Abstract booklet

New Avenues in Quantum Materials, NAQM 2024

Baltic Consortium of Theoretical Physics

29 – 31 August, 2024 at Chalmers University of Technology, Göteborg, Sweden

Venue: Kollektorn, MC2-building, chalmers
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Friday afternoon venue is Fasrummet, 4 floors directly above Kollektorn

Workshop website: https://www.chalmers.se/en/conference/balconnaqm2024/

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Kagome superconductivity: conventional or unconventional

Brian Møller Andersen

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I will discuss recent theoretical investigations of disorder response and the spin susceptibility of unconventional superconductivity on the kagome lattice. Despite the existence of a sign-changing gap structure, which sums to zero over the Fermi surface, such unconventional pairing states remain robust to disorder and exhibit a Hebel-Schlichter peak in the temperature-dependent spin-relaxation rate. It originates from destructive interference effects peculiar to the kagome lattice. For the same reason, unconventional pairing states on the kagome lattice do not exhibit a neutron resonance peak. These results build on previous theoretical studies of the surprising robustness of unconventional pairing states to disorder on the kagome lattice. Taken together these results imply that unconventional superconductivity on the kagome lattice is deceptive in the sense that its properties may appear similar to conventional non-sign-changing superconductivity. These results may be of relevance to the superconducting state of the kagome superconductors AV_3Sb_5 (A: K, Rb, Cs) and $CsTi_3Bi_5$.

Spin-1 Haldane chains of superconductor-semiconductor hybrids

Virgil V. Baran

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We theoretically explore the possibility of realizing the symmetry-protected topological Haldane phase of spin-1 chains in a tunable hybrid platform of superconducting islands (SIs) and quantum dots (QDs). Inspired by recent findings suggesting that an appropriately tuned QD-SI-QD block may behave as a robust spin-1 unit, we study the behavior of many such units tunnel-coupled into linear chains. Our numerical findings indicate that the QD-SI-QD chains exhibit emblematic features of the Haldane phase, such as fractional spin-1/2 edge states and non-vanishing string order parameters, and that these persist over a sizeable region of parameter space [1].

[1] V. V. Baran and J. Paaske, arXiv:2404.12207 (2024)

Self-Consistent Keldysh-Usadel Formalism Unravels Crossed Andreev Reflection

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Crossed Andreev reflection (CAR) is a process that creates entanglement between spatially separated electrons and holes. Such entangled pairs have potential applications in quantum information processing. However, CAR competes with another non-local process called elastic cotunneling (EC). In conventional normal metal/superconductor/normal metal heterostructures, theoretical predictions conclude that EC dominates over CAR. Nevertheless, we show numerically that when the Keldysh-Usadel equations are solved self-consistently, CAR can dominate over EC. We find that CAR dominates when the quasiparticle density of states is sufficiently suppressed for subgap energies. This suppression is determined by the interface transparency and the length of the superconductor. We also determine how spin-splitting in the superconductor alters the competition between CAR and EC.

Engineering and characterizing quantum spin liquids in magnetic van der Waals materials

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Quantum spin liquids (QSL) are exotic phases of matter featuring strong entanglement and fractional excita- tions [1]. They have attracted much research interest due to their potential Majorana physics and relation to high-temperature superconductivity. Despite the discovery of material candidates for QSL in magnetic van der Waals materials such as 1T-TaS2 [2], 1T-TaSe2 and α-RuCl3, it remains a remarkable challenge to (i) find stable QSL regimes and (ii) identify the QSL phase in these materials. To overcome these challenges, we propose impurity, twist, and substrate engineering of magnetic van der Waals materials as a means of realizing and identifying QSL. Focusing on the material candidate 1T-TaS2, we first show that a magnetic impurity can induce spinon zero modes in the potential Dirac QSL state in this material. We show that such spinon zero modes can be probed with scanning tunneling microscopy (STM), which enables the charac- terization of the Dirac QSL state [3]. Second, we show that a twisted bilayer 1T-TaS2 hosts Moire spinons, whose bandstructure can be modified by encapsulating the twisted bilayer with ferromagnets such as CrI3. We show that, applying a magnetic field on this heterostructure can tune the spinon bandstructure, which is a signature of the Dirac QSL state in 1T-TaS2 [4]. Finally, we show that by placing 1T-TaS2 on substrates with different dielectric constants, the Coulomb interaction between electrons in 1T-TaS2 can be modified due to different electric screenings. We show that this results in a screening-dependent effective Heisenberg model, which can be engineered toward the QSL regime [5]. Our results put forward new strategies to engineer and probe QSL in magnetic van der Waals materials.

