Coherence in Fermionic Matter: Fermion Pairing in Cold Atoms and Superconductors

Polish-German WE-Heraeus-Seminar

13 - 16 October 2019
at the Physikzentrum Bad Honnef/Germany

WILHELM UND ELSE
HERAEUS-STIFTUNG

Introduction

The Wilhelm und Else Heraeus-Stiftung is a private foundation that supports research and education in science with an emphasis on physics. It is recognized as Germany's most important private institution funding physics. Some of the activities of the foundation are carried out in close cooperation with the German Physical Society (Deutsche Physikalische Gesellschaft). For detailed information see https://www.we-heraeus-stiftung.de

Aims and scope of the Polish-German WE-Heraeus-Seminar:

On the initiative of the Wilhelm and Else Heraeus Foundation, the German Physical Society (DPG) together with the Foundation is pursuing a novel project called "Binational Wilhelm and Else Heraeus Seminars". These seminars are meant, in response to increasing and prevalent scepticism regarding Europe, to set an example of commonly organised physics workshops between the countries bordering with Germany: France, the United Kingdom, and Poland, as a signal of conducive partnership and scientific cooperation between those countries and their learned societies. In particular, the idea is to initiate new or foster existing collaborations between research groups in these countries and Germany. An additional reason for focussing on the above mentioned countries is the long tradition of prestigious jointly-awarded prizes. Accordingly, one of the scientific organizers of this Polish-German seminar is the recipient of the Marian Smoluchowski - Emil Warburg Physics Prize 2017.

The first seminar in the Polish-German series is devoted to an interdisciplinary issue, namely quantum coherence in fermionic systems as realized in cold atom gases and in novel superconductors. Speakers from both areas will elucidate experimental and theoretical aspects of both fields, with the goal of clarifying conceptual similarities and differences on a fundamental level, review the current status of the fields and their interconnections, and discuss future perspectives. In total, there are 16 invited speakers, half of them from Poland and the other half from Germany. The other participants, about 40, will present their recent results in a poster session. In a Special Talk, two representatives from the German Science Foundation will describe funding opportunities for joint German-Polish projects offered by DFG.

Scientific Organizers:

Prof. Dr. Ulrich Eckern	University of Augsburg, Germany E-mail: eckern@physik.uni-augsburg.de
Prof. Dr. Andrzej M. Oleś	Jagiellonian University, Kraków, Poland E-mail: amoles@fkf.mpg.de

Introduction

Administrative Organization:

Dr. Stefan Jorda
Martina Albert

Wilhelm und Else Heraeus-Stiftung
Postfach 15 53
63405 Hanau, Germany

Phone +49 6181 92325-14
Fax +49 6181 92325-15
E-mail albert@we-heraeus-stiftung.de
Internet: www.we-heraeus-stiftung.de

Venue:

Physikzentrum
Hauptstrasse 5
53604 Bad Honnef, Germany

Conference Phone +49 2224 9010-120

Phone +49 2224 9010-113 or -114 or -117
Fax +49 2224 9010-130
E-mail gomer@pbh.de
Internetwww.pbh.de

Taxi Phone +49 2224 2222

Registration:

Martina Albert (WE Heraeus Foundation)
at the Physikzentrum, reception office
Sunday (17:00 h – 21:00 h) and Monday morning

Door Code:

(Key symbol) 2 1 0 9 #
For entering the Physikzentrum
during the whole seminar

Program

Sunday, 13 October 2019

17:00 – 21:00	Registration	
from 18:30	*BUFFET SUPPER / Informal get together*	

Monday, 14 October 2019

07:30	*BREAKFAST*	
08:30 – 08:45	Ulrich Eckern Andrzej M. Oleś	**Opening and welcome**
08:45 – 09:00	Stefan Jorda	**About the Wilhelm and Else Heraeus Foundation**
09:00 – 10:00	Joerg Schmalian	**Nematic superconductivity in doped topological insulators**
10:00 – 11:00	Matteo Minola	**Spin excitations and charge density waves in high-T_c superconducting cuprates**
11:00 – 11:30	*COFFEE BREAK*	
11:30 – 12:30	Corinna Kollath	**Dynamic enhancement of pairing correlations**
12:30 – 12:40	**Conference Photo** (in front of the Physikzentrum/Main entrance)	
12:40	*LUNCH*	
14:00 – 15:00	Ewelina Hankiewicz	**Topological superconductivity in phase-controlled Josephson junctions on topological insulators and Rashba 2DEGs**

Program

Monday, 14 October 2019

15:00 – 16:00	Andreas Schnyder	**Topological superconductors: Classification, properties, and examples**
16:00 – 16:30	*COFFEE BREAK*	
16:30 – 17:30	Timo Hyart	**Correlated states in flat-band systems and topological properties of surface steps in the SnTe material class**
17:30 – 18:30	Małgorzata Samsel-Czekała	**Dirac fermions and topological superconductivity in layered quantum materials**
18:45	*DINNER*	
20:00 – 21:00	Piotr Magierski	**Superfluidity far from equilibrium**

Program

Tuesday, 15 October 2019

07:30	*BREAKFAST*	
08:30 – 09:30	Ilya Eremin	**Cooper-pairing with small Fermi energies in multiband superconductors: BCS-BEC crossover and time-reversal symmetry broken state**
09:30 – 10:30	Maciej M. Maśka	**Topological superconductivity and Majorana modes in one-dimensional systems**
10:30 – 11:00	*COFFEE BREAK*	
11:00 – 12:00	Tomasz Sowiński	**Emergence of pairing in systems of several particles**
12:00 – 13:00	Krzysztof Wohlfeld	**Electron localization in a Mott insulator: Theory *versus* cold atom simulations**
13:00	*LUNCH*	
14:30 – 15:30	Immanuel Bloch	**Quantum matter under the microscope**
15:30 – 16:00	*COFFEE BREAK*	
16:00 – 18:30	**Poster Session**	
18:30 – 19:45	*HERAEUS DINNER at the Physikzentrum (cold & warm buffet, free beverages)*	
20:00 – 20:45	A. Lottermann I. Paulus both DFG, Bonn	**Science across borders: DFG-funding opportunities for joint German-Polish projects**

Wednesday, 16 October 2019

07:30	*BREAKFAST*	
08:45 – 09:45	Katharina Franke	**Yu-Shiba-Rusinov states in single atoms and molecules on superconductors**
09:45 – 10:45	Tadeusz Domanski	**Constructive feedback of superconductivity on the Kondo effect in nanoscopic heterostructures**
10:45 - 11:15	*COFFEE BREAK*	
11:15 – 12:15	Krzysztof Sacha	**Time crystals**
12:15 – 12:30	Ulrich Eckern Andrzej M. Oleś	**Poster awards and closing**
12:30 – 13:30	*LUNCH*	

End of the seminar and *FAREWELL COFFEE* / **Departure**

Posters

01	Mestapha Arejdal	**The magnetocaloric effect in a Nano -system built on a Dendrimer structure: Monte Carlo Study**
02	Alexander Bauer	**Phase-dependent heat transport in Josephson junctions with p-wave superconductors and superfluids**
03	André Becker	**Magnon Transport with periodically driven barriers**
04	Wojciech Brzezicki	**Topological properties of multilayers and surface steps in the SnTe material class**
05	Piotr Busz	**Optimized entanglement witnesses - entanglement detection in Cooper pair splitters without magnetic detectors efficiency limit**
06	Aurelia Chenu	**Interference pattern of colliding composite-boson condensates**
07	Agnieszka Cichy	**Low-temperature phases in the two-band Hubbard model realized with ultracold atomic four-component mixtures in optical lattices**
08	Lukas Debbeler	**Superconductivity in locally non-centrosymmetric heavy-fermion materials: Influence of Rashba spin orbit interaction and correlation**
09	Jacek Dobrzyniecki	**Dynamics of a few interacting bosons escaping from an open well**
10	Paul Froese	**Non-equilibrium Higgs excitations in the presence of impurity scattering**

Posters

11	Max Geier	**Symmetry-based indicators for topological Bogoliubov-de Gennes Hamiltonians**
12	Szczepan Głodzik	**Nodal topological superconductivity in magnetic superstructures**
13	Moritz Hirschmann	**Topology in magnetic phases of SmB_6**
14	Satoshi Ikegaya	**Anomalous Nonlocal Conductance as a Fingerprint of Chiral Majorana Edge States**
15	Krzysztof Jachymski	**Quantum simulation of polaron physics in hybrid ion-atom systems**
16	Konrad Jerzy Kapcia	**Exact analytic solution of the extended Falicov-Kimball model in infinite dimensions**
17	Rüdiger Klingeler	**Nematicity in $LaFe_{1-x}Co_xAsO$ and AFe_2As_2 single crystals studied by thermal expansion and shear-modulus measurmeents**
18	Adam Kłosiński	**Motion of a single hole in Ca_2RuO_4**
19	Aksel Kobiałka	**Majorana Bound State leakage in nanoscopic structures**
20	Denis Kochan	**Spin-relaxation and Yu-Shiba-Rusinov states in Superconducting Graphene**
21	Arkadiusz Kuroś	**Discrete time quasicrystals**
22	Christian Martens	**Non-equilibrium optical conductivity for the antiferromagnetic single-band Hubbard model: Time-dependent Gutzwiller analysis**
23	Pawel Matus	**Fractional time crystals**

Posters

24	Benjamin Nagler	**Towards studies of the BEC-BCS crossover in a disordered environment**
25	Dillip K. Nandy	**Dynamical properties of a few mass-imbalanced ultra-cold fermions confined in a double-well potential**
26	Minh Nguyen Nguyen	**Topological states in 1D SnTe nanowires**
27	Katharina Noatschk	**Linear-Response Dynamics from the time-dependent Gutzwiller Approximation**
28	Tania Paul	**A quantum transport study of the interplay of quantum spin Hall effect and exciton condensation in electron-hole bilayers**
29	Daniel Pęcak	**Two-body correlations in mass-imbalanced few-body mixtures**
30	Andrzej Ptok	**Formation of the Majorana bound states on defects**
31	Marek Rams	**Breaking the entanglement barrier: Tensor network simulation of quantum transport**
32	Jürgen Röhler	**x_c and x_{opt} in Cuprate Superconductors**
33	Matthias Stosiek	**Self-consistent-field ensembles of disordered Hamiltonians: Efficient solver and application to superconducting films**
34	Tomasz Szołdra	**Determination of topological invariants in optical lattices**
35	Damian Tomaszewski	**Aharonov-Bohm and Aharonov-Casher effects of local and nonlocal Cooper pairs**

36	Bugra Tuzemen	**Stable Spin-Polarized Impurity in Unitary Fermi Gas**
37	Marek Tylutki	**Spin-Imbalanced Fermi Superfluid in a Lieb Lattice**
38	Damian Włodzyński	**Inter-component correlations in few-fermion systems induced by a shape of an external confinement**
39	Gabriela Wójtowicz	**Quantum Transport via Matrix Product States and Extended Reservoirs**
40	Piotr Wrzosek	**Superexponential Wave Function Decay: a Fingerprint of Strings in Doped Antiferromagnets**

Abstracts of Lectures

(in alphabetical order)

Quantum Matter under the Microscope

Immanuel Bloch

Quantum Many-Body Systems Division
Max-Planck Institute of Quantum Optics, Garching (Munich), Germany

