# XIX Krajowa Konferencja Nadprzewodnictwa

# XIX National Conference on Superconductivity

Niekonwencjonalne nadprzewodnictwo i silnie skorelowane układy elektronowe

Unconventional Superconductivity and Strongly Correlated Electron Systems

Program i streszczenia / Program and abstracts

6-11 października 2019 roku / October 6-11, 2019
Hotel Magellan, Bronisławów

# Przedmowa

XIX Krajowa Konferencja Nadprzewodnictwa w Bronisławowie jest kolejną konferencją z serii, która zapoczątkowana została w roku 1987 w Warszawie. Pierwsza konferencja, nosząca tytuł: I Międzynarodowe Sympozjum Nadprzewodnictwa Wysokotemperaturowego, była poświęcona teoretycznym i doświadczalnym badaniom wysokotemperaturowych nadprzewodników, odkrytych rok wcześniej. W kolejnych latach tematyka ewoluowała, obejmując zarówno zjawiska niekonwencjonalnego nadprzewodnictwa w innych materiałach, jak też wiele innych zjawisk, występujących w układach silnie skorelowanych. Obecna konferencja nosi podtytuł „Niekonwencjonalne nadprzewodnictwo i silnie skorelowane układy elektronowe”, i obejmuje szereg zagadnień:

- Nadprzewodnictwo: zjawiska, mechanizmy, nowe materiały, zastosowania
- Nadprzewodzące układy nanorozmiarowe i niskowymiarowe
- Współistnienie nadprzewodnictwa i magnetyzmu, efekty bliskości
- Układy z silnie skorelowanymi elektronami: ciężkie fermiony, fluktuacje spinowe, fluktuacje ładunkowe
- Kwantowe, topologiczne i klasyczne przejścia fazowe, zjawiska krytyczne
- Izolatory i półmetale topologiczne

Nasza konferencja stwarza okazję do prezentacji i dyskusji najnowszych wyników teoretycznych i doświadczalnych badań naukowych w powyższych dziedzinach, otrzymanych zarówno przez naukowców pracujących w polskich instytucjach badawczych, jak też przez polskich naukowców pracujących poza granicami kraju, oraz ich zagranicznych współpracowników. Szczególną uwagę zwróciliśmy na to, aby oprócz przeglądowych wykładów doświadczonych wykładowców, przewidzieć dużo czasu na prezentacje (zaproszone, ustne, i plakatowe) młodych naukowców. Mamy nadzieję, że konferencja umożliwi wymianę doświadczeń na temat metodologii badań, zarówno teoretycznych, jak też doświadczalnych, a także pomoże w nawiązaniu nowych kontaktów umożliwiających owocną współpracę naukową.

Komitet Organizacyjny

# Preface

XIX National Conference on Superconductivity continues a series of conferences, which started in 1987 in Warsaw. The topic of the first conference in series, entitled I International Symposium on High Temperature Superconductivity, focused on the theoretical and experimental studies on high temperature superconductors, discovered a year before. In subsequent years the conference topics evolved, including the studies of unconventional superconductivity in other materials, and the studies of various novel effects discovered in strongly correlated systems. The topics of the present conference, with subtitle “Unconventional Superconductivity and Strongly Correlated Electron Systems”, include the following:

- Superconductivity: phenomena, mechanisms, new materials, applications
- Superconducting nano-sized and low-dimensional systems
- Coexistence of superconductivity and magnetism, proximity effects
- Strongly correlated electron systems: heavy fermions, spin fluctuations, charge fluctuations
- Quantum, topological and classical phase transitions, critical phenomena
- Topological insulators and semimetals

Our conference provides a forum for presentations and discussions of the newest results of the theoretical and experimental studies in the above mentioned areas, conducted by scientists working in the polish laboratories, and by polish scientists and their collaborators working abroad. It has been our intention that the program of the conference, beside invited lectures by experienced lecturers, leaves ample of time for young investigator presentations (invited, oral, or poster). We hope that the conference will promote the exchange of ideas on various theoretical and experimental research methods, and that it will generate an opportunity for the development of new scientific contacts, which will result in future collaborations.

The Organizing Committee

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## Poprzednie konferencje / Previous Confrences

1. I Międzynarodowe Sympozjum Nadprzewodnictwa Wysokotemperaturowego kwiecień 1987 r., Warszawa
2. II Międzynarodowe Sympozjum Nadprzewodnictwa Wysokotemperaturowego 28-29 stycznia 1988 r., Kraków
3. III Międzynarodowe Sympozjum Nadprzewodnictwa Wysokotemperaturowego 21-22 października 1991 r., Wrocław, organizator: Instytut Niskich Temperatur i Badań Strukturalnych PAN
4. IV Międzynarodowe Sympozjum Nadprzewodnictwa Wysokotemperaturowego 1993 r., Poznań, organizator: Instytut Fizyki Molekularnej PAN, Uniwersytet im. Adama Mickiewicza w Poznaniu
5. V Międzynarodowe Sympozjum Nadprzewodnictwa Wysokotemperaturowego 22-25 stycznia 1995 r., Kazimierz Dolny, organizator: Instytut Fizyki Uniwersytetu Marii Curie-Skłodowskiej w Lublinie
6. VI Międzynarodowe Sympozjum Nadprzewodnictwa Wysokotemperaturowego 23-28 września 1996, r., Zakopane, organizatorzy: Instytut Fizyki Uniwersytetu Jagiellońskiego w Krakowie, Akademia Górniczo - Hutnicza w Krakowie
7. VII Krajowe Sympozjum Nadprzewodnictwa Wysokotemperaturowego 01-03 września 1997 r., Międzyzdroje, organizator: Instytut Fizyki Politechniki Szczecińskiej
8. VIII Krajowe Sympozjum Nadprzewodnictwa Wysokotemperaturowego 07-10 września 1999 r., Gdańsk-Sobieszowo, organizator: Wydział Fizyki Technicznej i Matematyki Stosowanej Politechniki Gdańskiej
9. IX Szkoła Nadprzewodnictwa Wysokotemperaturowego 10-14 czerwca 2001 r., Krynica-Czarny Potok, organizatorzy: Instytut Fizyki Uniwersytetu Jagiellońskiego w Krakowie, Akademia Górniczo - Hutnicza w Krakowie
10. X Krajowa Szkoła "Nadprzewodnictwo wysokotemperaturowe i inne zjawiska w perowskitach" 06-10 czerwca 2004 r., Warszawa, organizator: Krajowa Sieć Naukowa „Silnie skorelowane fermiony - od nadprzewodnictwa do kolosalnego magnetooporu", Instytut Fizyki Polskiej Akademii Nauk
11. XI Krajowa Szkoła Nadprzewodnictwa „Zjawiska kolektywne i ich współzawodnictwo" 25-29 września 2005 r., Kazimierz Dolny, organizator: Krajowa Sieć Naukowa „Silnie skorelowane fermiony - od nadprzewodnictwa do kolosalnego magnetooporu", Instytut Fizyki Uniwersytetu Marii Curie-Skłodowskiej w Lublinie
12. XII Krajowa Szkoła Nadprzewodnictwa "Układy skorelowanych elektronów wczoraj i dziś" 14-18 września 2006 r., Ustroń, organizator: Instytut Fizyki Uniwersytetu Jagiellońskiego w Krakowie
13. XIII Krajowa Szkoła Nadprzewodnictwa „Nadprzewodnictwo, uporządkowanie spinowe i ładunkowe" 06-10 października 2007 r., Lądek Zdrój, organizator: Instytut Niskich Temperatur i Badań Strukturalnych PAN
14. XIV Krajowa Szkoła Nadprzewodnictwa „Nadprzewodnictwo i niejednorodne układy skondensowane" 13-17 października 2009 r., Ostrów Wielkopolski, organizator: Instytut Fizyki Molekularnej PAN, Uniwersytet im. Adama Mickiewicza w Poznaniu
15. XV Krajowa Szkoła Nadprzewodnictwa „Sto lat nadprzewodnictwa" 09-13 października 2011 r., Kazimierz Dolny, organizator: Instytut Fizyki Uniwersytetu Marii Curie-Skłodowskiej w Lublinie
16. XVI Krajowa Konferencja Nadprzewodnictwa „Niekonwencjonalne nadprzewodnictwo i układy silnie skorelowane" 07-12 października 2013 r., Zakopane, organizatorzy: Instytut Fizyki Uniwersytetu Jagiellońskiego w Krakowie, Akademia Górniczo - Hutnicza w Krakowie
17. XVII Krajowa Konferencja Nadprzewodnictwa "Nadprzewodnictwo i inne stany emergentne w układach z silnie skorelowanymi elektronami" 25-30 października 2015 r., Karpacz, organizator: Instytut Niskich Temperatur i Badań Strukturalnych PAN
18. XVIII Krajowa Konferencja Nadprzewodnictwa "Niekonwencjonalne nadprzewodnictwo i silnie skorelowane układy elektronowe" 08-13 października 2017 r., Krynica Morska, organizator: Wydział Fizyki Technicznej i Matematyki Stosowanej Politechniki Gdańskiej

# Program

# Niedziela, 6 października 2019 r. / Sunday, October 6, 2019

17:00 – 18:30 Rejestracja / Registration

19:00 – 20:00 *Kolacja / Dinner*

20:00 – 20:30 Wykład specjalny / Special lecture
P. Szymczak (Instytut Fizyki Teoretycznej, Uniwersytet Warszawski)