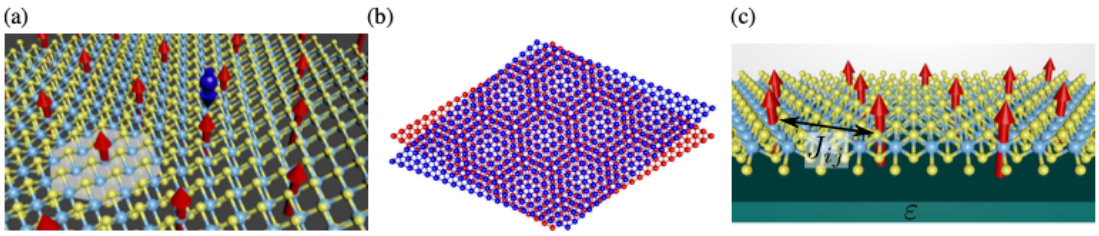

Fig. 1: Sketch of three ways to engineer and characterize QSL in the magnetic van der Waals material 1T-TaS_2. (a) Impurity engineering, where a magnetic impurity (blue) is coupled to the magnetic moments (red) in 1T-TaS_2 (light blue ball: Ta atom, light yellow ball: S atom). The white region shows the magnetic unit cell of 1T-TaS_2. (b) Twist engineering, where red (blue) balls represent a magnetic unit cell of 1T-TaS_2 on the bottom (top) layer in the twisted heterostructure. (c) Substrate engineering, where the dielectric constant ε of the substrate controls the spin exchange J_{ij} between magnetic unit cells i and j in 1T-TaS_2.

[1] L. Savary and L. Balents, Reports on Progress in Physics 80, 016502 (2016)
[2] K. T. Law and P. A. Lee, Proceedings of the National Academy of Science 114, 6996 (2017) [3] G. Chen and J. L. Lado, Phys. Rev. Research 2 033466 (2020)
[4] G. Chen and J. L. Lado, Phys. Rev. Research 3 033276 (2021)
[5] G. Chen, M. Ro ̈sner and J. L. Lado, Journal of Physics: Condensed Matter 34 48 (2022)

Topological superconductivity in twisted bilayer cuprates: A microscopic approach

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Abstract: TBA

Composite and dynamic (multi)ferroics

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Multiferroics combine electrical polarization and magnetization. First, we show that some materials exhibit a quadrupole composite order, prior to the ferroelectric or ferromagnetic transition [1]. In multiferroic materials, where polarization and magnetization are coupled, composites of both orders are possible. This formalism of composite orders naturally accounts for magnetoelectric monopole, toroidal, and quadrupole orders [1]. More broadly, composite orders may explain precursor phenomena in incipient (multi)ferroic materials, arising at temperatures above the ferroic phase transition and potentially contributing to the characterization of currently hidden orders. In the second part, I discuss the recently observed dynamical multiferroicity in SrTiO3 [2]. I show that this effect can be explained in terms of the phonon inverse Faraday effect [3], where a circularly polarized phonon mode induces a huge magnetization due to electron phonon coupling.