More than 30 years ago, Richard Feynman outlined his vision of a quantum simulator for carrying out complex calculations on physical problems. Today, his dream is a reality in laboratories around the world. This has become possible by using complex experimental setups of thousands of optical elements, which allow atoms to be cooled to Nanokelvin temperatures, where they almost come to rest. Recent experiments with quantum gas microscopes allow for an unprecedented view and control of such artificial quantum matter in new parameter regimes and with new probes. In our fermionic quantum gas microscope, we can detect both charge and spin degrees of freedom simultaneously, thereby gaining maximum information on the intricate interplay between the two in the paradigmatic Hubbard model. In my talk, I will show how we can reveal hidden magnetic order, directly image individual magnetic polarons or probe the fractionalisation of spin and charge in dynamical experiments. For the first time we thereby have access to directly probe non-local 'hidden' correlation properties of quantum matter and to explore its real space resolved dynamical features also far from equilibrium

Constructive feedback of superconductivity on the Kondo effect in nanoscopic heterostructures

T. Domański[1] and I. Weymann[2]

[1]Institute of Physics, M. Curie-Skłodowska University, 20-031 Lublin, Poland
[2] Faculty of Physics, A. Mickiewicz University, 61-614 Poznań, Poland

Superconductivity and magnetism are usually detrimental to each other. In nanoscopic systems, however, the electron pairing maysometimes cooperate with effective exchange interactions which are responsible for the Kondo effect. Such situation occur at low temperatures in the correlated quantum dots coupled between the conducting and superconducting reservoirs, where the proximity induced pairing enhances the Kondo peak upon approaching the quantum phase transition. We explain this intriguing tendency within the Anderson-type impurity scenario by means of: the generalized Schrieffer-Wolff canonical transformation, the second order perturbative treatment of the Coulomb repulsion, and the nonperturbative numerical renormalization group calculations [1]. Similar possibility can occur in 3-terminal structures, where the quantum dot is plcaed between two superconducting reservoirs, differing in phases, and hybridized with a metallic normal lead. This setup might be suitable for probing the subtle interplay between the correlation effects with the proximity-induced electron pairing, leading to the phase-tunable Kondo effect nearby 0-π crossover [2].
We also extend our study to heterostructures with the topological materials. In particular, we analyze the low energy spectrum and transport properties of correlated quantum dot coupled between normal and superconducting reservoirs and hybridized with a topological superconducting nanowire, hosting the Majorana end-modes. Under such circumstances the Majorana quasiparticle can be confronted simultaneously with the on-dot pairing and correlations. We study their mutual relationship, revealing that the Majorana mode has either constructive or destructive effect on the low-energy spectrum of the quantum dot, depending on spin [3]. Such spin-selective influence could be empirically verified using the polarized STM spectroscopy.

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Cooper-pairing with small Fermi energies in multiband superconductors: BCS-BEC crossover and time-reversal symmetry broken state

Ilya M.Eremin[1]

[1] *Institut für Theoretische Physik III, Ruhr-Universität Bochum, D-44780 Bochum, Germany*

In my talk I will consider the interplay between superconductivity and formation of bound pairs of fermions in multi-band 2D fermionic systems (BCS-BEC crossover). In two spatial dimensions a bound state develops already at weak coupling, and BCS-BEC crossover can be analyzed already at weak coupling, when calculations are fully under control. We found that the behavior of the compensated metal with one electron and one hole bands is different in several aspects from that in the one-band model. There is again a crossover from BCS-like behavior at EF>>E0 (E0 being the bound state energy formation in a vacuum) to BEC-like behavior at EF<< E0 with Tins > Tc. However, in distinction to the one-band case, the actual Tc, below which long-range superconducting order develops, remains finite and of order Tins even when EF = 0 on both bands. The reason for a finite Tc is that the filled hole band acts as a reservoir of fermions. The pairing reconstructs fermionic dispersion and transforms some spectral weight into the newly created hole band below the original electron band and electron band above the original hole band. A finite density of fermions in these two bands gives rise to a finite Tc even when the bare Fermi level is exactly at the bottom of the electron band and at the top of the hole band. I also analyze the formation of the s+is state in a four-band model across the Lifshitz transition including BCS-BEC crossover effects on the shallow bands. Similar to the BCS case, we find that with hole doping the phase difference between superconducting order parameters of the hole bands change from 0 to π through an intermediate s + is state, breaking time-reversal symmetry (TRS)..

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Yu-Shiba-Rusinov States in Single Atoms and Molecules on Superconductors

Katharina J. Franke[1]

[1]Fachbereich Physik, Freie Universität Berlin, Berlin, Germany

Magnetic adatoms and molecules on a superconducting substrate act as a pair-breaking scattering potential for the Cooper pairs and induce Yu-Shiba-Rusinov (YSR) states inside the superconducting energy gap. The states can be probed on the atomic scale by low-temperature scanning tunneling spectroscopy.
Here, we show that individual Manganese (Mn) atoms give rise to a distinct number of YSR states, depending on the crystal field imposed by the adsorption site. The spatial extent of these states directly reflects their origin as the singly occupied d-states [1]. When the atoms are brought into sufficiently close distance, we detect the formation of symmetric and anti-symmetric combinations of the corresponding YSR wave functions [2].
In contrast to the atomic adsorbates, molecules bear more flexibility and the possibility to tune their strength of the magnetic exchange scattering potential to the Cooper pairs. Upon tip approach we are able to continuously vary the energy of YSR states induced by Fe-porphin molecules on Pb(111) across the Fermi energy. This model system allows to study the quantum phase transition between a screened and unscreened spin [3].

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Topological superconductivity in phase-controlled Josephson junctions on topological insulators and Rashba 2DEGs

Ewelina M. Hankiewicz
Würzburg University
email: hankiewicz@physik.uni-wuerzburg.de

Topological superconductors can support localized Majorana states at their boundaries. Although signatures of Majorana bound states have been observed in one-dimensional systems, there is an ongoing effort to find alternative platforms that do not require fine-tuning of parameters and can be easily scaled to large numbers of states. In this talk, we show the combined experimental and theoretical approach towards a two-dimensional architecture of Majorana bound states [1]. Using Josephson junctions made of HgTe quantum wells coupled to thin-film aluminium, we are able to tune the transition between a trivial and a topological superconducting state by controlling the phase difference across the junction and applying an in-plane magnetic field. We determine the topological state of the resulting superconductor by measuring the tunnelling conductance at the edge of the junction. At low magnetic fields, we observe a minimum in the tunnelling spectra near zero bias, consistent with a trivial superconductor. However, as the magnetic field increases, the tunnelling conductance develops a zero-bias peak, which persists over a range of phase differences that expands systematically with increasing magnetic field. Our observations are consistent with theoretical predictions for this system and with full quantum mechanical numerical simulations performed on model systems with similar dimensions and parameters. Further, we study theoretically quantum wells with an arbitrary combination of Rashba and Dresselhaus spin-orbit couplings and show that one can use Dresselhaus coupling as an extra knob to modulate topological superconductivity [2]. Our work establishes phase controlled Josephson junctions as a promising platform for realizing topological superconductivity and for creating and manipulating Majorana modes.

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Correlated states in flat-band systems and topological properties of surface steps in the SnTe material class

Timo Hyart

International Research Centre MagTop, Institute of Physics, Polish Academy of Sciences, Aleja Lotnikow 32/46, PL-02668 Warsaw, Poland

The quenched kinetic energy in the flat-band systems increases the importance of interactions and leads to superconductivity and other correlated states. I will discuss examples of symmetry-broken states in flat-band systems starting from the best understood quantum Hall ferromagnets and exciton condensates [1] and continuing with more complicated quantum Hall systems [2] and moiré superlattices [3] which are characterized by competition between different order parameters [4]. I will emphasize that in contrast to the systems where the Fermi energy is the largest energy scale, the properties of the flat-band systems are determined by the whole band, including effects originating from the quantum metric of the Bloch wavefunctions [3,5]. Finally, I will discuss the topological properties of the flat bands appearing at the surface atomic steps in the SnTe material class [6].

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Dynamic enhancement of pairing correlations

C. Kollath[1]
[1]PI, University of Bonn, Nussallee14-16, 53113 Bonn,

Quantum matter with superconducting properties which have their origin in the pairing of the fermionic constituents have been intensively studied over many decades. However, the dynamic properties of this quantum matter and the dynamic enhancement of pairing correlations has only become of enormous interest with the experimental advances to control and probe the system properties on the relevant fermionic time-scales. In solid state experiments this is done by pump and probe experiments and in cold atomic gases by an direct access on many system parameters. In this talk I will discuss theoretical proposals how pairing properties can be enhanced in such system dynamically.

Superfluidity far from equilibrium

Piotr Magierski[1,2]

[1]*Warsaw University of Technology, Warsaw, Poland*
[2]*University of Washington, Seattle, U.S.A.*

Superfluidity and superconductivity are remarkable manifestations of quantum coherence at a macroscopic scale. The existence of superfluidity has been experimentally confirmed in many condensed matter systems, in 3He and 4He liquids, in nuclear systems including nuclei and neutron stars, in both fermionic and bosonic cold atoms in traps, and it is also predicted to show up in dense quark matter. The interplay between spin-polarization and superfluidity gives rise to fascinating phenomena manifested in Josephson-pi junction or in exotic phases like FFLO or Sarma (interior gap) phase, which involve nontrivial behavior of the order parameter.

I will present certain aspects of superfluidity in nonequilibrium conditions, which originate from dynamics of the order parameter both in unpolarized and spin-imbalanced systems. The examples of phenomena occurring in cold atomic systems, atomic nuclei and neutron stars will be presented.

In particular, I will discuss certain properties related to the structure and dynamics of quantum vortices as well as applications to modelling of neutron stars. I will also explore the role of pairing dynamics in nuclear reactions. Finally, the possibility of creation of stable, spin-polarized droplets (*ferrons*) in superfluid cold atomic systems will be considered.

Topological superconductivity and Majorana modes in one-dimensional systems

M. M. Maśka[1] **and T. Domański**[2]

[1]University of Silesia, Katowice, Poland
[2] Marie Curie-Sklodowska University, Lublin, Poland

Majorana fermions (particles that are their own anti-particles) have been proposed in 1937, but thus far they remain unobserved in the realm of elementary particles. Recently, the search has turned to condensed matter systems in which they can be constructed out of electron and hole excitations. They behave as anyons following non-Abelian braiding statistics, what makes them promising candidates for building blocks of fault-tolerant topological quantum computers.
The most promising platforms for realizing topological superconductivity with Majorana modes are one-dimensional systems (chains, nanowires) deposited on conventional superconductors. In these systems topological states can be created within the framework of two different scenarios. In the first one a nanowire has strong Rashba spin-orbit coupling and is placed in external magnetic field. In the second scenario a metallic chain of magnetic adatoms is used. As a result of the interaction between the spin of itinerant electrons and the localized moments a helical magnetic structure is formed. In both cases the proximity-induced superconductivity can become topologically nontrivial and the bulk-edge correspondence manifests in formation of Majorana edge states. We show how these systems enter the topological regime when model parameters are tuned. For the Rashba nanowire we study the role of disorder, which - despite the topological protection - can destroy the Majorana states. In the case of the magnetic chain we study thermal fluctuations which also can play destructive role limiting the temperature up to which Majorana states can exist.

Spin excitations and charge density waves in high-T_c superconducting cuprates

M. Minola[1]

[1]*Max Planck Institute for Solid State Research, Stuttgart, Germany*

High-T_c superconduting cuprates are characterized by a complex phase diagram encompassing different phases and decorated with a number of collective ordering phenomena and associated forms of collective fluctuations. Among these, antiferromagnetic spin fluctuations have been proposed to mediate the pairing, whereas incommensurate charge density waves (CDW) have been identified as the leading competitor of high-temperature superconductivity in all major families of layered copper oxides [1].