# Poniedziałek, 7 października 2019 r. / Monday, October 7, 2019

| | |
|---|---|
| 7:15 – 8:45 | *Śniadanie / Breakfast* |
| **9:00 – 10:30** | **Sesja I / Session I** |
| 9:00 – 9:35 | **ZD1** A. Kaminski "Collective excitations in unconventional superconductors" |
| 9:35 – 10:10 | **ZD2** W. Tabiś "Charge order and the Fermi surface in cuprates" |
| 10:10 – 10:30 | **U1** I. Biało "Uniaxial pressure studies of charge correlations in cuprates" |
| 10:30 – 11:00 | *Przerwa kawowa / Coffee break* |
| **11:00 – 12:50** | **Sesja II / Session II** |
| 11:00 – 11:35 | **ZD3** J. Spałek "Universal properties of superconductors: Beyond the renormalized mean field theory" |
| 11:35 – 12:10 | **ZD4** M. Zegrodnik "Superconductivity and charge ordering in the effective models of copper-based compounds" |
| 12:10 – 12:30 | **U2** M. Fidrysiak "Spin and charge fluctuations within variational approach: Dynamical response functions for Hubbard and t-J-U models" |
| 12:30 – 12:50 | **U3** W. M. Woch "Critical Exponents of $Tl_{0.8}Bi_{0.3}Sr_{1.8}Ba_{0.2}Ca_2Cu_3O_x$ bulk superconductor" |
| 13:00 – 15:00 | *Obiad / Lunch* |
| **15:00 – 16:40** | **Sesja III / Session III** |
| 15:00 – 15:35 | **ZD5** M. Konczykowski "Charge and Magnetic Orders in Superconductors, Competing or Intertwinned?" |
| 15:35 – 16:00 | **ZK1** K. Rogacki "BKT transition observed in magnetic and electric properties of $YBa_2Cu_3O_{7-\delta}$ single crystals" |
| 16:00 – 16:20 | **U4** P. Przysłupski "Emission of terahertz transients from $La_{0.7}Sr_{0.3}MnO_3$ / $YBa_2Cu_3O_{7-x}$ nanobilayers by femtosecond laser pulses" |
| 16:20 – 16:40 | **U5** A. Lynnyk "Upper critical field in superconducting iron selenides intercalated with organic molecules" |
| 16:40 – 17:10 | *Przerwa kawowa / Coffee break* |

**17:10 – 18:45 Sesja IV / Session IV**

17:10 – 17:45 **ZD6** D. Rybicki "Electronic and structural properties of $HgBa_2CuO_{4+\delta}$ single crystals concluded from NMR"

17:45 – 18:05 **U6** B. Camargo "Anomalous Hall effect in Bismuth"

18:05 – 18:25 **U7** R. J. Radwański "Crystal-field states in cuprates vs d-d excitations observed by RIXS: $La_2CuO_4$"

18:25 – 18:45 **U8** I. Zaytseva "Transport properties of compressed $La_{1.952}Sr_{0.048}CuO_4$ thin films"

19:00 – 20:00 *Kolacja / Dinner*

**20:00 – 21:00 Sesja plakatowa / Poster session**

# Wtorek, 8 października 2019 r. / Tuesday, October 8, 2019

7:15 – 8:45 *Śniadanie / Breakfast*

**9:00 – 10:30 Sesja V / Session V**

9:00 – 9:35 **ZD7** R. Szczęśniak "Superconducting state in the hydrogen-rich compounds"

9:35 – 10:10 **ZD8** T. Klimczuk "Searching for new superconducting materials"

10:10 – 10:30 **U9** S. Gutowska "Electron-phonon driven superconductivity of LiBi"

10:30 – 11:00 *Przerwa kawowa / Coffee break*

**11:00 – 12:50 Sesja VI / Session VI**

11:00 – 11:35 **ZD9** P. Starowicz "Hybridization Effects in $CeCoIn_5$ studied by ARPES, DFT and TBA calculations"

11:35 – 12:10 **ZD10** M. Matusiak "Thermoelectric signature of the nematic phase in iron-based superconductors"

12:10 – 12:30 **U10** R. Kurleto "The Interplay between Two Kondo Scales in the $Ce_3PdIn_{11}$ Heavy Hermion System Studied by Angle Resolved Photoelectron Spectroscopy"

12:30 – 12:50 **U11** M. J. Winiarski "Chemical view of bonding and superconductivity in LiBi and other intermetallic compounds: the importance of antibonding states"

13:00 – 15:00 *Obiad / Lunch*

**15:00 – 16:40 Sesja VII / Session VII**

15:00 – 15:35 **ZD11** P. Piekarz "DFT studies of noncentrosymmetric superconductors"

15:35 – 16:00 **ZK2** A. Cichy "Low-temperature phases in the two-band Hubbard model realized with ultracold atomic four-component mixtures in optical lattices"

16:00 – 16:20 **U12** B. Wiendlocha "Effect of the spin-orbit coupling on the electron-phonon interaction in superconductors: several case studies"

16:20 – 16:40 **U13** T. L. Mai "Magnetic state and electronic properties of $Sr_4V_2O_6Fe_2As_2$ studied by DFT calculations"

16:40 – 17:10 *Przerwa kawowa / Coffee break*

**17:10 – 18:45 Sesja VIII / Session VIII**

17:10 – 17:45 **ZD12** Z. Bukowski "Magnetic structures and superconductivity in iron-based superconductors containing europium"

17:45 – 18:05 **U14** K. Górnicka "Superconductivity in Li-based Heusler compounds"

18:05 – 18:25 **U15** V. H. Tran "Magnetic, electron transport, specific heat and Mössbauer spectroscopy properties of $Sr_2AFeAsO_3$ (A = V, Cr and Sc) materials"

18:25 – 18:45 **U16** K. Komędera "Interplay of magnetism, nematicity and superconductivity in '122' iron-pnictides studied by Mössbauer spectroscopy"

19:00 – 20:00 *Kolacja / Dinner*

**20:00 – 21:00 Sesja plakatowa / Poster session**

# Środa, 9 października 2019 r. / Wednesday, October 9, 2019

| | |
|---|---|
| 7:15 – 8:45 | *Śniadanie / Breakfast* |
| **9:00 – 10:30** | **Sesja IX / Session IX** |
| 9:00 – 9:35 | **ZD13** D. Kaczorowski "Metamagnetic quantum criticality in antiferromagnetic compound $CePtIn_4$" |
| 9:35 – 10:10 | **ZD14** A. Ślebarski "Novel superconducting state of $Y_5Rh_6Sn_{18}$; The impact of atomic scale disorder on superconductivity" |
| 10:10 – 10:30 | **U17** Z. Sobczak "Single crystal growth and physical properties of $MCo_2Al_9$ (M= Sr, Ba, Eu)" |
| 10:30 – 11:00 | *Przerwa kawowa / Coffee break* |
| **11:00 – 12:40** | **Sesja X / Session X** |
| 11:00 – 11:35 | **ZD15** J. Jaroszyński "Practical superconducting wires" |
| 11:35 – 12:00 | **ZK3** B. A. Głowacki "Interrelation between dynamic and static transport critical current values of superconductors" |
| 12:00 – 12:20 | **U18** J. Kozak "Resistive Superconducting Fault Current Limiter" |
| 12:20 – 12:40 | **U19** Ł. Tomków "Distribution of trapped magnetic flux in superconducting stacks magnetised by angled field" |
| 13:00 – 15:00 | *Obiad / Lunch* |
| 15:00 – 18:30 | Wycieczka / Excursion |
| 19:00 – 20:00 | *Kolacja grillowa / Barbecue dinner* |

# Czwartek, 10 października 2019 r. / Thursday, October 10, 2019

7:15 – 8:45 *Śniadanie / Breakfast*

**9:00 – 10:30** **Sesja XI / Session XI**

9:00 – 9:35 **ZD16** T. Domański "Conventional and topological realizations of subgap quasiparticles in nanoscopic superconductors"

9:35 – 10:10 **ZD17** T. Hyart "Correlated states in flat-band systems and topological properties of surface steps in the SnTe material class"

10:10 – 10:30 **U20** S. Głodzik "Nodal topological superconductivity in magnetic superstructures"

10:30 – 11:00 *Przerwa kawowa / Coffee break*

**11:00 – 12:50** **Sesja XII / Session XII**

11:00 – 11:35 **ZD18** G. Jung "Meyer-Neldel rule in low Ca-doped manganites"

11:35 – 12:10 **ZD19** A. Szewczyk "Peculiar magnetic susceptibility and phase transitions in $LiNiPO_4$"

12:10 – 12:30 **U21** P. Tomczak "Universal FMR procedure to probe magnetic characteristics of ferromagnetic samples"

12:30 – 12:50 **U22** T. Zajarniuk "Magnetic phase transition in $TbAl_3(BO_3)_4$ - classical or modified by quantum fluctuations?"

13:00 – 15:00 *Obiad / Lunch*

**15:00 – 16:40** **Sesja XIII / Session XIII**

15:00 – 15:35 **ZD20** M. M. Maśka "Proximity–induced topological superconductivity in a chain of magnetic atoms"

15:35 – 16:00 **ZK4** B. Scharf "Topological superconductivity in phase-controlled Josephson junctions on Rashba 2DEGs"

16:00 – 16:20 **U23** B. Dąbrowski "Single Mn-ion displacive-type perovskite multiferroics"

16:20 – 16:40 **U24** M. Roman "Charge density waves and magnetism in $RniC_2$ family (R - rare earth metal)"

16:40 – 17:10 *Przerwa kawowa / Coffee break*

**17:10 – 18:35 Sesja XIV / Session XIV**

17:10 – 17:35 **ZK5** A. Ptok "Artificial separation of trivial and topological superconducting domains"

17:35 – 17:55 **U25** B. Baran "Periodically driven quantum dot systems proximitized to supercon- ducting lead"

17:55 – 18:15 **U26** G. Górski "Spin-dependent transport through Quantum Dot-Majorana Wire System"

18:15 – 18:35 **U27** K. Pomorski "Description of interface between semiconductor and superconducting quantum computer"

19:00 – 20:00 *Bankiet / Conference dinner*

# Piątek, 11 października 2019 r. / Friday, October 11, 2019

| | |
|---|---|
| 7:15 – 8:45 | *Śniadanie / Breakfast* |
| **9:00 – 10:30** | **Sesja XV / Session XV** |
| 9:00 – 9:25 | **ZK6** N. Sedlmayr "The Superconductivity of Topologically Protected Surface States" |
| 9:25 – 9:50 | **ZK7** A. Wójs "Search for Jack states in fractional quantum Hall systems" |
| 9:50 – 10:10 | **U28** A. Więckowski "Majorana phase gate based on geometric phase" |
| 10:10 – 10:30 | **U29** A. Kobiałka "Majorana Bound State leakage in nanoscopic structures" |
| 10:30 – 11:00 | *Przerwa kawowa / Coffee break* |
| **11:00 – 12:00** | **Sesja XVI / Session XVI** |
| 11:00 – 11:25 | **ZK8** G. Michałek "Current auto and cross correlations in three terminal hybrid nanostructures with quantum dot" |
| 11:25 – 11:50 | **ZK9** T. Polak "Finite-temperature properties of the Mott phase in the Bose-Bose mixtures" |
| 11:50 – 12:00 | Zamknięcie konferencji / Closing of the conference |
| 13:00 – 15:00 | *Obiad / Lunch* |

# Wykłady zaproszone
# Invited Lectures

## ZD1

# Collective excitations in unconventional superconductors

**Adam Kaminski[1,2]**

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Collective excitations play a central role in theory of conventional superconductors and many models of unconventional superconductors. In cuprates for example, presence of collective mode was discovered over two decades ago [1, 2], however there is still no consensus as to its origin. It is not even known whether the mode is responsible for driving the pairing or a mere spectator of the superconducting transition. In this talk we will present new data revealing detailed properties of this mode and discuss implications as to its origin.