[1] R. M. Geilhufe, arXiv:2309.03312
[2] M. Basini, et al., Nature 628, 534–539 (2024)
[3] N. Shabala and R. M. Geilhufe, arXiv:2405.09538

NMR and the critical temperature of cuprate superconductivity

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Cuprate high-temperature superconductivity is typically described in a phase diagram that relates phases and properties of the cuprates to doped charges. Not captured in such a diagram is the maximum critical temperature that varies between families. Nuclear magnetic resonance (NMR) is able to measure the doping in terms of hole content at planar Cu (n_d) and O (n_p) [1] and shows that while doping is given by x = n_d + 2*n_p -1 of the CuO_2 plane ('1' is the inherent Cu hole), it is the hole sharing between n_d and n_p that sets the maximum Tc. For hole doping one finds: Tc,max ~ 200K *2n_p [2]. This relation is now proven by cellular DMFT [3]. In addition, this relation can also explain why cuprates can reach a higher Tc under pressure than by doping, i.e. pressure alters the sharing of the hole content in favor of 2n_p [4].
NMR is better known for measuring the electronic spin susceptibility, which was of great value for the cuprates, as well. However, over the years we showed that a single temperature dependent spin component, as widely assumed in these materials, does not explain the NMR shifts [5]. Then, we turned to all literature shift data and now developed a universal picture [6]. It shows the presence of two types of carriers. Planar carriers are rather universal to the cuprates, occupy Cu-O bonding orbitals (Emery model), and span the phase diagram with pseudogap. Very different are the inter-planar carriers that involve Cu 4s and show a clear family dependence that is not contained in the phase diagram. The condensation behavior of both types of carriers is linked, and their relation sets the maximum Tc. Thus, charge sharing and the appearance of the inter-planar carriers are related. This scenario reminds on of the often discussed role of the apical oxygen for the highest Tc [7].

[1] Jurkutat et al. PRB 2014,
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[4] Jurkutat et al. PNAS 2023.
[5] Haase et al J. Phys. Condens Matter 2009 PRB 2012,; Rybicki et al. PRB 2015; Haase et al. Condens Matte 2017.
[6] Bandur et al. arXiv 2023
[7] Ohta et al. PRB 1991. Pavarini, et al. PRL 2001. O'Mahony et al PNAS 2022

Correlated Superconductivity in a Two-Dimensional Metal-Organic Framework

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Metal-Organic Frameworks (MOFs) are composed of metallic clusters linked by organic ligands. Such materials are typically insulators, but recently there has been considerable progress in the development of conducting MOFs. Surprisingly, the conducting MOF Cu-BHT was found to be superconducting with a critical temperature T_C = 0.25 K. Furthermore, these results point to an unconventional type of superconductivity caused by electron correlations. Our model for Cu-BHT is a modified version of the Hatsugai-Kohmoto (HK) model, which takes into account the refined electronic structure of Cu-BHT. The HK model has infinite range correlations and shows both metal-insulator and insulator-superconductor transitions. Its great advantage is that it is exactly solvable, making it the ideal playground for analytical studies of correlated systems.

Josephson effect in a Fibonacci quasicrystal

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Quasiperiodicity has recently been proposed to enhance superconductivity and its proximity effect. At the same time, there has been significant experimental progress in the fabrication of quasiperiodic structures, also in reduced dimensions. Motivated by these developments, we use microscopic tight-binding theory to investigate the DC Josephson effect through a ballistic Fibonacci chain attached to two superconducting leads. The Fibonacci chain is one of the most studied examples of quasicrystals, hosting a rich multifractal spectrum, containing topological gaps with different winding numbers. We study how the Andreev bound states (ABS), current-phase relation, and the critical current depend on the quasiperiodic degrees of freedom, from short to long junctions. While the current-phase relation shows a traditional 2π sinusoidal or sawtooth profile, we find that the ABS obtain quasiperiodic oscillations and that the Andreev reflection is qualitatively altered, leading to quasiperiodic oscillations in the critical current as a function of junction length. Surprisingly, despite earlier proposals of quasiperiodicity enhancing superconductivity, we do not in general find an enhanced critical current. However, we find significant enhancement for reduced interface transparency due to the modified Andreev reflection. Furthermore, by varying the chemical potential, e.g. by an applied gate voltage, we find a fractal oscillation between superconductor-normal metal-superconductor (SNS) and superconductor-insulator-superconductor (SIS) behavior. Finally, we show that the winding of the subgap states leads to an equivalent winding in the critical current, such that the winding numbers, and thus the topological invariant, can be determined.