Resonant Inelastic X-ray Scattering (RIXS) is a powerful tool to measure collective excitations of strongly correlated systems and it has allowed a remarkable series of scientific achievements over the last decade, including, in particular, the first direct observation of both high-energy spin excitations [2,3] and CDW [4,5] in high-T_c cuprates. RIXS is in fact capable of mapping out both elastic scattering and inelastic dispersive excitations in a wide region of the reciprocal space and with unprecedented sensitivity, which allows also the study of small single crystals or ultrathin layers of material down to a few unit cells [6].

In this talk I will present an overview of several RIXS measurements (featuring the pioneering use of the analysis of the scattered photon polarization and of detuned incoming photon energy [7,8]) aimed at drawing a complete picture of the evolution of spin excitations [2,3,6-9] and CDW [4,5,10-12] across the phase diagram of cuprates as a function of different parameters (doping, temperature, strain, dimensionality) and I will discuss implications for the theoretical description of these systems.

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Time Crystals

Krzysztof Sacha

Jagiellonian University in Krakow
Lojasiewicza 11, Krakow, Poland

We show that periodically driven ultra-cold atoms can spontaneously self-organize in time, in a way similar that condensed matter systems do, forming:
1. discrete time crystals [1,2],
2. discrete time quasi-crystals [3],
3. fractional time crystals [4].

Moreover, we show that periodically driven ultra-cold atoms are able to reveal condensed matter behavior in the time dimension like:
1. Anderson (or many-body) localization in time due to the presence of disorder in time [5-7],
2. topological time crystals [8],
3. time crystals with exotic effective long range interactions [9],
4. time crystals with properties of 2D or 3D space crystals [9].

These time crystal phenomena are illustrated with ultra-cold atoms bouncing on an oscillating atom mirror [10]. However, they can be realized in any periodically and resonantly driven system unless it does not correspond to a driven harmonic oscillator.

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Dirac fermions and topological superconductivity in layered quantum materials

M. Samsel-Czekała, M.J. Winiarski and P. Ruszała

Institute of Low Temperature and Structure Research, Polish Academy of Sciences, Okólna 2, 50-422 Wrocław, Poland

Searching for topological superconductivity (TSC) amidst unconventional superconductors and Dirac quantum materials has recently become a promising and rapidly developing field, see e.g. [1-5]. The lecture provides an overview of non-trivial electronic structures, calculated *ab initio* and confirmed by e.g. angle-resolved photoemission spectroscopy (ARPES) measurements, and also a discussion on the possibility of an experimental realization of TSC in selected iron-based, heavy-fermion and other layered or 2D systems, adopting different crystal symmetries.

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Nematic superconductivity in doped topological insulators

Jörg Schmalian[1]

[1]*Institute for Theory of Condensed Matter and Institute for Solid State Physics, Karlsruhe Institute of Technology, Karlsruhe, Germany*

If the topological insulator Bi_2Se_3 is doped with electrons, superconductivity with $T_c \approx 3-4K$ emerges for a low density of carriers ($n \approx 10^{20} cm^{-3}$) and with a small ratio of the superconducting coherence length and Fermi wavelength: $\xi/\lambda_F \approx 2\,4$. These values make fluctuations of the superconducting order parameter increasingly important, to the extend that the T_c-value is surprisingly large. Strong spin-orbit interaction led to the proposal of an odd-parity pairing state. This begs the question of the nature of the transition in an unconventional superconductor with strong pairing fluctuations. We show that for a multi-component order parameter, these fluctuations give rise to a nematic phase at $T_{nem}>T_c$. Below Tc several experiments demonstrated a rotational symmetry breaking where the Cooper pair wave function is locked to the lattice. Our theory shows that this rotational symmetry breaking, as vestige of the superconducting state, already occurs above T_c. The nematic phase is characterized by vanishing off-diagonal long-range order, yet with anisotropic superconducting fluctuations. It can be identified through direction-dependent para-conductivity, lattice softening, and an enhanced Raman response in the E_g symmetry channel. In addition, nematic order partially avoids the usual fluctuation suppression of T_c.

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Topological superconductors: Classification, properties, and examples

Andreas P. Schnyder[1]

[1]*Max-Planck-Institut für Festkörperforschung, Heisenbergstraasse 1, D-70569 Stuttgart, Germany*

In this talk I will review the topological classification of superconductors, discuss their properties, and present a number or examples. I will give a pedagogical introduction into the field and then discuss the topological classification of superconductors in terms of time-reversal and particle-hole symmetry [1,2]. The invariants that characterize the topology of the Bogoliubov band structure will be discussed. By the bulk-boundary correspondence, these invariants lead to zero-energy in-gap surface states. Some candidate materials for topological superconductivity will be reviewed, including Sr2RuO4 and the (locally) non-centrosymmetric superconductors CePt3Si and SrPtAs [3,4].

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Emergence of pairing in systems of several particles

T. Sowiński[1]

[1] *Institute of Physics, Polish Academy of Sciences, Warsaw, Poland*

Existence of the superconductivity was one of the most challenging phenomena for a theoretical explanation in the history of physics. Luminous observation of L. Cooper [1] that effective attraction between opposite-spin fermions may lead to the spontaneous formation of correlated two-particle states above the Fermi see has opened after 50 years a route towards the proper theory – The Theory of Superconductivity by Bardeen, Copper, and Schrieffer [2]. In my talk, taking as a workhorse a very simplified one-dimensional model of a few particles, I will try to expose how the collective cooperation of attractively interacting fermions leads to the emergence of Cooper pairs in the system [3,4]. I will also shed some light on how the picture is modified when the system is imbalanced [5,6,7] or different mass-fermions are considered [8]. Although the model seems to be highly oversimplified, fortunately it can be directly applied to the state-of-the-art experiments in the field of ultra-cold atoms [9,10]. Therefore, I will also display some comparison of experimental data with theoretical predictions.

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Electron Localization in a Mott Insulator: Theory *versus* Cold Atom Simulations

K. Wohlfeld[1]

[1]*Faculty of Physics, University of Warsaw, Pasteura 5, PL-02093 Warsaw, Poland*

We study the problem of a single hole in a Neel antiferromagnet and, using the magnon expansion and analytical methods, calculate the expansion coefficients of its wave function in the magnon basis [1]. In a 1D case, i.e., once the string potential is absent, the hole is "weakly" localized in a potential well, and the magnon coefficients decay exponentially. This behavior is in sharp contrast to the 2D case for which the hole is subject to a string potential and is "strongly" localized with the coefficients decaying superexponentially. Thus, the superexponential decay of the wave function coefficients is a fingerprint of the existence of strings in doped antiferromagnets that can be recognized in the numerical or cold atom simulations of the 2D doped Hubbard model [2].

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Abstracts of Posters

(in alphabetical order)

The magnetocaloric effect in a Nano -system built on a Dendrimer structure: Monte Carlo Study

M. Arejdal[1,2,*], A. Abbassi [1,2]

[1] Material Physics and Energy Laboratory,Université Privée de Marrakech 13 Km , route d'Amezmiz CP : 42312 - Marrakech – Marocco.

[2] Laboratory of Condensed Matter and Interdisciplinary Sciences (LaMCScI), Faculty of Sciences, Mohammed V University, Av. Ibn Batouta,B.P. 1014, Rabat, Morocco.

In this paper, we studied the magnetic properties and the magneto caloric effect of a nano-system built on a hexagonal Dendrimer structure with the moment spin (S=7/2). The magnetic properties and the magneto-caloric effect were determined using Monte Carlo Simulations (MCS) in the framework of the Ising model. The main results attained in this present paper are as follows: The transition temperature, which was deduced through studying the magnetization, the susceptibility, specific heat and Binder's fourth-order cumulate of the order parameter also the effect of both the exchange coupling and the temperature on hysteresis loop behaviors which was treated. In addition to these results, the effect magneto caloric were deduced through studying the magnetic entropy change, adiabatic temperature change and the relative cooling power for the different external magnetic field as a. concluding part of the research paper.

Keywords: Nano-system; Dendrimer system; Monte Carlo simulations; magnetic properties; Hysteresis loop; the magneto-caloric effect.

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*) Corresponding author: arejdal.achdad@gmail.com

Phase-dependent heat transport in Josephson junctions with p-wave superconductors and superfluids[1]

Alexander G. Bauer and Björn Sothmann

Theoretische Physik, Universität Duisburg-Essen and CENIDE, D-47048 Duisburg, Germany

We investigate phase-coherent thermal transport in Josephson junctions[2] made from unconventional superconductors or superfluids. The thermal conductance is evaluated for one- and twodimensional junctions within the Bogoliubov-de Gennes formalism. We analyze three different scenarios of junctions between two triplet superconductors with (i) helical pairing, (ii) unitary chiral and (iii) nonunitary chiral pairing. We find that the phase-dependent thermal conductance allows us to distinguish the different pairings and provides insight into the formation of topologically nontrivial Andreev bound states in the junction.

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Magnon Transport with Periodically Driven Barriers

A. Becker, S. Fazzini, C. Dauer, A. Pelster and S. Eggert

Physics Department and Research Center OPTIMAS,
Technische Universität Kaiserslautern, Kaiserslautern, Germany

Periodic driving is a proper tool of quantum mechanics to obtain exciting effects, unrealisable in the static case.

Furthermore, experimentalists consider the behaviour of magnons in the magnetic insulator YIG in recent years [1]. The reason for this is a new research area called Magnonics. It provides a possible architecture for a future supercomputer [2].

This poster deals with the properties of those magnons under periodic driven magnetic fields. We distinguish two different cases:

Initially, global driving is analysed. Regarding the dispersion relation of the static case, the associated derivation is considered to be time-dependent. From this, it follows the result that periodic driving leads to a shift of the quasienergy.

Additionally, the case of local driving is reflected. In this instance, it is necessary to estimate the transmission coefficient of the periodically modulated barrier. Thus, similarities to a tight binding chain turn up [3], which occur by a so-called quantum- resonance-catastrophe for the transmission through the barrier depending on the driving frequency.

The tool to solve the associated time-dependent Hamiltonians is Floquet theory. Due to this, it is possible to map the time-dependent equations to static eigenvalue problems.

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Topological properties of multilayers and surface steps in the SnTe material class

Wojciech Brzezicki[1], Marcin Wysokiński[1] and Timo Hyart[1]

[1]International Research Centre MagTop, Institute of Physics, Polish Academy of Sciences, Aleja Lotnikow 32/46, PL-02668 Warsaw, Poland

Surfaces of multilayer semiconductors typically have regions of flat terraces separated by atom-high steps. We investigate the properties of the low-energy states appearing at such atomic steps in Sn(Pb)Te(Se) [1]. We identify the important approximate symmetries and use them to construct the topological invariants. We calculate the dependence of mirror- and spin-resolved Chern numbers on the number of layers and show that the step states appear when these invariants are different on the two sides of the step. Since the density of states is large at the step the system is susceptible to different types of instabilities, and we consider an easy-axis magnetization as one realistic possibility. We show that magnetic domain walls support low-energy bound states because the regions with opposite magnetization are topologically distinct in the presence of nonsymmorphic chiral and mirror symmetries, providing a possible explanation for the zero-bias conductance peak observed in the recent experiment [2].