### References

[1] M. R. Norman et al., Phys. Rev. Lett. 79, 3506 (1997).

[2] M. R. Norman and H. Ding, Phys. Rev. B 57, 11089 (1998).

## ZD2

# Charge order and the Fermi surface in cuprates

**Wojciech Tabiś[1,2], Izabela Biało[1,2], Neven Barišić[2]**

*[1]AGH University of Science and Technology, al. Mickiewicza 30, 30-059 Krakow, Poland*

*[2]Department of Solid State Physics, Vienna University of Technology, 1040 Vienna, Austria*

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A pivotal challenge in understanding the remarkably rich and complex electronic properties of the cuprates is to correctly select the governing broken symmetry states and to identify the evolution of the Fermi surface (FS) across the $T(p)$ phase diagram. Besides the antiferromagnetic order and the spin-density-wave tendencies, the charge-density-wave (CDW) correlations were identified as a universal property of underdoped cuprates. Using resonant elastic and inelastic X-ray scattering we have performed a systematic study of the CDW order in a model cuprate $HgBa_2CuO_{4+d}$ (Hg1201). The experiments showed that the dynamic charge fluctuations appear at intermediate temperatures (~250K) and transform into mostly static short-range CDW order below the doping dependent $T_{CDW}$. We have identified the doping and temperature range of the CDW correlations [1,2].

The electronic transport measurements in Hg1201 ($p \approx 0.09$) revealed the transformation of the FS upon decreasing the temperature and applying magnetic fields up to 68 T. At low temperatures and high magnetic fields, the CDW order is responsible for the reconstruction of the FS into a small electron-like pocket, indicating a phase transition between the normal state and the high-field state. The result implies that superconductivity in the cuprates does not evolve from Fermi pockets, but from *arc-like* remnants of the underlying large Fermi surface, and it provides a crucial missing link between different regions of the cuprate phase diagram.

**Acknowledgments** The work was supported by the European Research Council (ERC Consolidator Grant No. 725521) and project CeNIKS (Grant No. KK.01.1.1.02.0013).

### References

[1] W. Tabis *et al.*, Nat Commun. 5 (2014) 5875.

[2] W. Tabis *et al.*, Phys. Rev. B 96 (2017) 134510.

## ZD3

# Universal properties of superconductors: Beyond the renormalized mean field theory

**J. Spałek**[1], **M. Fidrysiak**[1], **M. Zegrodnik**[2], **A. Biborski**[2], **D. Goc-Jagło**[1]

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We overview our recent work over the years 2017-19 [1]. The work concerns a detailed elaboration of the theory of unconventional superconductivity (SC) in the three different classes of correlated systems: *(i)* high-temperature SC in the cuprates, *(ii)* exotic SC in the bilayer graphene systems, and *(iii)* coexistent ferromagnetic-SC phases in heavy-fermion system $UGe_2$ and related compounds. Those topics are also discussed in contributions coming from the group members. Here we discuss universal features of these three compound classes based on real-space pairing, resulting from a combined effect of correlations and exchange interaction. Comparison with experiment is carried out to single out specific non-BCS behavior of high-$T_c$ cuprates. If time allows, we will address briefly the question of real-space *versus* spin-fluctuation pairing mechanisms.

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## ZD4

# Superconductivity and charge ordering in the effective models of copper-based compounds

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Charge ordering [1] and nematic behavior [2] are believed to play an important role in the physics of underdoped copper-based high-$T_C$ superconductors. At the same time, the question of a minimal model which would describe, in a complete manner both the superconducting phase and other symmetry-broken states observed in the cuprates still remains open. Here, we will analyze superconductivity as well as both translational and $C_4$ symmetry breaking within the paradigm of strong electronic correlations. The effects resulting from a significant Coulomb repulsion, which lead to the stability of the considered phases have been taken into account by the higher order terms of the diagrammatic expansion of the Gutzwiller wave function [3]. We will compare the results obtained within the effective single- [3,4] and three-band descriptions [5], with the relation to the available experimental data. Also, the influence of the explicit inclusion of the oxygen degrees of freedom in the model is going to be discussed.

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## ZD5

# Charge and Magnetic Orders in Superconductors, Competing or Intertwinned?

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Superconductivity of iron-based pnictides (IBS) arises from the background of magnetic order (Spin Density Wave, SDW) while in transition metal dichalcogenides, charge order (Charge Density Wave, CDW) is a ground state. From one side long range of both magnetic and charge orders inhibit superconducting state, but their fluctuations contribute to formation of the Cooper pairs. Representative example is iron-based superconducting pnictides (IBS) where substitution induced depression of antiferromagnetism (AF) of parent compound lets emerge superconducting order. Similarly, in canonical transition metal dichalcogenide NbSe2, superconductivity stem from charge density wave (CDW) state. The key issue is in what extend the charge/spin order exclude superconductivity or contribute to pairing. In order to elucidate this question we investigated effect of disorder induced in controlled way by energetic particle irradiation on stability of ordered phases. In both types of systems, depression of charge or spin order by disorder leads to enhancement of superconducting state. In my presentation I will discuss evolution of composition - temperature phase diagram with point-like disorder induced by low temperature irradiation of 122 family of IBS and in NbSe2 [1]. In the later compound strong depression of CDW by disorder is associated with changes of phonon spectra monitored by Raman spectroscopy and X ray diffraction.

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## ZD6

# Electronic and structural properties of $HgBa_2CuO_{4+\delta}$ single crystals concluded from NMR

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Nuclear magnetic resonance (NMR) has significantly contributed to the research on high-temperature superconducting cuprates since their very beginning, e.g. by discovering the pseudogap [1]. Based on $^{63}$Cu and $^{199}$Hg NMR measurements of magnetic shifts, linewidths and quadrupolar splitting of $HgBa_2CuO_{4+\delta}$ single crystals I will show what kind of information can be obtained from NMR. Namely, regarding different lattice sites and their identification, presence of significant electronic (charge) inhomogeneities and multi-component electronic spin susceptibility [2–4].

**Acknowledgments** I am grateful to group of Prof. J. Haase from Leipzig University and Prof. M. Greven from University of Minnesota for providing samples.

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**ZD7**

# Superconducting state in the hydrogen-rich compounds

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The lecture is focused on the problems related to the induction of the superconducting state in hydrogenated compounds under the extermely high pressure conditions. The available experimental data make one aware that the special attention should be paid to the $H_2S$, $H_3S$, and $LaH_{10}$ compounds. It is worth emphasizing that the discovery of the superconducting state of extremely high critical temperature value in compounds such as $H_3S$ ($T_C = 203$ K for $p = 150$ GPa) and $LaH_{10}$ ($T_C = 215$ K for $p = 150$ GPa or $T_C = 260$ K for $p \in (180 - 200)$ GPa) is the greatest achievement in physics of the superconducting state in recent years. It is of particular interest that the superconducting state in the discussed group of materials is induced by conventional electron-phonon interactions. This results stands in contradiction to the generally accepted notion that the electron-phonon interaction can induce the superconducting state of maximum critical temperature value not exceeding 40 K. In my opinion, the research works concerning the superconducting state induced in the hydrogenated compounds will allow, very probably, to achieve two goals: (i) we will prove that the superconducting state can exist in the room temperature (under the extremally high pressure, however) and (ii) we will exemplify that we have the theory of the phonon-induced superconducting state developed to such a degree that it allows to predict (prior to carrying out the suitable experiments) the existence of the high-temperature superconducting state. It may be recognised in future that the reaching of this second goal is more essential than the realisation of the first one, because it may open the way to the search for the high-temperature superconducting state also in systems which are not under the influence of high pressure.

## ZD8

# Searching for new superconducting materials

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Searching for new superconducting materials is a challenge in both physics and solid state chemistry. The ultimate goal is to synthesize a new superconductor that will be used in everyday life, a superconductor characterized by a high critical temperature and a high critical field. Sometimes *new* does not mean a compound that has not been reported in literature, i.e. crystal structure of $MgB_2$ was known for decades before 2001.

There are several approaches to find a superconducting compound. In this lecture, I will try to convince you that we do not threw darts at the periodic table with a blindfold on. A typical strategy is to pick right elements that form in a promising for superconductivity crystal structure. Another strategy is detailed and careful study of the ternary phase diagrams. Finding strong diamagnetic response is usually not enough. What you need is collaboration - in particular with gifted crystallographers as well as with friendly theorists.

In this lecture we will present a path we followed to reveal superconductivity in recently reported $ScV_2Al_{20}$ and $LuV_2Al_{20}$ [1], $CaBi_2$ [2], $NbRh_2B_2$ [3], $WB_{4.2}$ [4] and the alkaline earth metal based Laves phase family compounds [5].

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**ZD9**

# Hybridization Effects in $CeCoIn_5$ studied by ARPES, DFT and TBA calculations

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Band structure of $CeCoIn_5$ was studied by means of angle-resolved photoemission spectroscopy (ARPES) using Ce 4d-4f resonance photon energy. The measurements have been performed for various Brillouin zones and in different experimental geometry. The data yield many effects of hybridization between Ce 4f-electrons and valence band. Heavy bands with high f-electron contribution are observed. It is found that certain bands are highly hybridized, while others are weakly correlated. Specific variation of 4f electron related spectral intensity is observed, which originates from both anisotropic hybridization and matrix element effects.

In order to interpret the data DFT and tight binding approximation calculations have been performed. DFT results allow to resolve atomic contribution to particular bands. It appears that electrons from In located within Ce-In planes exhibit the strongest hybridization, while Co electrons form weakly hybridized bands. Tight binding calculations performed for Ce-In planes visualize hybridization effects, which are reflected in intensity variation observed by ARPES. Thus, a realistic form of $V_{cf}$ matrix element denoting hybridization may be proposed. It is based on TBA calculations and ARPES experimental data.