[1] A. Sandberg, O. A. Awoga, A. M. Black-Schaffer, P. Holmvall, "Josephson effect in a Fibonacci quasicrystal", arXiv:2405.05660 (2024).

Microwave coupling, sensing and cavity engineering with magnets and superconductors

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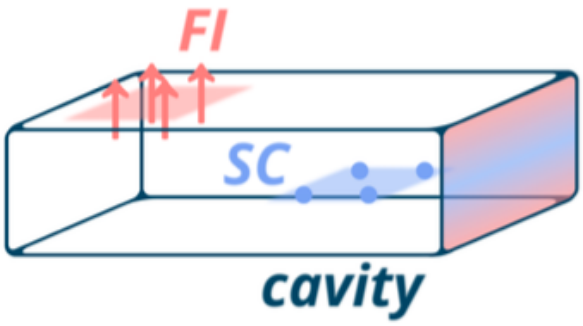
The demonstration of strong light-matter coupling in photonic cavities has emboldened international ambitions to combine solid state quantum computation with the long-distance information transport of quantum optics. Hybridization between cavities and magnets (ie microwave photon modes and magnons), and light-mediated hybridization of magnons and qubits, are key steps in this direction. We examine the different roles of photon coupling to bosonic and fermionic reservoirs in cavities, and show how light can mediate long-distance coupling between magnets (FI) and superconductors (SC) (see figure) [1,2]. This may be used to monitor the superconducting transition without proximal disruption of their orders. By using circularly polarized light instead of linear polarization, we also find a way of remotely measuring spin-splitting without driving, and a non-invasive route for engineering the lifetimes of cavity modes [3].

[1] Phys. Rev. B **107**, 035147 (2023) [Editor's suggestion]
[2] Phys. Rev. B **102**, 180506(R) (2020)
[3] arXiv: 2401.01929



Learning about decoherence sources in superconducting circuits from the measurements on high-Q superconducting resonators

Sergey Kubatkin

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Abstract: TBA

Realizing complex electronic states in van der Waals heterostructures

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Conventional materials hosting exotic quantum phases typically have complex atomic structures, inhomogeneities from defects, impurities, and dopants making it difficult to rationally engineer their electronic properties. This can be overcome using van der Waals (vdW) materials and their heterostructures that allow an almost arbitrary selection of the heterostructure building blocks. In a vdW heterostructure, proximity effects cause properties to “leak” between the adjacent layers and allow creating exotic quantum mechanical phases that arise from the interactions between the layers. These key features have recently made it possible to realize exotic quantum phases by design and engineer responses that do not readily occur in natural materials. I will highlight these concepts through our recent results on monolayer multiferroic materials and vdW heterostructures realizing artificial heavy fermion states [1-4]. In general, these examples highlight the versatility of vdW heterostructures in realizing quantum states that are difficult to find and control in naturally occurring materials.

[1] M. Amini, A.O. Fumega, H. González-Herrero, V. Vaňo, S. Kezilebieke, J.L. Lado, P. Liljeroth, Adv. Mater. 36, 2311342 (2024).

[2] S.C. Ganguli, M. Aapro, S. Kezilebieke, M. Amini, J.L. Lado, P. Liljeroth, Nano Lett. 23, 3412 (2023).

[3] V. Vaňo, M. Amini, S. C. Ganguli, G. Chen, J.L. Lado, S. Kezilebieke, P. Liljeroth, Nature 599, 582 (2021).

[4] X. Huang, J. Sainio, J.L. Lado, P. Liljeroth, S.C. Ganguli, arXiv 2401.08296 (2024).

Edge-selective extremal damping: topological edge physics in open and driven quantum systems

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The role of topology in open and driven quantum systems is an important frontier in condensed matter physics. In my talk, I will discuss the degree to which the coupling of a topological system to a bath destroys/alters its topological features (or not). In particular, I will review that different non-Hermitian generalizations of topological Hamiltonians govern the dynamics of open quantum systems on different time scales. As one application, I will discuss edge-selective extremal damping in open Chern insulators as a topological phenomenon, and show that it derives from edge states of non-Hermitian extensions of the parent Chern insulator Hamiltonian.