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Optimized entanglement witnesses - entanglement detection in Cooper pair splitters without magnetic detectors efficiency limit.

P. Busz, **D. Tomaszewski and J. Martinek**

Institute of Molecular Physics, Polish Academy of Science, Smoluchowskiego 17, 60-179 Poznan, Poland

Most of the proposed entanglement detection methods of spatially separated electrons of Cooper pairs require the use of ferromagnetic electrodes with high spin polarization and difficult experimental techniques. Therefore, we show new detection models [1-3], based on the ferromagnetic detectors attached to the Cooper pairs splitters [4-6], using entanglement witness approach. The presented models are based on electric current cross correlation measurements and, simpler to perform, DC current measurements. An advantage of the analyzed detection models over those proposed so far is their easier experimental implementation due to the use of DC current measurements and the reduced system requirements, e.g., in terms of detector efficiency. By proper optimization we demonstrate that under certain experimental conditions entanglement detection is possible even with magnetic detectors of any efficiency greater than zero. We determine also the minimal number of current cross correlation measurements necessary for correct detection of quantum entanglement of a Cooper pair in the singlet state, for any detectors efficiency. The proposed methods can be used for experimental detection of quantum entanglement of spatially separated electrons of Cooper pairs, and will allow for further progress of the electronic technology of quantum computing.

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Interference pattern of Colliding Composite-Boson Condensates

A. Chenu[1,2], S.-Y. Shiau[3] and M. Combescot[4]

[1] Donostia International Physics Center, San Sebastian, Spain
[2] Ikerbasque, Basque Foundation for Science, Bilbao, Spain
[3] Physics Division, National Center for Theoretical Sciences, Taiwan
[4] Sorbonne University, CNRS, Institut des NanoSciences de Paris, Paris, France

All particles consisting of an even number of fermions are boson-like, which bears a strong consequence: they must undergo Bose-Einstein condensation.

We predict [1] that, compared to elementary bosons, the interference pattern of two colliding BEC made of atomic dimers must have additional high frequency modes. These new modes being many-body in essence, previous experiments performed with rather dilute condensates only showed interferences ruled by the BECs' momentum difference, a result obtained taking atoms as elementary bosons. The higher frequency modes we predict result from fermion exchanges between condensates and thus constitute a striking signature of the dimer composite nature. We analytically derive the spatial correlation functions and use Shiva diagrams, specific to coboson many-body effects, to identify the physical origin of these modes and determine their experimental observation, using optical lattices. A dimer granularity appears because of Pauli blocking.

We anticipate cold-atom systems to provide a novel, fully controllable playground to investigate further the unique many-body effects that result from dimensionless fermion exchanges. Recent optical lattices already reach densities high enough for these to be observable, including the signature predicted here.

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Low-temperature phases in the two-band Hubbard model realized with ultracold atomic four-component mixtures in optical lattices

A. Cichy[1,2], A. Sotnikov[3] and Y. Zambrano[1]

[1] Adam Mickiewicz University, Poznań, Poland
[2] Johannes-Gutenberg-Universitaet, Mainz, Germany
[3] Kharkiv Institute of Physics and Technology, Kharkiv, Ukraine

We study ultracold quantum gases of alkaline-earth-like atoms loaded into three dimensional optical lattice.
In particular, we focus on the fermionic mixture of ytterbium-173 atoms due to their unique properties, in particular, low-lying metastable excited (*e*) electronic state, decoupling of the nuclear spin from the electronic degrees of freedom, and different AC-polarizabilities of the ground- (*g*-) and *e*-states.
This allows to realize and investigate in detail strongly-correlated many-body physics and emerging low-temperature phases in these mixtures.
We focus on the recent realization of the two-band Hubbard model [1,2] and study potential long-rang ordered states.
The theoretical analysis is performed in the region of applicability of the tight-binding approximation at different lattice depths and different fillings in the *g*- and *e*-bands.
By means of dynamical mean-field theory, we obtain dependencies for relevant physical observables, in particular, magnetization, particle density in each band, double occupancy, and compressibility. We construct the phase diagram at finite temeperature and various latice depths.

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Superconductivity in locally non-centrosymmetric heavy-fermion materials: Influence of Rashba spin orbit interaction and correlation

Lukas Debbeler[1] and Gertrud Zwicknagl[1]

[1]Institute of Mathematical Physics, Mendelssohnstraße 3, 38106 Braunschweig, Germany

Email: l.debbeler@tu-braunschweig.de

In recent years, the manufacturing of controlled ultra-thin superconducting films has made impressive progress. Important examples are monoatomic or monomolecular layers on a substrate, superconducting layers in a superlattice, or superconducting interfaces and surfaces. These systems have in common the absence of inversion symmetry and hence the presence of Rashba spin-orbit interaction. The latter can be modified to some extent by varying the thickness, the number of layers, or by applying an electric voltage. The subtle interplay of spin imbalance created by a magnetic field and the Rashba spin-orbit interaction gives rise to novel phenomena in quasi-2D superconductors which, in turn, could provide new functionalities. I discuss the results of a microscopic theory of superconducting films with population imbalance which are subject to Rashba spin- orbit interaction. Thereby I generalize previous calculations for isotropic s-wave order parameters [1] to the case of d-wave superconductors. The full range from small to large spin-orbit interaction is covered.

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Dynamics of a few interacting bosons escaping from an open well

J. Dobrzyniecki[1] and **T. Sowiński[1]**

[1]*Institute of Physics of the Polish Academy of Sciences,*
Al. Lotników 32/46, 02-668 Warsaw, Poland

The dynamics of a few ultra-cold bosons tunneling from a one-dimensional potential well into an open space is studied. In such a system several decay channels can be identified, each corresponding to a different number of bosons escaping simultaneously. We show that as the inter-particle interaction strength is changed, the system undergoes transitions between distinct regimes, characterized by the dominance of different decay channels. These transitions are reflected in the behavior of the decay rate of the system (see example for two bosons in Fig. 1). By means of a simple theoretical description, we show that the transitions occur at the points where a new decay channel becomes energetically viable.

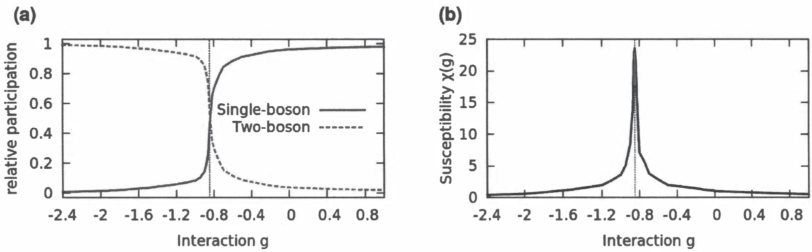

FIG. 1. (a) The relative participation of single-particle tunneling and pair tunneling in the dynamics of a two-boson system escaping from an open well, depending on the interaction strength. Two distinct regimes can be identified, corresponding to the dominance of either single-boson or pair tunneling. The transition between the two regimes occurs near $g \approx -0.9$. (b) The susceptibility $\chi(g) = d(\log \gamma)/dg$ of the decay rate $\gamma(g)$ of the escaping system. A distinct peak appears in $\chi(g)$ for the interaction strength $g \approx -0.9$ that corresponds to the transition.

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Non-equilibrium Higgs excitations in the presence of impurity scattering

P. Froese[1], **L. Schwarz**[1], **and D. Manske**[1]

[1]*Max-Planck-Institut für Festkörperforschung, Heisenbergstraße 1, D-70569 Stuttgart, Germany*

In superconductors, spontaneous U(1) symmetry breaking occurs at the transition to the superconducting state, which is reflected by a Mexican hat shaped free energy potential. Collective modes, corresponding to oscillations of the order parameter, arise as a result of this symmetry breaking. In particular, amplitude oscillations are known as the Higgs mode, in analogy to high energy physics. This mode is difficult to detect because it does not couple linearly to light. However, it was demonstrated that it can be excited and measured experimentally with ultrafast Terahertz spectroscopy. As this technique is relatively new, the exact excitation processes are not yet fully understood. In recent years, it was realized that it is necessary to distinguish whether the superconductor is in the clean or dirty limit. In the latter case, impurity scattering is non-negligible and enhances the Higgs excitation [1]. As Higgs oscillations in non-equilibrium and their spectroscopy are a promising new tool for identifying gap symmetries of unconventional superconductors [2], a thorough understanding of the relevant processes is important. Here, I aim to understand the excitation process in the presence of impurity scattering in more detail, allowing for clearer interpretations of experimental results and enabling better designs for future experiments.

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Symmetry-based indicators for topological Bogoliubov-de Gennes Hamiltonians

M. Geier[1], L. Trifunovic[2,3] and P. Brouwer[1]

[1]Dahlem Center for Complex Quantum Systems and Physics Department, Freie Universität Berlin, Arnimallee 14, 14195 Berlin, Germany
[2] RIKEN Center for Emergent Matter Science, Wako, Saitama 351-0198, Japan
[3]Department of Physics, University of Zurich, Winterthurerstrasse 190, 8057 Zurich, Switzerland

We develop a systematic approach for constructing symmetry-based indicators of a topological classification for superconducting systems. The topological invariants constructed in this work form a complete set of symmetry-based indicators that can be computed from knowledge of the Bogoliubov-de Gennes Hamiltonian on high-symmetry points in Brillouin zone. After excluding topological invariants corresponding to the phases without boundary signatures, we arrive at natural generalization of symmetry-based indicators [1] to Hamiltonians of Bogoliubov-de Gennes type.

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Nodal topological superconductivity in magnetic superstructures

Szczepan Głodzik[1] and Teemu Ojanen[2]

[1]Institute of Physics, M. Curie-Skłodowska University, Lublin, Poland
[2]Computational Physics Laboratory, Tampere University, Tampere, Finland
E-mail for corresponding author: *szglodzik@kft.umcs.lublin.pl*

Recent discovery of Ising pairing in superconducting transition metal dichalcogenides (TMDs)[1, 2] inspired enormous acitivity and has led to proposal of nodal topological superconductivity induced by in-plane magnetic field, which exhibits flat Majorana bands manifesting as zero-energy edge states [3, 4, 5]. In light of groundbreaking advanves in fabricating 2d ferromagnets on van der Waals materials[6, 7] we propose a setup in which rather than relying on external fields, the nodal topological phase is obtained by depositing an island of magnetic impurities on top of a TMD. We choose $NbSe_2$ as a particular realization, and discuss how our proposal has several advantages over the magnetic field induced phase.

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Topology in magnetic phases of SmB_6

M. M. Hirschmann[1], **H. Liu[1]**, **G. Khaliullin[1]**, **and A. P. Schnyder[1]**

[1]*Max Planck Institute for Solid State Research, Stuttgart, Germany*

The heavy fermion compound SmB_6 is known to be a topologically nontrivial Kondo insulator [1,2,3]. When pressure is applied, the valence of samarium increases which will give rise to magnetic order leading in turn to a metallic state [4,5].

To address the magnetic and topological properties under pressure, we construct a qualitative tight-binding model incorporating four orbitals and spin-orbit coupling. Using this model, we have obtained the static and dynamic susceptibility which suggests an A-type or G-type antiferromagnetic state as the most likely order. With this in mind we extend the topological analysis of SmB_6 to the candidate magnetic phases as well as a possible high-field ferromagnetic phase. We find several zero- and one-dimensional band crossings and characterize them by their topological invariants, symmetry analysis, and surface states.

