. We present a consistent theory which exploits the chiral transformation taking into account the principle contribution of the fermionic chiral anomaly to the effective action. The resulting equations clarify partitions of charges, currents and rigidity among subsystems of the condensed and normal carriers. On this basis we perform the numerical modeling of a spontaneously generated coherent sequence of phase slips - the space-time vortices - serving for the conversion among the injected normal current and the collective one.

Effect of Quenched Disorder on Quantum Spin Liquids and Geometrically Frustrated Magnets

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Geometrically frustrated magnets (GFMs) are the largest class of materials in which quantum spin liquids are sought. Quenched disorder may lead to the formation of the spin-glass state, incompatible with a quantum spin liquid. By analysing the available experimental data on the spin-glass freezing transition in GFMs, we demonstrate that contrary to common intuition, decreasing impurity density in them increases the glass-transition temperature, i.e. makes random spin freezing more favourable! This behaviour challenges the existence of quantum spin liquids. It also implies the existence of a hidden energy scale that is independent of disorder and drives glass transitions in very clean GF materials.

We develop a microscopic theory of the hidden energy scale. We show that the lowest-energy excitations in GFMs are continuously connected to spin-exchange processes in Ising ground states on the same GF lattice. The characteristic energy of such excitations is significantly smaller than the characteristic spin-spin interaction strength and manifests itself in spin-glass freezing, specific heat and neutron scattering.

We also demonstrate that the presence of vacancy defects results in the creation of quasispins, effective magnetic moments localised near the vacancies, which contribute to the magnetic susceptibility of the system together with the bulk spins. We show that increasing the vacancy density leads to an increase in the total magnetic susceptibility.

[1] S.V. Syzranov, A.P. Ramirez, Nat. Commun. 13, 2993 (2022).

[2] S.V. Syzranov, Phys. Rev. B 106, L140202 (2022)

[3] S. Sun, A.P. Ramirez, S. Syzranov, Phys. Rev. B 108, 174436 (2023)

[4] arXiv:2404.05845, M. Sedik, S. Sun, A.P. Ramirez, S. Syzranov (2024)

[5] arXiv:2406.12966, P. Popp, A.P. Ramirez, S. Syzranov (2024)

[6] arXiv:2408.xxxx, S. Syzranov and A.P. Ramirez (coming soon)

Numerical renormalization group in finite and infinite dimensions

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We present the renormalization group in the problem of localization in which the \beta-function is obtained in terms of the derivatives wrt ln(volume) of the "finite-size" fractal dimension computed numerically from the eigenfunction Shannon entropy. This RG is not supposed to be a-priori single-parameter and it reflects the irrelevant exponents as well. We demonstrate how the role of the irrelevant exponents increases with increasing the dimensionality d and the RG becomes two-parameter on the Bethe lattice (Random Regular Graph).

NON-TRIVIAL TOPOLOGIES IN STRONGLY INTERACTING ELECTRONIC SYSTEMS

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We discuss alternative routes to produce non-trivial topologies in the presence of strongly correlated electrons. The presence of such a strong coupling regime fractionalizes the electrons into charge and spin degrees of freedom. This creates a natural route for the emergence of time-reversal symmetry breaking and the emergence of those non-trivial topologies. As examples we discuss the onset of an Anomalous Hall Effect induced by a Classical spin background and the Majorana fermions in strongly correlated nanowires.

[1] K.K.Kesharpu, E.Kochetov and A. Ferraz, Phys. Rev. B 107, 155146(2023).

[2] K.K.Kesharpu, E. A. Kochetov and A. Ferraz, Phys. Rev. B 109, 115140(2023).