Dissipative and dispersive cavity optomechanics with a suspended frequency-dependent mirror

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An optomechanical microcavity can considerably enhance the interaction between light and mechanical motion by confining light to a subwavelength volume. However, this comes at the cost of an increased optical loss rate. A pathway to reduce optical losses is to use a strongly frequency-dependent mirror, such as a photonic crystal mirror.
In this talk, I will present the quantum-coupled-mode description we formulated for such a system [1], including both the standard dispersive optomechanical coupling as well as dissipative coupling, and show how it matches our experimental measurements of a free-space on-chip optomechanical microcavity [2]. Finally, I will outline strategies to achieve ground-state cooling in such a device [1], including using a coherent feedback scheme [3].

[1] J. Monsel, A. Ciers, S. K. Manjeshwar, W. Wieczorek, and J. Splettstoesser, Phys. Rev. A 109, 043532 (2024).
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[3] L. Du, J. Monsel, W. Wieczorek, and J. Splettstoesser, arXiv:2405.13624.

Pure spin-triplet currents and Josephson diode effect in strongly polarized SFS junctions

Danilo Nikolić, Niklas L. Schulz, and Matthias Eschrig

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Motivated by recent experiments on the proximity effect in the superconductor (S) - helimagnet (F) systems [1], we present a systematic theoretical study of such an effect occurring at the SF interface with strongly polarized F. The theory is done in the framework of the quasiclassical Green's function formalism. However, due to the large splitting between the spin bands in F, the standard quasiclassical approach [2] cannot be applied directly but a somewhat modified description is required [3]. Applying this approach, we account for equal-spin triplet correlations and investigate their influence on observables. For instance, we calculate the Josephson current-phase relation (CPR) in an SFS weak link considering the helimagnetic ordering in F. Remarkably, the CPR takes a nontrivial form leading to both the anomalous and the Josephson diode effect. This effect has a clear physical interpretation based on the coupling between the superconducting phase and an effective U(1) gauge field induced by inhomogeneous magnetization of F. A similar effect can be achieved by specific relative orientation between the magnetizations of the SF interfaces and the F layer which manifests itself as an effective U(1) gauge field that couples to the superconducting phase even in a homogeneous ferromagnetic case [4].

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[2] G. Eilenberger, Z. Phys. **214**, 195 (1968); A. I. Larkin and Yu. N. Ovchinnikov, Sov. Phys. JETP **28**, 1200 (1969); K. D. Usadel, Phys. Rev. Lett. **25**, 507 (1970); A. I. Buzdin, Rev. Mod. Phys. **77**, 935 (2005)
[3] M. Eschrig, Phys. Rev. B **80**, 134511 (2009); R. Grein *et al*, Phys. Rev B **81**, 094508 (2010); M. Eschrig, Rep. Prog. Phys. **78**, 104501 (2015); I. V. Bobkova *et al*, Phys. Rev. B **96**, 094506 (2017)
[4] R. Grein *et al*, Phys. Rev. Lett. **102**, 227005 (2009)

Quantum-dot simulators of chemistry

Jens Paaske

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Gateable semiconductor quantum dots (QDs) provide a versatile platform for analog quantum simulations of electronic many-body systems. In particular, gate-defined QD arrays offer a natural representation of the π-electron system of small hydrocarbons. In this seminar I will discuss the prospects for extending QD simulators to also encompass the nuclear degrees of freedom by representing the molecular vibrational modes by single-mode microwave resonators. As an example, we study the gate-tunable energy transfer from a voltage-biased triple quantum dot system to a finite-Q single-mode resonator. This system constitutes a gate-tunable micromaser and thereby works as a simulator of current-induced vibrational instabilities in single-molecule junctions. In selected parameter regimes, the energy transfer may be calculated using Lindblad master equations and/or perturbative Keldysh Green functions, and this voltage-biased TQD-resonator system provides for an illuminating comparison between the two methods. As for the other parameter regimes, we shall await the results of actual experimental simulations.