## ZD10

# Thermoelectric signature of the nematic phase in iron-based superconductors

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Studies of copper-based superconductors demonstrate how their phase diagram becomes more complex as experimental probes improve, able to distinguish among subtly different electronic phases. One of those phases, nematicity, has become a matter of great interest also in iron-based superconductors, where it is detected deep in the tetragonal state. We report the evolution of the in-plane Nernst effect anisotropy in the strain detwinned $Ba(Fe_{1-x}Co_x)_2As_2$ and $Ca(Fe_{1-x}Co_x)_2As_2$ single crystals, which is interpreted using the approach developed to describe the nematic order parameter in liquid crystals. Such a model turns out to be universally applicable also to data from other superconductors. We conclude the observed broken rotational symmetry of the electronic system is a consequence of the emerging thermodynamic electronic nematic order at a temperature much higher than the onset of the magnetic and structural transitions.

## ZD11

# DFT studies of noncentrosymmetric superconductors

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The absence of an inversion center induces the antisymmetric spin-orbit coupling, enabling a mixture of the spin-singlet and spin-triplet Cooper pairing. For the series of noncentrosymmetric superconductors ThXSi, where X = Co, Ni, Ir, and Pt [1, 2], we performed the density functional theory (DFT) studies. We analyse the effect of the spin-orbit coupling, which splits the degenerate electronic states and modifies the Fermi surfaces. The calculated phonon spectra strongly depend on atom type X, showing a tendency for dynamical instability in ThCoSi and ThIrSi.

$Cd_2Re_2O_7$ is the first discovered pyrochlore oxide superconductor. We studied the structural and phonon properties of the high-temperature cubic and two low-temperature tetragonal phases. We revealed the soft mode in the Brillouin zone centre, which breaks the tetragonal symmetry and induces the orthorhombic structure. This result explains the recent Raman measurements. For this new orthorhombic phase, we analyse the electronic band structure.

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**ZD12**

# Magnetic structures and superconductivity in iron-based superconductors containing europium

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Superconductivity and magnetism are generally considered to be mutually exclusive states. Superconducting iron-based pnictides containing europium are a rare case where superconductivity and magnetic ordering co-exist. In these compounds superconductivity emerges after suppression of the SDW order of Fe magnetic moments by chemical doping while the low-temperature magnetic ordering of $Eu^{2+}$ moments persists.

I shall summarize the results of magnetic structure investigations in doped $EuFe_2As_2$ by means of single crystal neutron diffraction in connection with superconducting properties. Next, I will present an overview of the ferromagnetic and superconducting properties of the closely related compounds $EuAFe_4As_4$ (A = Rb, Cs). Finally, I will discuss crystal structure, magnetic properties and superconductivity in the recently discovered $EuFeAs_2$ and Ni-doped $EuFe_{1-x}Ni_xAs_2$.

Although superconductivity originating from the 3d Fe electrons and the magnetism of localized 5f Eu electrons are electronically separated, a clear interaction of both systems is observed in all compounds investigated.

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## ZD13

# Metamagnetic quantum criticality in antiferromagnetic compound $CePtIn_4$

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For past two decades, understanding quantum critical point (QCP) associated with a quantum phase transition (QPT) in strongly correlated electron systems has become one of the outstanding challenges in modern physics due to its affluent and fairly enigmatic physics content. However, the lack of sufficient experimental systems forestalls the conclusive progress in this field of research. Thus, the search for new systems manifesting QCP has become an exigent goal in recent time. In this framework, Ce-bearing compounds turn out to be quite promising due to unstable nature of $4f$ orbitals, which allows relatively easy tuning of their magnetic properties leading to QCP.

In this work, thermodynamic and electrical transport properties of a novel compound $CePtIn_4$ were studied down to 50 mK in magnetic fields up to 14 T. The experimental data revealed the occurrence of long-range antiferromagnetic (AFM) order that sets in at $T_N$ = 2.3 K. In our attempt to suppress this AFM ordering by external magnetic field, we explored a fascinating magnetic phase diagram, in which the mean-field like suppression of $T_N$ is terminated at a tricritical point, which is also a triple point separating AFM, paramagnetic and intermediate metamagnetic (MM) states. Beyond that point, the transition splits into two first-order MM boundaries approaching quantum critical end points as $T \to 0$. Remarkably, magnetotransport, entropy landscape and most notably field dependencies of the heat capacity taken at different temperatures collectively corroborate the presence of quantum critical fluctuations in the system. $CePtIn_4$ turns out to be an almost unique example in the existing literature revealing such an interesting phase diagram that involves both second- and first-order phase transitions. Our findings expand the frontier of QPTs, and generate an opportunity to further exploit experimental and theoretical understanding of the associated perplexing physics.

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## ZD14

# Novel superconducting state of $Y_5Rh_6Sn_{18}$; The impact of atomic scale disorder on superconductivity

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In the critical regime, the strongly correlated electron systems are at the treshold of an instability and even weak perturbations, e.g., disorder can cause significant effects by changing the nature of the quantum macro state. Recently [1] we documented experimentally, that the effect of nanoscale disorder in skutterudite-related $La_3M_4Sn_{13}$ Remeika superconductors leads to the appearance of an inhomogeneous superconducting state, with the critical temperature $T_c^\star$ higher than $T_c$ of the bulk phase. The similar *high-temperature* superconducting phase $T_c^\star$ has also been reported for number of other SCES superconductors (e.g., $PrOs_4Sb_{12}$, $CaIrIn_5$, $CePt_3Si$) and *high-*$T_c$ materials. The $La_3M_4Sn_{13}$ superconducting metals were examined in detail, leaving $Y_3Rh_4Sn_{13}$ as a possible candidate for study. The microanalysis showed a stoichiometry of the Y-Rh-Sn system that prefers the formula unit $Y_5Rh_6Sn_{18+\delta}$ ($\delta < 1$). $Y_5Rh_6Sn_{18+\delta}$ haveing a cage-like structure crystallizes in tetragonal structure with the space group $I4_1/acd$. Its gap structure is found not to be characteristic of conventional BCS type superconductor. A two BCS-type gaps model better describes its upper critical field $H_{c2}(T_c)$ in $H-T$ diagram than those based on the isotropic BCS theory. The *ab initio* band structure calculations confirm a significant impact of $s$ and $p$ Sn bands as well as Rh and Y $d$-electron states at the Fermi level (this supports the multi-band superconductivity of $Y_5Rh_6Sn_{18}$) and suggest a nesting of the Fermi surface, related to occurence of CDW.

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**ZD15**

# Practical superconducting wires

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Just after discovery of superconductivity (1911) Heike Kamerlingh Onnes designed a 10T superconducting electromagnet, citing only the difficulty in obtaining 'relatively modest financial support' for its construction. However, for all known superconductors of the time critical values of current $J_c$ and field $H_c$ were low, making fabrication of strong magnets impossible. It took half a century, and the investigation of thousands of different superconducting materials until the useful superconductors $Nb_3Sn$ (1961) and NbTi (1962), with a high $J_c$ and $H_c$ were found. Within a short time, kilometer lengths of $Nb_3Sn$ wire were fabricated and the first 6T 'supermagnet' was tested the same year. During the following decades, these low temperature superconductors (LTS) entered their industrial phase. NbTi magnets are the most widely used, taking $\sim$ 80% of the market, while NbTi + $Nb_3Sn$ magnets are used where fields above 10T are needed. The record magnetic field generated by LTS is 23.5T.

After the discovery of high-temperature superconductors (HTS) in 1986, it took around 30 years to construct prototypes of 32T, and 45 T, only partially HTS magnets. In turn, 11 years after discovery of iron based superconductors (IBS) we observe only limited achievements in coils fabrication. IBS are ideal candidates for applications. Indeed, some of them have quite a high $J_c$, even in strong magnetic fields, and a low superconducting anisotropy. Moreover, the cost of IBS wire can be four to five times lower than that of $Nb_3Sn$, still more expensive than NbTi, but with much higher critical parameters than $Nb_3Sn$. At present, long superconducting wires are only produced from seven superconductors: NbTi, $Nb_3Sn$, $MgB_2$, Bi2223, Bi2212, REBCO, and Ba-122. Only wires of Nb compounds are used industrially, with intensive work on Nb3Sn optimization still under way. The other materials are still considered in the R&D phase. Here I will talk about superconducting wires development at the NHMFL and its application to magnet construction.

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## ZD16

# Conventional and topological realizations of subgap quasiparticles in nanoscopic superconductors

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In-gap quasiparticles appearing at impurities, defects, or their arrangements like nanoscopic wires and islands proximitized to bulk superconductors are the topic of recent intensive studies. These bound states are valuable for basic science because they allow for experimentally controllable confrontation of superconductivity with magnetism and strong electron correlations, which usually are antagonistic to one another. In nanoscopic systems, however, these phenomena don't have to be conflicting and sometimes behave in cooperative manner giving rise to completely new phases. One of such spectacular emergent phenomena is *topological superconductivity* observed in nanoscopic size magnetic wires and islands, where a certain fraction of in-gap quasiarticles existing near their boundaries evolve into the zero-energy modes resembling the long sought Majorana fermions.

These conventional and topological subgap quasiparticles are both appealing for applications in nanoelectronics and quantum information processing. For instance, the conventional variants enable creation of the spatially entangled electronic states and activation of the efficient non-local charge/heat transport using the Cooper-pair-splitter heterostructures. As far as the topological variants are concerned (which are immune to external perturbations due to symmetry protection) they are promising for such modern technological applications as, stable qubits, quantum computations, unconventional transistors, amplifiers, detectors, etc.

We shall give a comprehensive overview of the physical properties of such in-gap quasiparticles, discussing their particle-hole dualism, characteristic spatial and temporal scales, and features induced by periodically driven forces. We will also discuss the possible means to distinguish the trivial from nontrivial bound states.

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## ZD17

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

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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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**ZD18**

# Meyer-Neldel rule in low Ca-doped manganites

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In the last KKN conference we have reported on macroscopic random telegraph conductivity fluctuations in low doped manganite $La_{1-x}Ca_xMnO_3$ (LCMO) single crystals and suggested that the mechanism of the telegraph noise is related to Meyer-Neldel rule (MNR) of the crystals conductivity [1]. Here we report on experimental investigations of LCMO conductivity modified by Ca-doping $x$, hydrostatic pressure, current bias, and ageing.

We have established that MNR behavior of the manganite conductivity stems from multi-excitation entropy mechanism [2]. The behavior of of the isokinetic Meyer Neldel temperature $T_{MN}$ with changing experimental parameters revealed that conductivity changes due to both, changing doping and applied pressure, are caused by enhancement of $e_g$ conduction electrons, while bias influences the conductivity through a different mechanism, likely consisting in melting of small polarons into free carriers at phase-separated interfaces. $T_{MN}$ of the high resistivity metastable state is higher than in the low resistivity one. Systematic increase of $T_{MN}$ with ageing brought us to the conclusion that resistivity increase in aged metastable states consists in ordering of the LCMO electronic system.