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Anomalous Nonlocal Conductance as a Fingerprint of Chiral Majorana Edge States

S. Ikegaya[1], **Y. Asano**[2], **and D.Manske**[1]

[1]*Max-Planck-Institute for Solid State Research, Stuttgart, Germany*
[2]*Hokkaido University, Sapporo, Japan*

During the past two decades, chiral Majorana edge states appearing at the boundary of a spin-triplet chiral *p*-wave superconductor has attracted intensive attention. The perovskite superconductor Sr2RuO4 is the most promising candidate material for spin-triplet chiral *p*-wave superconductors. At present, finding a conclusive signature of chiral Majorana edge states in this compound is an urgent issue in physics of topological phase of matter and that of spin-triplet superconductivity.

In this work, we demonstrate that the chiral nature of Majorana edge states is drastically manifested in nonlocal conductance in a junction consisting of a chiral *p*-wave superconductor and two ferromagnetic leads. The nonlocal conductance in the present junction is insensitive to the distance between the two leads and is sensitive to the chirality of the pair potential. These two drastic features enable us to identify the moving direction of the chiral Majorana edge states in the single experimental setup only by changing the lead wire to which the bias voltage is applied. We propose a smoking-gun experiment to identify the chiral Majorana edge states in the chiral *p*-wave superconductor.

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Quantum simulation of polaron physics with hybrid ion-atom systems

K. Jachymski[1] and **A. Negretti[2]**

[1]Peter Grünberg Institute, Forschungszentrum Jülich, Jülich, Germany
[2] Centre for Optical Quantum Technologies, Hamburg, Germany

Hybrid quantum systems of ions and atoms provide exciting opportunities for quantum chemistry, few-body physics and quantum simulation [1]. Ion chains have an intrinsic phonon structure which is absent in traditional optical lattice setups. This allows for natural realization of an analogue of a solid-state system with tunable properties. Moreover, strong ion-atom interactions naturally provide atom-phonon coupling needed for polaron physics. The prospects of such systems for simulation of different regimes from weak to strong coupling and the possibility of tuning nonlocal phonon-induced interactions in order to achieve exotic states will be discussed [2].

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Exact analytic solution of the extended Falicov-Kimball model in infinite dimensions

K.J. Kapcia[1] and **R. Lemanski**[2]

[1] Institute of Nuclear Physics, Polish Academy of Sciences, Kraków, Poland
[2] Institute of Low Temperature and Structure Research, PAS, Wrocław, Poland

The Falicov-Kimball model [1] is a simplified version of the Hubbard model, where only electrons with, e.g., spin down are itinerant and the other are localized. In this presentation, we discuss results for the extended Falicov-Kimball model at half-filling on the Bethe lattice in the limit of large dimensions derived within the dynamical mean field theory formalism [2-6], which is a rigorous approach in this limit. The on-site and the intersite density-density interactions between particles occupying neighboring sites are included in the Hamiltonian [4-6]. We determined the exact phase diagrams of the model both in the ground state [5] and at finite temperatures [6]. Using analytical formulas and having calculated the temperature dependent density of states we study thermodynamic properties of the system starting from its free energy and then we construct the phase diagrams in the variables temperatures and onsite interactions for a few values of intersite repulsion [5,6]. Our calculations give that inclusion of the intersite coupling causes the finite temperature phase diagrams to become asymmetric with respect to a change of sign of onsite interaction [5,6]. On these phase diagrams we detected stability regions of eight different kinds of ordered phases, where both charge-order and antiferromagnetism coexists (five of them are insulating and three are conducting) and three different nonordered phases (two of them are insulating and one is conducting) [6]. Moreover, both continuous and discontinuous transitions between various phases were found.

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Nematicity in $LaFe_{1-x}Co_xAsO$ and AFe_2As_2 single crystals studied by thermal expansion and shear-modulus measurements

S. Sauerland[1], X. Hong[2], L. Wang[1], F. Scaravaggi[2,3], A. Wolter[2], R. Kappenberger[2], S. Aswartham[2], S. Wurmehl[2], S. Sykora[2], F. Caglieris[2], C. Hess[2], B. Büchner[2,3], R. Klingeler[1]

[1]*Kirchhoff Institute for Physics, Heidelberg University, Germany*
[2]*Leibniz Institute for Solid State and Materials Research IFW, Dresden, Germany*
[3]*Institute for Solid State Physics, TU Dresden, Germany*

We report shear modulus and thermal expansion measurements on La(Fe,Co)AsO single crystals and study the critical nematic response. The results are compared with corresponding data on $BaFe_2As_2$. Anomalies in the thermal expansion coefficient at the structural and magnetic transition temperatures, T_S and T_N, evidence coupling of spin and structure. The evolution of the orthorhombic distortion is illustrated by length changes of the *a*- and *b*-axes and the experimentally determined orthorhombicity δ. Decrease of δ upon Co-doping is discussed. Softening of the shear modulus towards the structural phase transition is observed by means of the three-point-bending technique. The data indicate Curie-Weiss-like divergence of the nematic susceptibilities and confirm electronic origin of nematicity in LaFeAsO. The characteristic energy λ^2/aC_0 of the coupling between the lattice and the electronic degrees of freedom is deduced to ~30 K. Comparison with corresponding measurements on $BaFe_2As_2$ single crystals reveals similar temperature dependencies of the shear modulus. While in BaFe2As2 the uncoupled nematicity diverges as the nematic susceptibility obtained from elastoresistivity studies, Weiss temperatures of both quantities are significantly different in LaFeAsO.

Motion of a single hole in Ca_2RuO_4

A. Kłosiński[1], **D. Efremov[2], J. van den Brink[2], and K.Wohlfeld[1]**

[1]Faculty of Physics, University of Warsaw, Warsaw, Poland
[2]Institute for Theoretical Solid State Physics, IFW Dresden, Dresden, Germany

In recent years there has been a growing interest in the understanding of the correlated physics of Ca_2RuO_4 , fuelled by the fundamental importance of the spin-orbit interaction in this compound on the one hand and by its close resemblance to the well-studied copper oxides on the other. In order to understand the latter, we focus here on the propagation of a single hole introduced into the Mott insulating ground state of Ca_2RuO_4 and verify its quantitative as well as qualitative differences w.r.t. the cuprates. To this end we introduce an effective multiorbital t-J-like model which we then solve using the linear spin wave theory and self-consistent Born approximation. We obtain the spectral function for fermionic spinless holes whose most striking feature is its quasi-1D character.

Majorana Bound State leakage in nanoscopic structures.

Aksel Kobiałka[1,*], Andrzej Ptok[2], and Tadeusz Domański[1]

[1]Institute of Physics, M. Curie-Skłodowska University, pl. M. Skłodowskiej-Curie 1, 20-031 Lublin, Poland
[2]Institute of Nuclear Physics, Polish Academy of Sciences, ul. W. E. Radzikowskiego 152, 31-342 Kraków, Poland
[*]E–mail:akob@kft.umcs.lublin.pl

In condensed matter physics, in order for Majorana Bound States to emerge, we need interaction between superconductivity, spin-orbit coupling and magnetic field in some nanoscopic system [1]. In finite 1D Rasha nanowires those states are manifested by emergence of a pair of zero-energy Majorana bound states [2]. On the other hand, in 2D systems spin currents contributed by the edge states might appear. If we are to conjoin these two ingredients a vast, new possibilities for probing the behaviour of Majorana Bound States present itself. Therefore, we investigate properties of such bound states in low dimensional hybrid structures [3] consisting of quantum dot (0D), 1D Rashba nanowire and bounded 2D surfaces, by means of local density of states as well as theoretical analogue of spin polarised tunnelling technique [4].

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Spin-relaxation and Yu-Shiba-Rusinov states in Superconducting Graphene

D. Kochan[1] and J. Fabian[1]

[1]*Institute of Theoretical Physics, University of Regensburg, Germany*

2D materials in the proximity of super-/semi-conductor are expected to host a wide spectrum of different phenomena. In my poster I will focus on spin-relaxation in graphene proximitized by an s-wave superconductor [1]. Adatom impurities can affect spin-relaxation via locally enhanced spin-orbit coupling (SOC) and local magnetic moments. I will discuss their impact on quasiparticle spin-relaxation with an attempt to disentangle contributions from the local SOC and local magnetic moments. Moreover, I will analyze the stability of the induced local magnetic moments and the emergence of Yu-Shiba-Rusinov (YSR) bound states in such proximity induced superconducting systems.

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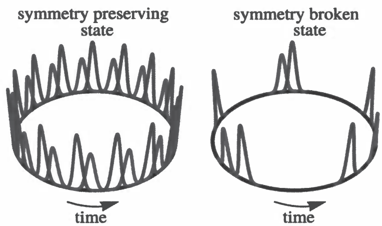
Discrete time quasicrystals

K. Giergiel[1], A. Kuroś[1] and K. Sacha[1,2]

[1]Instytut Fizyki imienia Mariana Smoluchowskiego, Uniwersytet Jagielloński, ulica Profesora Stanisława Łojasiewicza 11, PL-30-348 Kraków, Poland
[2]Mark Kac Complex Systems Research Center, Uniwersytet Jagielloński, ulica Profesora Stanisława Łojasiewicza 11, PL-30-348 Kraków, Poland

Between space crystals and amorphous materials there exists a third class of aperiodic structures which lack translational symmetry but reveal long-range order. They are dubbed quasicrystals and their formation, similar to the formation of space crystals, is related to spontaneous breaking of translational symmetry of underlying Hamiltonians. Recently, it has been shown that spontaneous formation of a crystalline structure is also possible in the time domain [1], which has been already realized experimentally [2].



Here, we investigate spontaneous emergence of discrete time quasicrystal. We consider a quantum many-body system which is driven by a periodically oscillating force and we show that interactions between particles result in spontaneous self-reorganization of its motion. We analyze how a quasicrystal structure forms due to spontaneous breaking of discrete time translation symmetry of a many-body time-periodic Hamiltonian [3].

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Non-equilibrium optical conductivity for the antiferromagnetic single-band Hubbard model: Time-dependent Gutzwiller analysis

C. Martens[1], J. Bünemann[2] and G. Seibold[1]

[1] *BTU Cottbus – Senftenberg, Institute of Physics, 03046 Cottbus, Germany*
[2] *TU Dortmund, Faculty of Physics, 44227 Dortmund, Germany*

Based on the time-dependent Gutzwiller approximation (TDGA) for the Hubbard model we analyze the optical conductivity $\sigma(\omega)$ in an out-of equilibrium situation for underlying antiferromagnetic ground states. The equilibrium state is perturbed by an instant quench of the local Coulomb interaction parameter U or by an electric field $E(t)$. We analyze various shapes for the applied electric field and discuss our results with regard to the optical conductivity determination from pump-probe experiments. In the linear response regime, RPA corrections to the TDGA vanish, so that the optical response is determined by the bare current-current correlation function. In contrast, far from the linear response regime the out-of equilibrium case shows a more interesting behavior and in particular mixes double occupancy fluctuations to the current response.