Noise mechanisms in short ballistic graphene Josephson junctions

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CNR-IMM, Catania (University) Unit, via Santa Sofia 64, I-95123 Catania, Italy

The future of quantum technologies lies in hybrid systems achieving multitasking potentialities by combining different physical components with complementary functionalities. In particular, devices based on hybrid Josephson junctions have opened up new possibilities to engineer noise protected qubits being at the same time easily tunable via electrical ports. To this aim, accurate control of the electronic properties of graphene Josephson junctions (GJJ) in the presence of disorder is essential. We investigate a short ballistic graphene Josepshon junction and show that two points and higher order correlations of carrier density fluctuations of the graphene channel lead to fluctuations of the critical current with a characteristic 1/f dependence on frequency [1]. The same mechanism is responsible for 1/f second spectrum of charge carrier density fluctuations in graphene [2].
In addition we study the effect of a dilute homogeneous spatial distribution of non-magnetic impurities on the equilibrium supercurrent of the GJJ [3]. The effects of a single short-range impurity on the local electron density of states evidences that the subgap energy dependence distinguishes scattering processes that involve energy transfer beyond momentum and allows to identify the magnetic nature of the impurity. These results suggest a roadmap for the analysis of decoherence sources in the implementation of coherent devices by hybrid nanostructures and highlight the potentialities of the supercurrent power spectrum for the spectroscopy of hybridized Andreev bound states-impurities spectrum.

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[2] F. Pellegrino, G. Falci, E. Paladino, Appl. Phys. Lett. **122**, 253102 (2023).
[3] F. Pellegrino, G. Falci, E. Paladino, Communication Physics, **5**, 265 (2022).

Thermometry and thermalization in circuit QED

Jukka Pekola

Aalto University, Helsinki, Finland

I discuss our recent experiments on thermal transport in quantum circuits. I also give examples of how thermal (bolometric) detection can offer a tool to investigate open quantum systems formed of superconducting circuits. At the end I discuss condition of thermalization in isolated quantum systems.

Parafermions in moiré minibands

Hui Liu, Raul Perea-Causin, Emil J. Bergholtz

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Moiré materials provide a remarkably tunable platform for topological and strongly correlated quantum phases of matter. Very recently, the first zero field Abelian fractional Chern insulators (FCIs) have been experimentally demonstrated [1,2] and it has been theoretically predicted that non-Abelian states with Majorana fermion excitations may be realized in the nearly dispersionless minibands of these systems [3]. Here we provide telltale evidence in terms of low-energy quantum numbers, spectral flow and entanglement spectra for the even more exotic possibility of moiré-based non-Abelian FCIs exhibiting Fibonacci parafermion excitations [4].

[1] Y. Xie, et al., Nature 600, 439–443 (2021)
[2] H. Park, et al., Nature 622, 74–79 (2023)
[3] A. P. Reddy, N. Paul, A. Abouelkomsan, L. Fu, arXiv:2403.00059 (2024)
[4] H. Liu, R. Perea-Causin, E. J. Bergholtz, arXiv: 2406.08546 (2024)

Thermo-electric transport theory of Landau levels as prototype of flat band systems

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I will talk about a kinetic equation derived from non-equilibrium quantum field theory for interacting electrons in a uniform magnetic field of arbitrary magnitude. Exposing an electronic system to a constant magnetic field quenches its energy bands into a series of discrete energy levels, known as Landau levels.This is a prototypical model of flat band physics. Following Keldysh formalism, we derive the quantum kinetic equation with the Landau-level basis. As an application of our quantum transport equation, we calculate magneto-thermoelectric coefficients of a disordered two-dimensional electron gas (2DEG) in the quantum hall regime interacting with acoustic phonons.