It can be concluded that Meyer-Neldel temperature can constitute an excellent parameter enabling one to monitor and characterize changes in the conductivity associated with metastable resistivity states, provided a microscopic model relating electrical transport in mixed valence manganite systems with multi excitation entropy conditions will be further developed in the future [2].

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## ZD19

# Peculiar magnetic susceptibility and phase transitions in $LiNiPO_4$

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Among orthorhombic olivines, considered for cathodes of Li-ion batteries, $LiNiPO_4$ shows a unique set of properties, e.g., (i) two-step formation of a quasi-2D antiferromagnetic structure via the $2^{nd}$ order transition to an incommensurate phase at 21.8 K and the $1^{st}$ order transition to the antiferromagnetic phase at 20.9 K, (ii) complex exchange interactions, and (iii) strong linear magnetoelectric effect.

Detailed studies of specific heat, magnetization and magnetic torque of $LiNiPO_4$, aimed at (i) seeking for a transition to a multiferroic state, (ii) constructing the phase diagram in the magnetic field, $B$, up to 9 T, (iii) verifying whether the complex exchange interactions, strong anisotropy, and the quasi 2D magnetic structure lead to any uncommon macroscopic magnetic properties - will be presented.

The specific heat studies, supplemented by the "slope analysis method", allowed to find a splitting of the specific heat anomaly associated withe $1^{st}$ order transition, suggesting that these are two coupled transitions, one of which can be the ferroelectric one. Measurements of the specific heat of a single crystal as a function of temperature, $T$, for nonzero $B$ allowed to determine analytical equations describing the phase transition lines in the $T$-$B$ plane, and to model evolution of a shape of the specific heat anomalies accompanying the phase transitions in a powder sample under influence of $B$.

By measurements of angular dependences of magnetic torque and magnetization for $B$ rotating within the $a$-$c$ and $b$-$c$ crystalline planes, for many fixed $T$ and $B$ values, we found a new effect, that we called "off-diagonal nonlinear magnetic susceptibility", i.e., we found that for each of the main crystalline axes ($a$, $b$, and $c$), an additional component of magnetic susceptibility, proportional to the square of the perpendicular to this axis component of $B$ exists. A phenomenological model of this effect, describing the experimental results very well, was proposed.

## ZD20

# Proximity–induced topological superconductivity in a chain of magnetic atoms

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Performing Monte Carlo simulations we study the temperature dependent self–organization of magnetic moments coupled to itinerant electrons in a finite–size one–dimensional nanostructure proximitized to a superconducting reservoir. At low temperature an effective interaction between the localized magnetic moments, that is mediated by itinerant electrons, leads to their helical ordering. This ordering, in turn, affects the itinerant electrons, inducing the topologically nontrivial superconducting phase that hosts the Majorana modes. In a wide range of system parameters, the spatial periodicity of a spiral order that minimizes the ground state energy turns out to promote the topological phase. We determine the correlation length of such spiral order and study how it is reduced by thermal fluctuations. This reduction is accompanied by suppression of the topological gap (which separates the zero-energy mode from continuum), setting the upper (critical) temperature for existence of the Majorana quasiparticles. Monte Carlo simulations do not rely on any ansatz for configurations of the localized moments, therefore they can be performed for arbitrary model parameters, also beyond the perturbative regime.

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## ZK1

# BKT transition observed in magnetic and electric properties of $YBa_2Cu_3O_{7-\delta}$ single crystals

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The BKT transition (Nobel Prize in 2016) was predicted by Berezinskii, Kosterlitz and Touless for two-dimensional (2D) systems, films in reality. If a film becames superfluid at a temperature $T_c$ then the superfluid density, $n_s$, appears at $T_c$ and increases with decreasing temperature if no BKT transition occurs. But if BKT transition takes place at $T_{BKT}$, then at temperatures $T_{BKT} < T < T_c$, the superfluid density remains close to zero due to the creation of pairs of vortices with opposite vorticity. This is possible if the vortex attraction force varies as $1/r$, just as for superfluid He films. For superconducting films, such behaviour is possible at a distance smaller than the magnetic screening length

$$L_s = 2\lambda^2/d, \quad (1)$$

where $\lambda$ is the London penetration depth of bulk material and $d$ is the film thickness [P. Minnhagen, Rev. Mod. Phys. (1987)]. At $T < T_{BKT}$ the vortices are bonded.

Numerous experimental results performed for thin superconducting films of usual and high-temperature (HTSC) superconductors are not convincing because, due to sample inhomogeneity, the BKT transition is blurred [L. Benfatto, *et al.*, PRB (2009), C. Xu, *et al.*, Nature Mat. (2015)] or not observed at all [J. M. Repaci, *et al.*, PRB (1996)]. Further theoretical analysis has shown that Eq.(1) which restricts sample dimensions is not sufficient because, due to the boundary conditions at the film edges, the interaction between vorticies turns into a short-range type with near exponential decay [V.G. Kogan, PRB (2007)]. Thus BKT transition will most likely not appear in thin superconducting films of usual superconductor deposited on insulating substrate. The ability to eliminate the edge effects in HTSC consisting of a stack of separated superconducting $CuO_2$ planes was not yet examined.

In our work superconductivity of $YBa_2Cu_3O_{7-\delta}$ single crystals was investigated in small magnetic fields. In magnetic measurements the superconducting transition for $\mathbf{H}\perp ab$ ($T_c^{ab}$) appears 0.4 K higher than for $\mathbf{H}||ab$ ($T_c^c$). Thus, in the temperature range from $T_c^c$ to $T_c^{ab}$ superconductivity is truly two-dimensional. Resistivity in the *ab*-plane and along the *c*-axis was measured simultaneously. In these measurements 2D superconductivity was observed in a temperature range of $0.6-0.8$ K with the clear signs of the BKT transition which occurs approximately 0.15 K below $T_c$, the mean-field transition temperature.

## ZK2

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

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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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**ZK3**

# Interrelation between dynamic and static transport critical current values of superconductors

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Measurements of transport critical current of superconducting conductors with respect to temperature and magnetic field is of particular importance for medical and energy applications. The main interest of using the superconducting materials such as $MgB_2$, Bi-based and $YBa_2Cu_3O_7$ is in the range of 4 - 40 K and testing facilities covering such a range of temperatures and magnetic fields can be costly, especially when considering the cooling power required in the cryogenic system and also dramatically raising cost of liquid helium and its shortage. Transport critical currents in excess of 1000 A at temperatures above LHe are common for commercial wires, making the testing of such samples difficult in setups cooled via a cryocooler even by force gas cooling.

There is also a fundamental interest in the study of superconducting conductors in magnetic fields higher than 20 T, such fields can be obtained by using pulse techniques, however data interpretation can be difficult and there are some discrepancies.

In the current paper we present how qualitative analysis of collective pinning-collective creep theory that does resolve substantial differences between magnetization loops obtained using VSM (Vibrating Sample Magnetometer) and PFMM (Pulsed Field Magnetization Measurement) can provide methodology to define Stepwise Current and Signal Averaging procedure (SCSA) [Mariusz PhD] to conduct combined pulse transport current and pulse magnetic field measurements that deliver results identical to combined DC transport current and DC magnetic field in milliseconds and with minimum boil-off of helium.

## ZK4

# Topological superconductivity in phase-controlled Josephson junctions on Rashba 2DEGs

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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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## ZK5

# Artificial separation of trivial and topological superconducting domains

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Interplay between superconductivity, spin orbit coupling and magnetic field can lead to realization of the topological phase shift [1]. Existence of this topological phase allows for emergence of the bound states, which most famous example is the Majorana bound states that emerge at the boundary of the one dimensional nanostructure [2, 3]. However, similar topological bound state can be also realized in two dimensional system [4]. Moreover, recent experimental works suggest possibility of realization of the topological superconducting domain in magnetic nanostructure coupled with bulk superconductor [5, 6]. In such a case, boundary between trivial and topological phase are "marked" by nearly-zero in-gap bound state. In this seminar, I will discuss and shown how using artificial nanoflake structure can realize similar situation – topological domain surrounded by the nearly-zero energy bound state.

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**ZK6**

# The Superconductivity of Topologically Protected Surface States

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The superconducting proximity effect induced in materials in close contact with a superconductor is well established. We reveal that similarly the topologically protected surface states recently found on the surfaces of special crystals can leak into appropriate adjoining materials. We bring these two effects into proximity and study how superconductivity and topologically protected surface states interact with each other [1], a situation of interest in the search for Majorana bound states. We look at the scanning tunnelling microscopy of a large topological insulator with superconducting islands deposited on the surface, and analyse theoretical models which capture the hybridization between the topological surface states and the superconducting states. The density of states of both the topological insulator and the superconductor turn out to exhibit interesting proximity effects and open up new possibilities for observing Majoranas.

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**ZK7**

# Search for Jack states in quantum Hall systems

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Dilute 2D electrons in magnetic field represent a strongly correlated system in that the Coulomb interaction among the electrons partially filling an isolated degenerate Landau level (LL) defines the only relevant energy scale. Various emergent correlations depend on the LL filling factor $\nu$ and details of the interaction pseudopotential, which depend on the LL index, material, or the 2D layer thickness.

These correlations are elegantly described in terms of composite fermions (CFs), which are topological bound states of the electrons and vortices of the complex polynomial many electron wave function. For example, the Laughlin liquid, generated as a unique and exact zero-energy ground state of two-body contact repulsion at $\nu = 1/3$, corresponds to a single filled LL of essentially noninteracting CFs.

Remarkably, some of the correlated CF states are generated by multi-body interactions. For example, the $\nu = 5/2$ "Pfaffian" state, viewed as either Bose condensate of identical $p$-wave paired CFs in effectively vanishing magnetic field or a dual partition of noninteracting CFs completely filling a LL, is an exact eigenstate of the three-body contact repulsion. Emergence of Coulomb ground states from simple multi-body interactions introduces Jack symmetric polynomials in the analytical construction of those states and their elementary excitations [1].

Here we generate Coulomb ground states at $\nu = K/(K+2)$, compare with ground states of the relevant $(K+1)$-body repulsion, and interpret in terms of $K$-flavored CFs [2]. We arrive at a simple formula for a two-body repulsion generating the nearly exact Jacks for any $K$ [3]. We also determine which Jacks can emerge as Coulomb states in various LLs of GaAs or graphene.