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Fractional time crystals

Paweł Matus[1] **and Krzysztof Sacha**[1,2]

[1] *Instytut Fizyki imienia Mariana Smoluchowskiego, Uniwersytet Jagielloński, ulica Profesora Stanisława Łojasiewicza 11, PL-30-348 Kraków, Poland*
[2] *Mark Kac Complex Systems Research Center, Uniwersytet Jagielloński, ulica Profesora Stanisława Łojasiewicza 11, PL-30-348 Kraków, Poland*

Ordinary crystals are many-body systems which form periodic structures in the ground state, thus breaking the translational symmetry of the hamiltonian. Time crystals behave in a similar way, but in the time domain. Recent years have seen a discovery of a range of periodically driven systems, where interactions between the particles make the system evolve with a multiple of the driving period, this way breaking the discrete time symmetry of the hamiltonian [1]. So far, however, attention has been paid only to situations, where the new period of motion is an integer multiple of the driving period.
In this poster, we present a study of a system consisting of ultracold atoms bouncing on a vibrating atomic mirror, and we show that under appropriate conditions this system undergoes a time-translational symmetry breaking such, that the resulting period of particles' motion is a fractional multiple (eg. 3:2) of the driving period [2]. This novel behaviour is dubbed a 'fractional time crystal'.

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Towards studies of the BEC-BCS crossover in a disordered environment

Benjamin Nagler[1,2], **Sian Barbosa**[1], **Jennifer Koch**[1] **and Artur Widera**[1]

[1]*Department of Physics and Research Center OPTIMAS, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany*

[2] *Graduate School Materials Science in Mainz, Gottlieb-Daimler-Straße 47, 67663 Kaiserslautern, Germany*

Ultracold atoms have proven to be an invaluable tool for the precise investigation of quantum systems that are difficult to access otherwise. One example are particles in disordered potentials which exhibit compelling phenomena like Anderson [1] or many-body localization [2] and the Bose glass [3].

In order to examine such systems, we have set up a new experiment in which a degenerate Fermi gas of lithium atoms is immersed into a disordered optical speckle potential. By addressing a magnetic Feshbach resonance, the atomic interaction parameter can be tuned to arbitrary values, which allows us to access both bosonic and fermionic superfluidity. One major question we will address is how disorder affects pairing in the various regimes of the crossover.

Here I present first results on the impact of disorder onto the shape of a molecular Bose-Einstein condensate confined in a harmonic trap. In addition, I introduce a novel method to characterize the potential strength of optical speckle.

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Dynamical properties of a few mass-imbalanced ultra-cold fermions confined in a double-well potential

Dillip K. Nandy and Tomasz Sowinski

Institute of Physics, Polish Academy of Sciences, Aleja Lotnikow 32/46, PL-02668 Warsaw, Poland

A comprehensive analysis of the exact unitary dynamics of two-component mass-imbalanced fermions in a one-dimensional double-well potential is accomplished by considering the total number of particles up to six. The simultaneous effect of mass imbalance between the flavors and their mutual interaction on the particle dynamics is scrutinized through exact diagonalization. In particular, we investigate the occupation dynamics of such mass-imbalanced system with two distinct initially prepared configurations: spatially separated two-components and maximally one atom paired up scenario. The minimal system (system with two-particle) show some regularity in tunneling behavior with respect to the interaction strength. Subsequently when particles are added to the minimal system, the dynamics become more robust due to the cumulative effect of mass imbalance and interaction. In the spatially separated scenario, the dynamics leads to highly suppressed tunneling behavior for certain values of interactions parameter, that can only be addressed within the many-body picture. On the other hand the paired up initial state show finite stable dynamical character up to reasonable range of interaction respecting the Pauli exclusion principle. Further, by looking at the dynamics of the single-particle entanglement entropy, we notice, although the dynamics is highly suppressed, the inter-particle correlation show significant value at these interaction points.

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Topological states in 1D SnTe nanowires

N.M.Nguyen[1] **W.Brzezicki**[1] **and T.Hyart**[1]

[1]*International Research Centre MagTop, Institute of Physics, Polish Academy of Sciences, aleja Lotnikow 32/46, PL-02668 Warsaw, Poland*

Since it was theoretically predicted that SnTe as topological crystalline insulator[1], the Tin telluride has attracted worldwide interest. Tin telluride topological crystalline insulator nanowires have been grown by molecular beam epitaxy on graphene/SiC substrates[4]. Futher, Non-symmorrphic chiral symmetry was found to be important in the 1D-like version of the SnTe[2]. Recently the 1D nanowires of SnTe has been sythesized and studied and exotic superconductingstate was found[3]. In this works, we analyze the topological properties of the SnTe nanowires grown in the (001) direction in presence of external magnetic field. We show that the in-gap states can emerge due to approximate non-symmorphic chiral symmetry and a Z2 invariant. We present a topological phase diagram as a function of field strength and direction and analyze additional symmetries protecting the end-states. We study the behavior of the in-gap states in presence of a magnetic domain wall separating topologically distinct phases.

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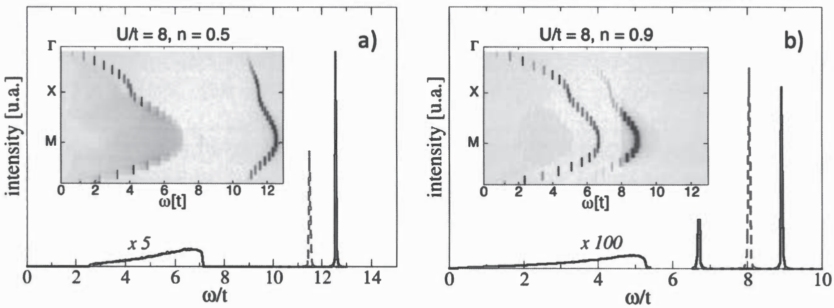
Linear-Response Dynamics from the time-dependent Gutzwiller Approximation

K. Noatschk[1] and G. Seibold[1]

1BTU Cottbus-Senftenberg, Institute of Physics, 03046 Cottbus, Germany

The time dependent Gutzwiller approximation for the Hubbard model is obtained from the Lagrangian equation of motion for the density matrix and variational parameters. Expansion of the resulting equations up to second order in these dynamical variables yields an effective electron-boson problem where the bosons represent fluctuations of the double occupancy [1]. Within this formalism we investigate the charge excitations of the single-band Hubbard model for parameters relevant for cuprate superconducters. We further clarify the connection to related slave-boson calculations where fluctuations are obtained within an expansion around the functi-



onal integral saddle-point.

Fig. 1: Main panels: Imaginary part of the bare (red, dashed) and full (black, solid) double occupancy propagator at momentum q = (π, π) for densities n = 0.5 (a) and n = 0.9 (b). For clarity the low energy part of the full propagator which mixes to the ph-continuum has been scaled as indicated in the panels. The insets report the corresponding imaginary part of the charge susceptibility along the path Γ = (0, 0), X = (π, 0), M = (π, π). On-site repulsion U/t = 8.

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A quantum transport study of the interplay of quantum spin Hall effect and exciton condensation in electron-hole bilayers

T. Paul, V. F. Becerra, M. Płodzień and T. Hyart

International Center for Interfacing Magnetism and Superconductivity with Topological Matter, Institute of Physics, Polish Academy of Sciences, Aleja Lotnikow 32/46, 02668, Warsaw, Poland

Experiments tell us that certain 2D systems like InAs/GaSb, HgTe/CdTe and WTe2 exhibit approximately quantized conductances in short samples which are consistent with the appearance of quantum spin Hall (QSH) effect in these materials. It has also been noted that such materials in the presence of proximity induced superconductivity can host Majorana zero modes, hence making these materials promising for quantum information processing. However, certain aspects of these materials are still not completely understood. In particular, the edge modes in quantum spin Hall insulators are supposed to be protected against backscattering from all perturbations obeying the time-reversal symmetry, but experiments have revealed reasonably short mean free paths which depend only weakly on temperature. A multitude of backscattering mechanisms have been considered as a possible explanation of these observations but currently there is no consensus about the interpretation of this apparent lack of topological protection. It is, therefore, important to study the interplay of topology and interactions to understand the various backscattering mechanisms present. It has been proposed that in band-inverted electron-hole bilayers in the presence of Coulomb interactions there exists phase transitions from a trivial s-wave condensate phase to an insulating phase with spontaneously broken time-reversal symmetry and then finally to a nontrivial QSH phase as a function of the density of electrons and holes[1]. The phase with spontaneously broken time-reversal symmetry is able to justify the observation of the temperature independent mean free path. We study quantum transport in this system on a Corbino disc, which has the advantage of separating the edge and bulk contributions from each other. We show that in this transport geometry clear signatures of the different phases and phase transitions can be observed allowing an experimental confirmation of the theoretically proposed phase diagram.

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Two-body correlations in mass-imbalanced few-body mixtures

D. Pęcak[1] and T. Sowiński[2]

[1]*Faculty of Physics, Warsaw University of Technology, Warsaw, Poland*
[2] *Institute of Physics, Polish Academy of Sciences, Warsaw, Poland*

Ground-state properties of a few attractively interacting ultra-cold atoms of different mass confined in a one-dimensional harmonic trap are studied. The analysis is performed in terms of the noise correlation, which captures the two-particle correlations induced by the mutual interactions. Depending on the mass ratio between the components' atoms, the inter-particle correlations change their properties significantly from a strong pair-like correlation to an almost uncorrelated phase. This change is accompanied by a simultaneous change in the structure of the many-body ground state. A crucial role of the quantum statistics is emphasized by comparing properties of the Fermi-Fermi mixture with a corresponding Fermi-Bose system.

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Formation of the Majorana bound states on defects

A. Ptok[1]

[1]*Institute of Nuclear Physics, Polish Academy of Sciences, ul. W. E. Radzikowskiego 152, PL-31342 Krakow, Poland*

Zero--energy Majorana quasiparticles can be induced at the edge of a low dimensional systems. Non--Abelian statistics of this state makes it a good candidate for the realization of quantum computing. From the practical point of view, it is crucial to obtain an intentional creation and manipulation of this type of bound states. We show such a possibility in a setup of several systems (e.g. optical trap [1] or quantum dot-nanoring hybrid system [2]) in which we specify a 'defect' (inhomogeneity) region via electrostatic means. States in such defect can lead to the emergence of Andreev and Majorana bound states in investigated system. We study the differences between those bound states and the possibility of their manipulation.

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Breaking the entanglement barrier: Tensor network simulation of quantum transport

Marek M. Rams[1] and Michael Zwolak[2]

[1]*Jagiellonian University, Marian Smoluchowski Institute of Physics, Łojasiewicza 11, 30-348 Kraków, Poland*

[2]*Biophysics Group, Microsystems and Nanotechnology Division, Physical Measurement Laboratory, National Institute of Standards and Technology, Gaithersburg, MD 20899, USA*

The recognition that large classes of quantum many-body systems have limited entanglement in the ground and low-lying excited states led to dramatic advances in their numerical simulation via so-called tensor networks. However, global dynamics elevates many particles into excited states, and can lead to macroscopic entanglement and the failure of tensor networks. Here, we show that for quantum transport -- one of the most important cases of this failure -- the fundamental issue is the canonical basis in which the scenario is cast: When particles flow through an interface, they scatter, generating a ``bit'' of entanglement between spatial regions with each event. The frequency basis naturally captures that -- in the long time limit and in the absence of an inelastic event -- particles tend to flow from a state with one frequency to a state of identical frequency. Recognizing this natural structure yields a striking -- exponential in some cases -- increase in simulation efficiency, greatly extending the attainable spatial and time scales, and broadening the scope of tensor network simulation into hitherto inaccessible classes of non-equilibrium many-body problems.