Dielectrics for 2D Nanoelectronics

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2D materials have drawn significant interest as these have potential to outperform Si in many emerging applications, including logic and memory technology. Gate insulator and its interface with the channel material in a transistor are the key factors deciding technological feasibility of a semiconductor channel material. Conventional CMOS gate dielectrics (e.g., SiO_2, HfO_2) form a poorer interface with 2D materials rendering and an alternative solution is needed. Compatible van der Waals gate dielectric materials are now instead actively explored which could seamlessly be integrated with 2D layered materials. A few novel dielectrics have been emerged including h-BN, CaF_2, and Sb_2O_3. We provide insights into the material behaviour and corelate the device performance with the atomic level degradation and dielectric breakdown using ex-situ and in-situ TEM. These will provide guidelines to design robust gate dielectrics for the emerging 2D nanoelectronics.

Superconducting Diode Effect in Diffusive Superconductor-Ferromagnet Heterostructures

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Long-range equal-spin triplet supercurrents are of fundamental importance for applications of superconducting spintronics [1]. In this work we investigate the proximity and the Josephson effect in a trilayer junction consisting of a strong ferromagnet (sFM) connected to BCS superconductors (SC) by ferromagnetic insulating barriers. For non-coplanar arrangements of the barrier and bulk magnetisations spin-geometric phases arise additionally to the superconducting phase difference [2]. In general, such spin-geometric phases are induced by gauge fields entering the transport equation [3] and in the considered case the geometric phases are caused by spin-dependent U(1) gauge fields. The resulting current-phase relation in such devices then allows for the observation of a Josephson diode effect in the charge current for symmetric systems and a diode effect in the spin current for asymmetric configurations. Furthermore we observe that the corresponding Fourier components fulfill certain symmetry relations which can be derived from the strong exchange splitting in the bulk ferromagnet.

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[2] R. Grein, M. Eschrig, G. Metalidis, and G. Schön, Phys. Rev. Lett. **102**, 227005 (2009)
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Phonon Inverse Faraday effect from electron-phonon coupling

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The phonon inverse Faraday effect describes the emergence of a DC magnetization due to circularly polarized phonons. Using time-dependent second order perturbation theory and electron-phonon coupling we develop a miscrosopic formalism for phonon inverse Faraday effect. We arrive at a general and material-independent equation which describes the effect and allows to estimate the effective magnetic field expected for the ferroelectric soft mode in the oxide perovskite $SrTiO_3$ [1]. Our estimates are consistent with recent experiments showing a huge magnetization after a coherent excitation of circularly polarized phonons with THz laser light [2]. Hence, our theoretical approach is promising for shedding light into the microscopic mechanism of angular momentum transfer between ionic and electronic angular momentum, which is expected to play a central role in the phononic manipulation of magnetism.

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High temperature superconductivity in the cuprates within variational approach: Beyond mean-field theory and comparison with experiment

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Abstract: TBA

Electrical noise spectroscopy of magnons in a quantum Hall ferromagnet

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Collective spin-wave excitations, magnons, are promising quasi-particles for next-generation spintronics devices, including platforms for information transfer. In a quantum Hall ferromagnet, detection of these charge-neutral excitations relies on the conversion of magnons into electrical signals in the form of excess electrons and holes. However, if the number of excess electrons and holes are equal, detecting a finite electrical signal, and thus the presence of magnons, is highly challenging.

In this talk, I will present recent theory-experiment work [1] on how this shortcoming can be overcome by measuring the electrical fluctuations, i.e., noise, generated by the magnons. In the symmetry-broken quantum Hall ferromagnet of the zeroth Landau level in graphene one may launch magnons by voltage biasing an edge-attached contact. Above the Zeeman energy, absorption of these magnons creates excess noise which can be finite even when the average electrical signal is zero. I will also present a complementary theoretical model in which the noise is produced by equilibration between quantum Hall edge channels and propagating magnons. This model also allows to pinpoint the regime of ballistic magnon transport in the device.