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## ZK8

# Current auto and cross correlations in three terminal hybrid nanostructures with quantum dot

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We investigate auto and cross correlations in electrical currents, which flow through the quantum dot (QD) strongly coupled to superconducting electrode and weakly coupled to two normal metal electrodes. Due to the superconducting proximity effect there appear the Andreev bound states, which strongly affect electron and hole transport. In the so called 'superconducting atomic limit' (*i.e.* for very large superconducting energy gap) subgap transport is provided by electrons tunneling (ET) between the normal metal electrodes and direct (crossed) Andreev reflection processes – DAR (CAR), when electron from one normal metal electrode is converted into the Cooper pair in the superconducting electrode reflecting a hole back to the same (other) normal metal electrode.

We consider various bias voltage configurations: i) symmetrical, ii) asymmetrical and iii) splitter, in which the average CAR, DAR and ET currents vanish, respectively. Taking into account strong Coulomb interactions on the QD the interplay between ET, DAR and CAR processes are studied in the current auto and cross correlation functions. We have decomposed auto and cross correlations into contributions between individual electron and hole events in order to find microscopic processes. In particular, the current cross correlation between normal metal leads is sensitive on the dominant tunneling process involved in transport: it is negative (positive), when ET (CAR) process dominates.

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**ZK9**

# Finite-temperature properties of the Mott phase in the Bose-Bose mixtures

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Using recently developed SC-SBO technique we investigate variation of generic Bose-Hubbard model – the two species Bose-Hubbard model with density-density interaction term. Using equations of motions for Green's functions and RPA decoupling scheme for standard basis operators, one can introduce self-consistent approach to describe such quantum interacting many-body system. The mean-field results are significantly extended due to improved description of quantum and thermal fluctuations. Detailed discussion of equilibrium condition for system of two gases was conducted. Such boson mixtures were also studied from experimental perspective, from which data are compared to SC-SBO approach.

# Prezentacje ustne
# Oral Presentations

**U1**

# Uniaxial pressure studies of charge correlations in cuprates

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The cuprates are known to exhibit a rich variety of electronic orders that break the lattice symmetry. An example is the two-dimensional charge density wave (CDW) order within the $CuO_2$ planes,universally present in all families of cuprates [1]. The CDW order can be responsible for the Fermi surface reconstruction assuming the bidirectional symmetry of these correlations [2, 3]. In contrary, some measurements demonstrated that the CDW order is consistent with a local unidirectional *stripe* order and splits into domains equally distributed along the [100] and [010] directions [4]. Motivated by this controversy, we performed resonant X-ray scattering measurements under uniaxial pressure (up to 250 MPa) in electron-doped cuprate $Nd_{2-x}Ce_xCuO_4$. The applied uniaxial pressure was used as a symmetry breaking field, which in the case of unidirectional CDW order is expected to align the domains along one direction. The lack of the effect of the pressure on the CDW order would be consistent with the bidirectional CDW order. In addition to the RXS studies, the preliminary results of the electronic transport under uniaxial pressure will be presented.

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## U2

# Spin and charge fluctuations within variational approach: Dynamical response functions for Hubbard and $t$-$J$-$U$ models

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The generic phase diagram of high-$T_c$ cuprates encompasses antiferromagnetic (AF) insulator phase that is rapidly destroyed by hole doping. Intense damped magnetic excitations, however, persist up to the overdoped regime [1]. The properties of those collective modes have been recently measured by resonant X-ray scattering for varying chemistry and hole concentrations, revealing substantial differences in the magnetic zone-boundary spectra [2]. Whereas the data may be fitted using effective Heisenberg-models with farther-neighbor exchange, the relation between magnetic modes and the dynamics of correlated itinerant electrons away from half-filling remains unclear. In this contribution we develop an approach that allows to study both the collective-mode fluctuations and single-particle excitations close to the Mott localization on the same footing. This is achieved by adjusting the $1/N$ expansion, commonly employed in paramagnon studies, so that its saddle point coincides with the Gutzwiller-type variational state. We evaluate both the transverse- and longitudinal spin susceptibilities, as well as the charge response in the AF state for the Hubbard and $t$-$J$-$U$ models at intermediate Hubbard-$U$. The primary effect of electronic correlations is the enhancement of magnetic zone-boundary dispersion and suppression the low-energy spectral weight of charge excitations.

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**U3**

# Critical Exponents of $Tl_{0.8}Bi_{0.3}Sr_{1.8}Ba_{0.2}Ca_2Cu_3O_x$ bulk superconductor

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The $Tl_{0.8}Bi_{0.3}Sr_{1.8}Ba_{0.2}Ca_2Cu_3O_x$ - 1223 superconductor was fabricated by the standard mix-oxide technique. The critical temperature of the sample is $T = 120.3\,K$ and the width of the transition to the superconducting state $\Delta T = 1.6\,K$. A.C. susceptibility as well as the magneto-resistance measurements in the magnetic fields up to $90\,kOe$ were carried out to calculate the critical current densities and the irreversibility fields of the sample. The critical current density of the thallium ceramic superconductor was found to be $J_c = 4.8\,kA/cm^2$ in the liquid nitrogen temperature and the irreversibility field in that temperature was obtained to be $B_{irr}(77\,K) = 87\,kOe$. The critical exponents obtained from magnetic susceptibility, magnetoresistance and specific heat measurements are presented and discussed.

**U4**

# Emission of terahertz transients from $La_{0.7}Sr_{0.3}MnO_3$ / $YBa_2Cu_3O_{7-x}$ nanobilayers by femtosecond laser pulses

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Perovskite oxide materials posses a number of functionalities that are very interesting not only in the case of superconductivity, but also in spintronics. The latter include such properties as half-metallicity, mixed valence, colossal magneto-resistive effect, etc. In recent years, we have observed emergence of novel spintronic phenomena based the generation of pure spin currents through spin-orbit interaction in semiconducting and metallic systems. One of such examples is generation of sub-picosecond in duration (THz bandwidth) bursts of electromagnetic radiation at a ferromagnet/metal interface, when it is illuminated by femtosecond optical pulses [1]. The physics of this phenomenon is based on the inverse spin Hall effect. In this report we present the very first studies on THz transient generation in $La_{0.7}Sr_{0.3}MnO_3/YBa_2Cu_3O_{7-x}$ (LSMO/YBCO) nanobilayers excited by 100-fs–wide, 800-nm wavelength optical pulses generated by a Ti:sapphire self-mode–locked solid state laser. Both the LSMO manganite and YBCO cuprate films were grown by high pressure sputtering on (100) LSAT substrates |citeAleshkevych. The thickness of our LSMO films was 9.6 nm, in the order to assure that their Curie temperature would be above 300 K. The thickness of YBCO films was 10 nm. Upon excitation by 100-fs optical pulses our all-oxide nanobilayers emitted at 300 K a small (below 1 mV in amplitude), but well resolved 1.1-ps–wide electromagnetic transients. The corresponding power spectrum extended above 3 THz. Results of low-temperature emissions of the THz transients including the case when YBCO is in the superconducting state, as well as the studies of the LSMO/Ir system will be presented at the conference.

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**U5**

# Upper critical field in superconducting iron selenides intercalated with organic molecules

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A weak bonding between iron chalcogenide layers in superconducting selenides opened new possibilities in modifications of their structure, i.e., allowed to intercalate selenides with organic molecules. However, the problem of the impact of organic intercalants on superconducting properties of the material is still unresolved. There is lack of papers related to superconducting state properties and the majority of the papers published so far concern determination of superconducting transition temperature, $T_c$, only. Superconductors with general formula $(\text{Li-}O)_x(\text{FeSe}_z Ch_{1-z})_y$ ($O$ - Py, EDA; $Ch$ - S, Te) were obtained by solvothermal intercalation of polycrystalline $\text{FeSe}_z Ch_{1-z}$ using Schlenk technique. Superconducting properties of iron selenides intercalated with organic molecules have been investigated by means of SQUID (superconducting quantum interference device) magnetometer. Superconducting phase transition temperature of about 40 K has been revealed from ZFC (zero field cooling) and FC (field cooling) curves at constant field of 10 Oe. Distinct bifurcation between those curves is the result of relatively high content of magnetic phase compare to superconducting one. Upper critical field, $H_{c2}$, was determined with ac magnetic susceptibility in external magnetic field. Magnetization via magnetic field dependences clearly showed irreversibility properties above 30 K and high $T_c$ of the studied materials could be explained by influence of magnetic inhomogeneity on superconductivity in studied systems.

**U6**

# Anomalous Hall effect in Bismuth

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We report the occurrence of ferromagnetic-like anomalous Hall effect (AHE) below 30 mT in Bismuth single and policrystals. The signatures of ferromagnetism in transport are not corroborated in magnetization measurements, thus suggesting the induction of non-intrinsic magnetism at surfaces and grain boundaries in Bismuth. The suppression of the AHE with the increase of magnetic field and temperature coincides with previous reports of superconductivity in Bi, suggesting an interplay between the two phenomena.

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**U7**

# Crystal-field states in cuprates vs *d-d* excitations observed by RIXS: $La_2CuO_4$

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Although the crystal-field electronic structure, from ionic point of view, is quite simple, it has not been established despite of being experimentally studied from the beginning of discovery of high-Tc superonductivity in Sr doped $La_2CuO_4$ in 1986. It already passed 30 years. It is a hope that the derivation of the CEF electronic structure proposed in a paper of Moretti Sala *et al.* [1] with very good experimental team is close to the reality. In $La_2CuO_4$ the Cu ion sits in the local tetragonally-distorted octahedron. In the exact octahedron there are 5 orbital states of the $Cu^{2+}$ ion ($3d^9$ ion, $L$=2 and $S$=1/2), associated with $L_z = \pm 2, \pm 1, 0$. The states are usually denoted as $d_{xy}$, $d_{xz}$, $d_{yz}$, $d_{z^2}$ and the last one $d_{x^2-y^2}$, being the ground state. For establishing the fine electronic structure (FES) it is necessary, apart of experimental revealing excitation energies, to ascribe the eigenfunctions. For, instance, the $d_{z^2}$ state by 25 years was placed at the energy of 0.4-0.6 eV whereas authors of Ref. [1] put it at 1.70 eV.

From theoretical point of view there are very different approaches to explain the obtained FES and CEF parameters, starting from a point charge model to very complex models with taking into account the covalency, hybridization and many other effects.