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x_c and x_{opt} in Cuprate Superconductors

Jürgen Röhler

Fachgruppe Physik, Universität zu Köln, 50937 Köln, Germany

An analysis is presented of the striking discontinuities [1,2,3] in the underdoped-overdoped transition regime of hole doped cuprate superconductors. It is shown that the strong increase of the condensation energy in a weakly overdoped regime up to $x_c \sim 0.19$ may be connected with the collapse of the columnar 4*a* nanopatterns of pseudogap excitations [4] occurring at maximal T_c, $x_{opt} \sim 0.16$. This is due to a huge gain of long range coherence in the condensate of hole pairs and RVB singlets by a displacive transition from columnar to tweed-like pseudogap excitation patterns.

The model assumes the closest bond centered hole - hole distance equal to 3*a*, and the relative amplitudes of hole pairs and spin singlets coherent and locked together. Two bond-centered holes, tied to resonating spin singlets in slowly fluctuating arrays of at least 3x4 Cu sites, attract each other over 3*a* by a common inversion center for all spin and hole coordinates in the array. A rigid electron - hole condensate is created at the full filling fraction $1/6 \sim x_{opt} \sim 0.16$.

Hence fillings beyond x_{opt} must accommodate the overdoped "excess" holes site centered next to the bond-centered *3a hole* pairs. Thus:

First, even a tiny amount ($x_c - x_{opt}$) of "excess" holes will seed long range coherence of the charge fluctuations along the lattice diagonals (nodal in *k*-space).

Second, "excess" holes will act pair breaking, since holes site centered next to *3a hole* pairs locally unlock the spin and charge sectors, create uncondensed paramagnetic electrons and decrease the superfluid density linearly with *x* [5].

The tweed-like pattern may be understood as precursor of the quantum critical point of the *S-N* transition at the upper end of the superconducting dome, $x = 1/4 = 0.25$.

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Self-consistent-field ensembles of disordered Hamiltonians: Efficient solver and application to superconducting films

Matthias Stosiek[1] and Ferdinand Evers[1]

[1] *Institute of Theoretical Physics, University of Regensburg, D-93040 Germany*

Our general interest is in self-consistent-field (scf) theories of disordered fermions. They generate physically relevant sub-ensembles ("scf-ensembles") within a given Altland-Zirnbauer class. We are motivated to investigate such ensembles (i) by the possibility to discover new fixed points due to (long-range) interactions; (ii) by analytical scf-theories that rely on partial self-consistency approximations awaiting a numerical validation; (iii) by the overall importance of scf-theories for the understanding of complex interaction-mediated phenomena in terms of effective single-particle pictures.

In this poster we present an efficient, parallelized implementation solving scf-problems with spatially local fields by applying a kernel-polynomial approach. Our first application is the Boguliubov-deGennes (BdG) theory of the attractive-U Hubbard model in the presence of on-site disorder; the scf-fields are the particle density $n(\mathbf{r})$ and the gap function $\Delta(\mathbf{r})$. For this case, we reach system sizes unprecedented in earlier work. They allow us to study phenomena emerging at scales substantially larger than the lattice constant, such as the interplay of multifractality and interactions, or the formation of superconducting islands. For example, we observe that the coherence length is a non-monotonous function of the disorder strength already at moderate U. With respect to methodology our results are important because we establish that partial self-consistency ("energy-only") schemes as typically employed in analytical approaches tend to miss qualitative physics such as island formation.

Determination of topological invariants in optical lattices

T.Szołdra[1], K. Sacha[1] and A. Kosior[2]

[1]Instytut Fizyki imienia Mariana Smoluchowskiego, Uniwersytet Jagielloński, ulica Profesora Stanisława Lojasiewicza 11, PL-30-348 Kraków, Poland
[2] Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Straße 38, D-01187 Dresden, Germany
Email: tszoldra@gmail.com

Ultracold atoms in optical lattices form a clean quantum simulator platform to examine topological phenomena and test exotic topological materials [1]. Here we will propose an experimental scheme to measure Chern number of two-dimensional multiband topological insulators with bosonic atoms. We will show how to extract the topological invariants out of a sequence of time-of-flight images applying a phase retrieval algorithm to Bose-Einstein Condensate matter waves [2]. We will illustrate advantages of using bosonic atoms as well as efficiency and robustness of the method with two prominent examples: the Harper-Hofstadter model with an arbitrary commensurate magnetic field [3] and the Haldane model on a brick-wall lattice [4].

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Aharonov-Bohm and Aharonov-Casher effects of local and nonlocal Cooper pairs

D. Tomaszewski[1], P. Busz[1], R. López[2], R. Žitko[3,4], M. Lee[5], and J. Martinek[1]

[1] *Institute of Molecular Physics, Polish Academy of Science, Smoluchowskiego 17, 60-179 Poznan, Poland*
[2] *Institut de Física Interdisciplinar i de Sistemes Complexos IFISC (CSIC-UIB), E-07122 Palma de Mallorca, Spain*
[3] *Jožef Stefan Institute, Jamova 39, SI-1000 Ljubljana, Slovenia*
[4] *Faculty of Mathematics and Physics, University of Ljubljana, Jadranska 19, SI-1000 Ljubljana, Slovenia*
[5] *Department of Applied Physics and Institute of Natural Science, College of Applied Science, Kyung Hee University, Yongin 17104, Korea*

In recent years, there is substantial progress in creation of specially separated spin entangled electrons in solid state using the splitting of Cooper pairs, which is necessary ingredient of quantum communication and computing. It is also possible to generate a Josephson supercurrent form by split nonlocal Cooper pairs [1]. This new Josephson current required further studies especially its interference properties. While the behavior of single electrons under the influence of Aharonov-Bohm (AB) and Aharonov-Casher (AC) effects is well understood, it raises the question of the impact of these effects on nonlocal superconducting Cooper pairs that for s-wave superconductors are in spin singlet state. We analyze a normal ring, where a single electron interference is possible and two parallel nanowires connected to two superconducting electrodes, where a single-electron interference can be absent but a cross Andreev reflection is possible [2]. At low transmission, we can link the AB effect only to local Cooper pairs and the AC effect to nonlocal Cooper pair transport. We demonstrate that by using two quantum dots we can obtain different AC phases for the non-spin-flip and spin-flip transport processes that leads to a beating in the AC effect [3].

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Stable Spin-Polarized Impurity in Unitary Fermi Gas

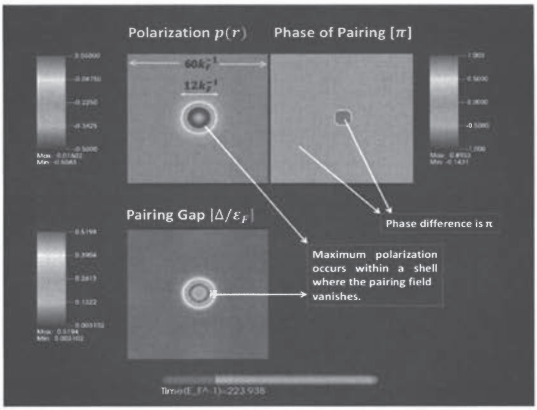
Buğra Tüzemen, Piotr Magierski, Gabriel Wlazłowski
Warsaw University of Technology

Abstract

Non-equilibrium quantum many-body dynamics in superfluid Fermi systems are more demanding than their bosonic equivalents. The main tool to inspect such systems is the *Density Functional Theory* (DFT). However while extending the theory into Fermi superfluids, a great deal of difficulty arises from pairing correlations $\Delta(r, r')$, which are in principle non-local and give rise to a set of integro-differential equations. One way to overcome this problem is to introduce instead a local pairing field, $\Delta(r)$. This method is known as *Superfluid Local Density Approximation* (SLDA) [1] and it is particularly well suited for leadership class computers of hybrid (CPU + GPU) architecture. Using the most powerful supercomputers we are currently able to study a real-time 3D dynamics without any symmetry restrictions evolving up to hundred of thousands of superfluid fermions. It represents a true qualitative leap in quantum simulations of non-equilibrium systems, and allowed to describe for the first time a variety of phenomena, including the generation, real-time evolution, and interaction of quantized vortices, as well as their crossing and reconnection [2].

It is also allowed to describe pairing dynamics during nuclear reactions [3] and to reproduce all stages of a solitonic cascade observed in experiment in ultra-cold atomic cloud [4]. The recent extension of SLDA (so-called ASLDA) allows to simulate the spin-imbalanced systems as well.

In my presentation, I will show a dynamically created stable, spin-polarized impurity in the *Unitary Fermi Gas* (UFG) - see figure [5]. The stability of this new excitation mode is governed by a pairing structure which resembles to the behavior of the pairing field in the FFLO phase. I will present the procedure for generation of this impurity and conditions for its stability. Furthermore, I will share some preliminary results on its dynamics.



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Spin-Imbalanced Fermi Superfluid in a Lieb Lattice

Marek Tylutki[1,*] and **Päivi Törmä**[1]

[1]*Department of Applied Physics, Aalto University, Helsinki, Finland*
[*] *present address: Warsaw Uniwersity of Technology, Warsaw, Poland*

I discuss the Hubbard model with spin imbalance in a Lieb lattice. The Lieb lattice features a flat band in its single-particle spectrum, which is known to enhance superfluidity due to a diverging density of states. I will present a phase diagram of this system with a variety of unconventional superfluid phases. Apart from the standard BCS state and the normal state, there are different types of the Fulde-Ferrell-Larkin-Ovchinnikov state with space-dependent pairing function. There is also a thermodynamically stable Sarma phase, where the imbalance coexists with a spatially uniform order parameter; this phase is possible due to a modulation of the order parameter inside a unit cell.

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Inter-component correlations in few-fermion systems induced by a shape of an external confinement

Damian Włodzyński, Daniel Pęcak and Tomasz Sowiński

Institute of Physics, Polish Acadamy of Sciences, Warsaw, Poland

In a one-dimensional two-component mixture of a few fermions having different mass, their spatial arrangement depends on a particular shape of external confinement. In a harmonic trap, the lighter component is split and push out of the trap, while the heavier component is located in the center. In contrast, in a flat box potential, the heavier component is split. In consequence, when the external trap adiabatically changes its shape, the ground-state of the few-fermion system undergoes a specific transition between these spatial orderings. It is known that the transition has many interesting properties similar to the properties of the quantum phase transitions. Here we analyze this transition from the inter-component correlations point of view.

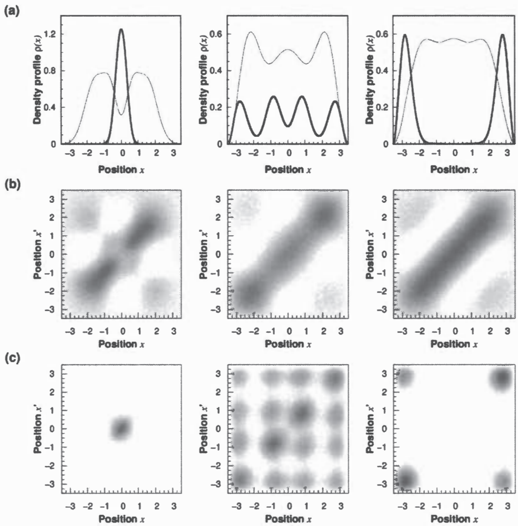

FIG. Structural transition in the ground state of the system of $N_A=3$ and $N_B=1$ interacting fermions from a single-particle point of view ($m_B/m_A=40/6$). Successive columns correspond to different external traps, from the harmonic oscillator (left) to the flat box (right). (a) Single-particle density profile for heavier (thick line) and lighter (thin line) component depending on the shape of the external trap. (b-c) Single-particle density matrix of the lighter and heavier component, respectively.