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Absence of a dimensional reduction in the stable ”healed” variant of $BaCuSi_2O_6$

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A prominent material where a two dimensional square lattice of dimers is realized and the appearance of a field-induced Bose-Einstein condensation (BEC) of triplons was reported, is $BaCuSi_2O_6$ [1]. The occurrence of magnetic field-induced ordered states, which can be described as BEC of triplons has the main idea behind that dimers of two Cu^{2+}-ions, which each carry a spin 1/2, can be mapped onto bosons to realize a BEC [2,3]. The interest in the compound as a material to observe a 3D-2D crossover at the quantum phase transition [4] vanished after the discovery of an incommensurately modulated low temperature structure with structurally inequivalent adjacent bilayers below 100K [5,6] complicating the model and its physics [7,8].
However, substitutions were reported to stabilize the tetragonal room temperature structure of $BaCuSi_2O_6$ down to lowest temperatures already with 5% Strontium substitution on the Barium place [8]. We present an analysis of the dimerized groundstate of $Ba_{0.9}Sr_{0.1}CuSi_2O_6$, the stable tetragonal structure variant of $BaCuSi_2O_6$. We explore the single particle excitation spectrum via inelastic neutron scattering and the high field groundstate with pulsed-field magnetization, specific heat, and magnetocaloric effect as well as static high field torque, and NMR studies. We find a single slightly broadened mode of single dimer kind in this ”healed” structure. With the extracted interaction parameters we use Quantum Monte Carlo (QMC) calculations to describe our experimental phase border. Unlike proclaimed for $BaCuSi_2O_6$ we find a critical exponent of 0.69(9) and no dimensional reduction [9].

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Ultrafast Thermodynamics in Magnets

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Quantum materials find increasingly many applications in high-performance technology. Such technology requires rapid nanoscale material manipulation, emphasizing the importance of understanding non-equilibrium behavior at fundamental scales. Translating thermodynamic principles to the (sub)picosecond timescale of material excitations drives the field of ultrafast thermodynamics.
We develop the ultrafast thermodynamics framework on the example of non-equilibrium magnets. Using a path integral formalism and stochastic thermodynamics, we simulate the entropy and heat production for laser driven magnetization dynamics.

Using proximitized quantum corral eigenmodes for non-local detection of Yu-Shiba-Rusinov states

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Quantum mirages are non-local projections of local quantum states induced by an atomic scale defect in a bath of conduction electrons that can be tailored by cages of nonmagnetic atoms, so-called quantum corrals [1, 2]. Here, we observe, by scanning tunnel spectroscopy, the mirage of the Yu-Shiba-Rusinov state induced by a magnetic atom in the eigenmodes of a quantum corral which are gapped by proximity to a superconducting substrate [2]. We reveal a characteristic corral-eigenenergy dependent oscillation in the mirage‘s particle-hole asymmetry. Our modelling shows that the mirage is dominated by an indirect coupling of the Yu-Shiba-Rusinov state induced in the bulk superconductor with the proximitized corral eigenmodes.

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Structured Light and Induced Vorticity in Superconductors

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Questions of controlling the quantum states of matter via light have been at the forefront of research on driven phases. We demonstrate the effects of imprinted vorticity on superconducting coherent states using structured light. Within the framework of the generalized time-dependent Ginzburg-Landau equation, we show the induction of coherent vortex pairs moving in phase with electromagnetic wave oscillation. The structured light, generated by a Laguerre-Gaussian beam, provides light sources with various quantum properties, such as spin angular momentum and orbital angular momentum. This state of light is also well known as an optical vortex, characterized by a twisted phase front. In the current work, we investigate the optically induced dynamics of superconducting coherent states using both normal light sources and optical vortices. These results uncover rich hydrodynamics of superconducting states and suggest new optical applications for imprinting quantum states on superconducting materials.

Laguerre-Gaussian light induction of orbital currents and Kapitza stabilization in superconducting circuits

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We investigate the effect of a Laguerre-Gaussian (LG) microwave beam on the superconducting rings with Josephson junctions. We show that the optical vortex angular momentum affects the superconducting state and induces currents. We establish that coupling a dc SQUID to the AC magnetic flux of a LG beam can stabilize \pi phase in the SQUID. This can happen via developing a global or a local minimum in the effective potential. In the latter case, this occurs via the Kapitza stabilization mechanism.