In this contribution, we will present the derived FES with eigenfunctions, the derived CEF parameters, and first-principles calculations, based on the point-charge model, of the CEF parameters. Within the ionic model we have found very strong correlations between the local tetragonal distortion and the realized fine electronic structure examining different oxides like $La_2CuO_4$, $Sr_2CuO_2Cl_2$, $CaCuO_2$ and $Nd_2CuO_4$. These oxides have been chosen because in this queue the tetragonal distortion increases. $CaCuO_2$ is called "infinite layer" oxide with no apical oxygens - $CuO_2$ sheets are separated by $Ca^{2+}$ spacers. The performed calculations for cuprates are consistent with our earlier calculations of the octahedral parameter $10Dq$ for monooxides FeO, CoO and NiO.

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## U8

# Transport properties of compressed $La_{1.952}Sr_{0.048}CuO_4$ thin films

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It is well known that in thin epitaxial films superconductivity may be enhances by the strain resulting from the lattice mismatch between the film and the substrate [1]. In turn, a magnetic field applied perpendicular to the plane of a disordered thin film can induce the superconductor-insulator transition (SIT). The SIT in thin disordered films has been studied theoretically and experimentally for several decades [2] and various unusual, not yet understood effects, have been revealed. One of such unusual effects is the presence of intermediate metallic phase (MP), which is observed in some systems [3].

In this work we study the SIT in a set of thin $La_{(2-x)}Sr_xCuO_4$ (LSCO) films, with thickness from 26 nm to 120 nm, grown by pulsed laser deposition on $LaSrAlO_4$ substrates. The films are deposited from non-superconducting target with x = 0.048, but in thin films the superconductivity becomes apparent as a result of large, compressive, substrate-induced strain. We observe that the SIT in the LSCO films is strongly dependent both on the film thickness, and on the strain. In particular, the zero-resistive superconducting state is absent in the thinner and more strained films while the temperature dependence of the magnetoresistance resembles the behaviors for arrays of superconducting islands. The results of the transport measurements will be discussed.

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**U9**

# Electron-phonon driven superconductivity of LiBi.

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LiBi is a very intriguing material, as it is built up from the heaviest and the lightest nonradioactive metals in the periodic table. Bismuth is a semimetal with interesting Dirac-like electronic states, while lithium contains only one valence electron and has nearly free-electron Fermi surface. LiBi superconducts below $T_c = 2.45$ K and its crystal structure is tetragonal and can be seen as *bcc* structure distorted along *z*-axis.

In this work, theoretical and experimental studies of LiBi are presented. The experimental part constists of magnetic susceptibility and heat capacity measurements. *Ab initio* calculations of the electronic structure, phonons and the electron-phonon interaction function were done. On this basis two important features of superconductivity are calculated, the transition temperature and electron-phonon coupling constant. The band structure of LiBi is affected by structural distortion and is an interesting interplay between dominating *p*-states of Bi and states of Li, while phonons reflect the huge mass difference of these two elements. Superconductivity of this material is driven by the electron-phonon coupling with moderate magnitude.

Finally, our results are confronted with properties of NaBi, superconductor with $T_c = 2.15$ K, which is isostructural and isoelectronic with LiBi and whose bandstructure was reported to show a topological character [1].

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## U10

# The Interplay between Two Kondo Scales in the $Ce_3PdIn_{11}$ Heavy Hermion System Studied by Angle Resolved Photoelectron Spectroscopy

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The $Ce_3PdIn_{11}$ heavy fermion superconductor ($T_c = 2.3$ K) belongs to the $Ce_nT_mIn_{3n+2m}$ ($T$ - transition metal) family, which is a platform to study physics close to a quantum critical point. The Ce atoms occupy two nonequivalent positions with different chemical environment, what leads to the presence of two different Kondo scales in this compound. Theoretical studies predict complex phase diagram with multiple magnetic phase transitions for such systems [1].

We have performed the angle resolved photoelectron spectroscopy near the Ce $4d \rightarrow 4f$ resonant transition at temperature equal to 6 K. The itinerant character of $f$ electrons is reflected in the spectra. The anomalies in the band dispersion near the Fermi energy are present due to the anisotropic mixing between the conduction band and f levels from different Ce sublattices.

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**U11**

# Chemical view of bonding and superconductivity in LiBi and other intermetallic compounds: the importance of antibonding states

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We have observed superconductivity below $T_c$ = 2.4 K in the low-temperature phase of the LiBi intermetallic compound. The tetragonal CuAu-type structure of $\alpha$-LiBi is difficult to understand in terms of simple packing of hard spheres scheme. It can be, however, viewed as a CsCl-type structure with a tetragonal elongation, which stems from a Peierls-like distortion due to 2/3-filling of the Bi-*p* band.

Our analysis of the projected density of states (DOS) and crystal orbital Hamilton population (COHP [1]) for $\alpha$-LiBi shows a dominant contribution of Bi-Bi antibonding states to the $DOS(E_F)$, which makes LiBi similar to NbRuB and SrSnP superconductors [2, 3]. Further COHP analysis of various intermetallics showed that in many superconducting systems, such as some of the Heusler phases, the $E_F$ lie in the region of nearest neighbor antibonding interactions.

It was shown by Dronskowski *et al.* [4] that intermetallic systems driven by doping towards antibonding interactions often develop an itinerant magnetic order that reduces the electronic free energy via spin polarization. By analogy with this argument we postulate that the superconducting transition is another way for a metallic system to relieve the electronic stress due to occupied antibonding states. The COHP analysis can be therefore considered as a useful chemical tool in the search for new superconductors.

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## U12

# Effect of the spin-orbit coupling on the electron-phonon interaction in superconductors: several case studies.

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Recent widespread interest in topological materials intensified studies on various compounds containing heavy elements, like Pb or Bi. This is of course related to the strong spin-orbit coupling (SOC), which should be present in such materials, and should strongly influence their physical properties. Because some of these materials exhibit superconductivity, a natural question arises what is the spin-orbit coupling effect of the electron-phonon interaction and superconductivity of such materials, containing heavy elements?

Thanks to the ongoing development of computational techniques, calculations of the electron-phonon interaction function, taking into account the spin-orbit coupling, became available recently. In this work we present several case studies, where the spin-orbit interaction effects on the electronic structure, phonons, and the electron-phonon coupling (EPC) is investigated using density-functional calculations. As the prime example we will discuss the role of spin-orbit interaction in determining the electronic and phononic properties of the type-I superconductor $CaBi_2$ [1]. In this case SOC, mainly via the modifications of the Fermi surface topology, reduces the strength of EPC almost twice. As the next two cases we will present Pb-Bi alloy, with extremely strong electron-phonon coupling, and noncentrosymmetric $ThCoC_2$, where SOC splits the Fermi surface but surprisingly has a little impact on the electron-phonon interaction.

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## U13

# Magnetic state and electronic properties of $Sr_4V_2O_6Fe_2As_2$ studied by DFT calculations

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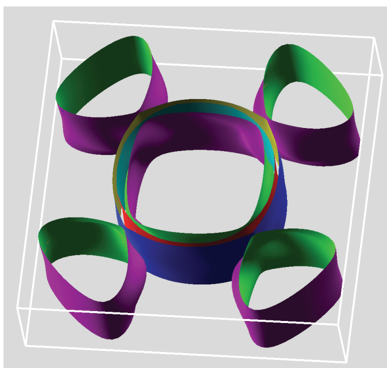
$Sr_4V_2O_6Fe_2As_2$ is known as the superconductor with $T_c$ approximately 37 K [1] as well as large upper critical magnetic field, promising for many application. Unfortunately, there are some inconsistent data concerning the magnetic ordering and superconductivity in this compound [2, 3]. Thus, we decided to investigate stability of possible magnetic arrangements of Fe and V moments using DFT calculations. We also established the electronic properties such as Density of states, Electronic band structures, Fermi surfaces, Electron Localization Function of those configurations and compared to the case of nonmagnetic ordering, e.g. 3D Fermi surface topology shown in the figure below.



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## U14

# Superconductivity in Li-based Heusler compounds

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Although discovered more than 100 years ago, the Heusler material class remains an interesting and active research area. Very recently we described the first Li-based Heusler superconductor, $LiGa_2Rh$ [Chem. Mater., 2019, 31 (6), pp 2164–2173]. Motivated by finding another the Li-based Heusler superconductor, we synthesized and tested several $LiPd_2M$ materials (M = Si, Ge, Sn). All samples were synthesized by a two-step solid state reaction using high-purity Li-chunks, Pd-powder and Ge-powder. The elements were mixed together, pressed into a pellet using a hydraulic press, placed in a tantalum crucible and then sealed inside an Ar-filled quartz tube. The tubes were heated at $550°C$ and $610°C$. As obtained samples were first examined by the powder X-ray diffraction method (pXRD). Rietveld refinement of the patterns confirms that all three compounds crystallize in the cubic $Fm-3m$ crystal structure (space group no 225) with estimated lattice parameters a = 5.9016 Å ($LiPd_2Si$), 6.0105 Å ($LiPd_2Ge$) and 6.2642 Å ($LiPd_2Sn$).Superconductivity, with $T_c$ above 1.8 K, was found only for ($LiPd_2Ge$. It was characterized by means of magnetic susceptibility, heat capacity and resistivity methods. The bulk transition is confirmed by a large heat capacity (HC) anomaly at $T_c$ = 1.96 K. Fitting the HC data yields the Sommerfeld coefficient $\gamma = 5.8(1) mJmol^{-1}K^{-2}$ and the Debye temperature $\theta_D = 244(3)K$. The electron-phonon coupling $\lambda_{e-p} = 0.53$ implies weak-coupling superconductivity. Electronic structure, phonons and electron-phonon interaction functions are computed using the density functional theory. $LiPd_2Ge$ exhibits the strongest electron-phonon coupling within the studied series, in agreement with the observation of superconductivity.