Quantum Transport via Matrix Product States and Extended Reservoirs

Gabriela M. Wójtowicz [1]

[1] *Jagiellonian University, Marian Smoluchowski Institute of Physics,*
Lojasiewicza 11, 30-348 Kraków, Poland
E-mail: g.wojtowicz@student.uj.edu.pl

Tensor networks are a powerful tool for many-body ground states, provided that entanglement is limited. Time-dependent processes, such as quantum transport or quenches, can be nonetheless inadequate, since entanglement growth is linear in time. For a matrix product state decomposition, this necessitates a bond dimension that grows exponentially with time, imposing a hard limit on the duration of the simulation. In the case of quantum transport, this growth can be reduced to logarithmic when the reservoir states of a closed system are arranged according to their scattering state structure.

This approach was extended to open systems via the use of extended reservoirs. What brings many-body transport calculations into a regime that is not limited by finite size effects or carrier depletion, and thus can access true steady-states as well as time-dynamics and periodic driving. The application of this approach was demonstrated by calculation of the transport characteristics of an open, interacting, many-body system. Our method yields a highly versatile approach for many-body quantum transport simulations.

Superexponential Wave Function Decay: a Fingerprint of Strings in Doped Antiferromagnets

K. Bieniasz[1,2], P. Wrzosek[3], A. M. Oleś[4,2], and K. Wohlfeld[3]

[1] *Stewart Blusson Quantum Matter Institute, University of British Columbia, Vancouver, British Columbia, Canada V6T 1Z4*

[2] *Marian Smoluchowski Institute of Physics, Jagiellonian University, Prof. S. Łojasiewicza 11, PL-30348 Kraków, Poland*

[3] *Faculty of Physics, University of Warsaw, Pasteura 5, PL-02093 Warsaw, Poland*

[4] *Max Planck Institute for Solid State Research, Heisenbergstraße 1, D-70569 Stuttgart, Germany*

We determine the spectral function of a hole for the one-dimensional (1D) Ising t-J^z model using the magnon language and obtain an exact result only when the magnon-magnon interactions are included. Interestingly, the magnon-magnon interactions completely cancel the string potential in 1D and the hole wave function has coefficients which decay exponentially with the increasing length of hole path. This stays in contrast with the two-dimensional (2D) case, for which the hole is always confined in a string potential and a superexponential decay of the hole wave function coefficients is predicted. The latter behavior is a fingerprint of the existence of strings in doped antiferromagnets, that can be observable in the numerical or cold atom simulations of the 2D doped Hubbard model.

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Participants

Mestapha Arejdal
Université privée de Marrakech
Physics
Marrakesh, Morocco
arejdal.achdad@gmail.com

Alexander Bauer
Universität Duisburg-Essen
Fakultät Physik AG Sothmann
Duisburg, Germany
alexander.bauer@uni-due.de

André Becker
Technische Universität Kaiserslautern
Fachbereich Physik
Kaiserslautern, Germany
an_becke@rhrk.uni-kl.de

Immanuel Bloch
Max Planck Institute of Quantum Optics
Quantum Many-Body Systems
Garching, Germany
immanuel.bloch@mpq.mpg.de

Wojciech Brzezicki
Polish Academy of Sciences
International Research Centre MagTop
Warsaw, Poland
Brzezicki@MagTop.ifpan.edu.pl

Piotr Busz
Polish Academy of Sciences
Institute of Molecular Physics
Poznań, Poland
piotr.busz@ifmpan.poznan.pl

Aurelia Chenu
Donostia International Physics Center (DIPC)
Physics
San Sebastian, Spain
achenu@dipc.org

Agnieszka Cichy
Adam Mickiewicz University
Faculty of Physics
Poznań, Poland
agnieszkakujawa2311@gmail.com

Lukas Debbeler
TU Braunschweig
Institute of Mathematical Physics
Braunschweig, Germany
l.debbeler@tu-braunschweig.de

Participants

Jacek Dobrzyniecki
Institute of Physics of the Polish Academy of Sciences
Division of Theoretical Physics
Warsaw, Poland
jacek.dobrzyniecki@ifpan.edu.pl

Tadeusz Domanski
Maria Curie-Skłodowska University
Institute of Physics
Lublin, Poland
doman@kft.umcs.lublin.pl

Ulrich Eckern
University of Augsburg
Institute of Physics
Augsburg, Germany
eckern@physik.uni-augsburg.de

Ilya Eremin
Ruhr-University Bochum
Institut für Thoeretische Physik III
Bochum, Germany
ilya.eremin@rub.de

Katharina Franke
Freie Universtität Berlin
Fachbereich Physik
Berlin, Germany
kjfranke@zedat.fu-berlin.de

Paul Froese
Max Planck Institute for Solid State Research
Quantum Many-Body Theory
Stuttgart, Germany
p.froese@fkf.mpg.de

Max Geier
Freie Universität Berlin
Institut für Physik
Berlin, Germany
maxgeier@zedat.fu-berlin.de

Szczepan Głodzik
Maria Curie-Skłodowska University
Institute of Physics, Condensed Matter Theory Department
Lublin, Poland
szglodzik@kft.umcs.lublin.pl

Ewelina Hankiewicz
Würzburg University
Physics Department
Würzburg, Germany
ewelina.hankiewicz@physik.uni-wuerzburg.de

Participants

Moritz Hirschmann
Max Planck Institute for Solid State Research
Quantum Many-Body Theory
Stuttgart, Germany
m.hirschmann@fkf.mpg.de

Timo Hyart
Institute of Physics, Polish Academy of Sciences
International Research Centre MagTop
Warsaw, Poland
timo.hyart@magtop.ifpan.edu.pl

Satoshi Ikegaya
Max Planck Institute for Solid State Research
Stuttgart, Germany
S.Ikegaya@fkf.mpg.de

Krzysztof Jachymski
Forschungszentrum Jülich
Peter Grünberg Institute
Jülich, Germany
k.jachymski@fz-juelich.de

Konrad Jerzy Kapcia
Institute of Nuclear Physics, Polish Academy of Sciences
Department of Computational Materials Science
Kraków, Poland
kakonrad@tlen.pl

Rüdiger Klingeler
Heidelberg University
Kirchhoff Institute of Physics
Heidelberg, Germany
klingeler@kip.uni-heidelberg.de

Adam Kłosiński
University of Warsaw
Faculty of Physics
Warsaw, Poland
adam.klosinski@fuw.edu.pl

Aksel Kobiałka
Maria Curie-Skłodowska University
Institute of Theoretical Physics
Lublin, Poland
akob@kft.umcs.lublin.pl

Denis Kochan
University of Regensburg
Institute of Theoretical Physcis
Regensburg, Germany
denis.kochan@gmail.com

Participants

Corinna Kollath
University of Bonn
Physikalisches Institut
Bonn, Germany
corinna.kollath@uni-bonn.de

Arkadiusz Kuroś
Jagiellonian University
Atomic Optics Department
Kraków, Poland
arkadiusz.kuros@uj.edu.pl

Piotr Magierski
Warsaw University of Technology
Faculty of Physics
Warsaw, Poland
piotr.magierski@pw.edu.pl

Christian Martens
BTU Cottbus - Senftenberg
Computational Physics
Cottbus, Germany
christian.martens@b-tu.de

Maciej M. Maśka
University of Silesia
Institute of Physics
Chorzów, Poland
maciek@phys.us.edu.pl

Pawel Matus
Jagiellonian University
Marian Smoluchowski Institute of Physics,
Atomic Optics Department
Kraków, Poland
pawel.matus@student.uj.edu.pl

Matteo Minola
Max Planck Institute for Solid State Research
Solid State Spectroscopy
Stuttgart, Germany
m.minola@fkf.mpg.de

Benjamin Nagler
TU Kaiserslautern
Physics
Kaiserslautern, Germany
nagler@rhrk.uni-kl.de

Dillip K. Nandy
Polish Academy of Sciences
Institute of Physics
Warsaw, Poland
nandy.pawan@gmail.com

Participants

Minh Nguyen Nguyen
Institute of Physics PAS - Instytut Fizyki PAN
International Centre for Interfacing
Magnetism and Superconductivity with
Topological Matter – MagTop, IF PAN
Warsaw, Poland
Minh.Nguyen.Nguyen@magtop.ifpan.edu.pl

Katharina Noatschk
BTU Cottbus - Senftenberg
Computational Physics
Cottbus, Germany
Katharina.Noatschk@b-tu.de

Andrzej Michal Oleś
Jagiellonian University
Marian Smoluchowski Institute of Physics
Kraków, Poland
amoles@fkf.mpg.de

Tania Paul
International Center for Interfacing
Magnetism and Superconductivity with
Topological Matter
Institute of Physics, Polish Academy of
Sciences
Warsaw, Poland
Tania.Paul@magtop.ifpan.edu.pl

Daniel Pęcak
Warsaw University of Technology
Faculty of Physics
Warsaw, Poland
daniel.pecak@pw.edu.pl

Andrzej Ptok
Institute of Nuclear Physics PAN
Department of Computational Materials
Research
Kraków, Poland
aptok@mmj.pl

Marek Rams
Jagiellonian University
Institute of Physics
Kraków, Poland
marek.rams@uj.edu.pl

Jürgen Röhler
Universität zu Köln
Fachgruppe Physik
Köln, Germany
juergen.roehler@uni-koeln.de

Participants

Krzysztof Sacha
Jagiellonian University
Marian Smoluchowski Institute of Physics
Kraków, Poland
sacha@if.uj.edu.pl

Małgorzata Samsel-Czekała
Polish Academy of Sciences
Institute of Low Temperature and Structure
Warsaw, Poland
m.samsel@int.pan.wroc.pl

Joerg Schmalian
Karlsruhe Institute of Technology
Theory of Condensed Matter
Karlsruhe, Germany
joerg.schmalian@kit.edu

Andreas Schnyder
Max Planck Institute for Solid State Research
Quantum Many Body Theory
Stuttgart, Germany
a.schnyder@fkf.mpg.de

Tomasz Sowiński
Polish Academy of Sciences
Institute of Physics
Warsaw, Poland
tomasz.sowinski@ifpan.edu.pl

Matthias Stosiek
University of Regensburg
Institute of Theoretical Physics
Regensburg, Germany
matthias.stosiek@ur.de

Tomasz Szołdra
Jagiellonian University
Atomic Physics Department
Kraków, Poland
tszoldra@gmail.com

Damian Tomaszewski
Polish Academy of Sciences
Institute of Molecular Physics
Poznań, Poland
damian.tomaszewski@ifmpan.poznan.pl

Bugra Tuzemen
Warsaw University of Technology
Faculty of Physics
Warsaw, Poland
tuzemen@if.pw.edu.pl

Participants

Marek Tylutki
Warsaw University of Technology
Faculty of Physics
Warsaw, Poland
marek.tylutki@gmail.com

Damian Włodzyński
Institute of Physics PAS
Division of Theoretical Physics
Warsaw, Poland
wlodzynski@ifpan.edu.pl

Krzysztof Wohlfeld
University of Warsaw
Faculty of Physics
Warsaw, Poland
krzysztof.wohlfeld@fuw.edu.pl

Gabriela Wójtowicz
Jagiellonian University
Faculty of Physics, Astronomy and Applied
Computer Science
Kraków, Poland
g.wojtowicz@student.uj.edu.pl

Piotr Wrzosek
University of Warsaw
Faculty of Physics
Warsaw, Poland
piotr.wrzosek@fuw.edu.pl