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**U15**

# Magnetic, electron transport, specific heat and Mössbauer spectroscopy properties of $Sr_2AFeAsO_3$ (A = V, Cr and Sc) materials

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Superconducting and magnetic properties of the series of $Sr_2AFeAsO_3$ (A = V, Cr and Sc) materials have been studied by several groups [1–3]. However, the reported results until now are not conclusive yet. For instance, there is a lack of consistency in both magnetic and superconducting states in V- and Sc-based materials, probably due to, i.a. persistent impurities i.e., of $Sr_2VO_4$, FeAs, $SrV_2O_6$, SrO, etc., and the non-stoichiometric effect of O position. In this contribution, we report on the results of magnetic susceptibility $\chi(T)$, specific heat $C_p(T)$, electrical resistivity $\rho(T)$, magnetoresistance *MR(T)*, Hall effect $R_H(T)$ measurements of polycrystalline samples of $Sr_2AFeAsO_3$ (A = V, Cr and Sc), for which the foreign phases have been reduced as much as to be less than 4%. The lattice parameters of our samples have been determined as follows: a = b = 3.9352 Å, c = 15.715 Å and a = b = 3.917 Å, c = 15.781 Å and a = b = 4.051 Å, c = 15.774 Å for V-, Cr- and Sc-based compounds, respectively. Our bulk measurements have revealed CDW ordering in all samples studied but superconductivity only in $Sr_2VFeAsO_3$ below $T_c$ = 27 K, antiferromagnetic ordering in $Sr_2CrFeAsO_3$ below $T_N$ = 39 K and absence of any magnetic ordering and superconductivity in $Sr_2ScFeAsO_3$. The discussion of the obtained data will be concerned to the microscopic Mössbauer spectroscopy and electronic band structure properties from DFT calculations.

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**U16**

# Interplay of magnetism, nematicity and superconductivity in '122' iron-pnictides studied by Mössbauer spectroscopy

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The '122' iron pnictides i.e. $BaFe_2(As_{1-x}P_x)_2$ and $Eu(Fe_{1-x}Ni_x)_2As_2$ were studied by $^{57}$Fe and $^{151}$Eu Mössbauer spectroscopy. Superconductivity in $BaFe_2(As_{1-x}P_x)_2$ is induced by partial substitution of As by P with simultaneous suppression of the spin-density wave (SDW). Underdoped $BaFe_2(As_{0.9}P_{0.1})_2$ is paramagnetic down to 140 K and undergoes orthorhombic distortion with SDW order below 110 K. Mössbauer spectra between 140 K and 110 K (nematic phase) show residual magnetic order. Optimal doping is achieved for $BaFe_2(As_{0.7}P_{0.3})_2$ with $T_c$ = 28 K and the spectral shape below 50 K indicates traces of magnetic order. The oscillations of the charge modulation are observed within the temperature region of the superconductivity for $BaFe_2(As_{0.5}P_{0.5})_2$. The electron-doping is achieved by partial substitution of Fe by Ni in $Eu(Fe_{1-x}Ni_x)_2As_2$. Substitution causes suppression of the SDW and traces of the 3d itinerant magnetism are seen up to x = 0.1. The lack of superconductivity is observed down to 1.8 K, unlike other $EuFe_2As_2$-based compounds substituted for example with Co, Ir or Ru. The $^{57}$Fe and $^{151}$Eu Mössbauer spectra indicate that $Eu^{2+}$ magnetic moments order below 20 K and the hyperfine magnetic transfer field from the 4f rare-earth localized magnetism on the Fe nuclei is observed.

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**U17**

# Single crystal growth and physical properties of $MCo_2Al_9$ (M= Sr, Ba, Eu)

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Single crystals of $SrCo_2Al_9$, $BaCo_2Al_9$ and $EuCo_2Al_9$ were grown using a self-flux method. The crystal structure was examined with x-ray powder diffraction measurements and the Rietveld refinement. Physical properties of the compounds were studied for the first time by means of electrical resistivity, magnetic susceptibility and heat capacity measurements. The measurements revealed that $SrCo_2Al_9$ and $BaCo_2Al_9$ both show diamagnetic behavior and $EuCo_2Al_9$ is an antiferromagnet wit $T_N$ = 3.5 K and effective magnetic moment of $\mu_{eff} = 7.86\mu_B$. Field dependent magnetization for $EuCo_2Al_9$, measured with magnetic field applied along the c direction shows a complex step-like behavior. Heat capacity measurement confirms the bulk nature of the transition and shows that $T_N$ decreases with applied magnetic field, regardless of the measurement configuration. Resistivity measurements show metallic behavior of all three compounds, with no visible transitions.

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## U18

# Resistive Superconducting Fault Current Limiter

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The recent changes in the power networks such as the stronger need for interconnection and the rise of distributed generation result in an increasing demand for protection against high fault currents. Superconducting fault current limiters (SFCL) gives a solution to handle of such faults. The application of a SFCL in power network leads to reduction in hazard potential and savings in switchgear equipment [1] [2] [3]. The paper presents the design and the experimental results of a conduction cooled 6 kV superconducting fault current limiter.

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**U19**

# Distribution of trapped magnetic flux in superconducting stacks magnetised by angled field

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Some novel energy applications require the use of complex shapes of stacks of superconducting tapes as trapped field magnets. A trapped field magnet magnetised in a superconducting motor may experience an angled magnetising field rather than a field normal to its surface. This will affect the trapped magnetic flux distribution.
This work presents the results of the experimental and numerical analysis of the stacks magnetised in an angled magnetic field. The normal trapped flux is measured on two sides of the magnetised stack and compared. The finite elements model using H-formulation is developed to compute the induced superconducting currents.
The resulting distribution of the magnetic flux as well as the electric currents is computed, presented and discussed in details. The importance of the observed distribution patterns is discussed in the context of the implementation of such stacks in a fully superconducting electric motor.

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## U20

# Nodal topological superconductivity in magnetic superstructures

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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 [3–5]. In light of ground-breaking 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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## U21

# Universal FMR procedure to probe magnetic characteristics of ferromagnetic samples

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One of the main goals of performing FMR experiments is to find how the magnetic energy of a sample under investigation depends on magnetic field direction with respect to a sample crystallographic axes. This information is usually obtained by examining the experimental dependence of the resonance field value on its direction in space. The traditional analysis of experimental data is carried out using the well-known Kittel or Smit-Beljers equations describing the precessional motion of the sample magnetization.

We report [1] a new FMR data analysis method by referring to the geometric meaning of the Smit-Beljers equation: the resonance frequency of the magnetic moment precessional motion is equal to the Gaussian curvature of the spatial distribution of the magnetic free energy. This approach allows finding all the values of relevant physical quantities with high accuracy (the saturation magnetization $M$, $g$-factor, demagnetizing tensor $N_{\alpha\beta}$ and magnetocrystalline anisotropy constants $K_{\alpha}$) and consequently the spatial distribution of the free energy from a single set of FMR experimental data. We have tested this approach using the cross-validation procedure [2] for bulk magnetite, (Ga,Mn)As thin film and for YIG ultrathin film. Note, that it was necessary while doing the cross-validation, to use a proper form of the free energy dependence on all above mentioned magnetic parameters characterizing the sample of each ferromagnet under investigation. Therefore, the criterion of the correctness of the free energy formulas given in [2] was also applied in this work. Let us emphasize that none of the known methods of analysis of FMR experiments does give such universal opportunities.

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**U22**

# Magnetic phase transition in $TbAl_3(BO_3)_4$ - classical or modified by quantum fluctuations?

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$R\mathrm{Al}_3(\mathrm{BO}_3)_4$ aluminoborates, crystallizing in the trigonal *R32* structure, are attractive research objects, e.g., all of them show a large magnetoelectric effect and compounds with different *R* ions exhibit different magnetocrystalline anisotropy. For practical applications, their properties near room temperature are the most important (Y, Gd and Nd borates are used in lasers), nevertheless, deep knowledge of their properties over a wide temperature range is useful and desirable.

Studies of a magnetic phase transition, discovered by us in $TbAl_3(BO_3)_4$ at temperature $T$<1 K and related to appearance of a long-range ordering of magnetic moments of the $Tb^{3+}$ ions, aimed at investigating its evolution under influence of an external magnetic field, **B**, will be presented. The studies were performed for 0.1 <$T$ < 300 K, by using the PPMS Dilution Refrigerator and Heat Capacity options, a homemade Hall magnetometer, constructed by us for the dilution refrigerator option of our PPMS (working down to 50 mK), as well as the Quantum Design MPMS-XL SQUID magnetometer equipped with a Helium 3 option.

The specific heat and magnetization studies performed showed the phase diagram of $TbAl_3(BO_3)_4$ to be intriguing for 50 mK $\leq T < 2$ $K$. In this range, under influence of $B$, the temperature of the phase transition decreases. Simultaneously, the magnetization studies showed that the appearing order has a ferromagnetic character with Tb magnetic moments directed along the $c$ axis. Thus, this is the counterintuitive behavior, opposite to that observed in classical ferromagnets. For this reason, a hypothesis was formulated that the transition discovered has a quantum character, i.e., it is influenced by quantum fluctuations.

The phase diagram of $TbAl_3(BO_3)_4$ at subkelvin temperatures, in the coordinates: temperature – differently oriented magnetic, was constructed.

**U23**

# Single Mn-ion displacive-type perovskite multiferroics

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Multiferroics exhibiting simultaneous ferroelectric and magnetic ordering are a topic of intense investigations due to potential breakthrough applications in spin-based electronics. Single-phase and single-ion multiferroics are extremely rare because of almost mutually exclusive requirements, $d^n$ electrons for magnetism and empty $d^0$ shells for ferroelectricity. We have studied ferroelectric and multiferroic phases present in the $Sr_{1-x}Ba_xMn_{1-y}Ti_yO_3$ perovskite system. We have proven the relation between ferroelectric parameter $T_C$ and the structural parameter, the tolerance factor $t = [\text{A-O}]/2^{1/2}[\text{Ti-O}] > 1$, by substituting smaller M = Mn and Ge for Ti, which **enhanced $T_C$** to 420 K. This result supported our assumption that the major parameter responsible for the development of displacive ferroelectric transition is the tension excreted on the perovskite M-O bonds. Similar tolerance factor larger than one is expected for the cubic antiferromagnetic ($T_N$ = 234 K) $SrMnO_3$ for which the Mn-O bonds are also under tension, and such tensions would increase with the substitution of a larger Ba for Sr. By using the two-step synthesis procedure to stabilize the perovskite $Sr_{1-x}Ba_xMnO_3$ materials with the large expected tolerance factor, we have indeed found new multiferroics for x $\geq$ 0.43, which exhibit both antiferromagnetism ($d^3$) and robust ferroelectric distortions originating exclusively from Mn displacements. Typical, displacive-type ferroelectric phase with a polarization of dozens $\mu$C/cm$^2$ occurs when the Mn ions move out of the center of the $MnO_6$ octahedral units at $T_C \sim 350$ K. The Mn spins order below $T_N \sim 210$ K into a simple G-type magnetic structure and the ferroelectric distortions are suppressed. We have recently extended our investigation to the Ti-substituted system for which the displacive distortions significantly exceed the size of distortions in ferroelectric $BaTiO_3$, and the temperatures are increased up to $T_C \sim 420$ K. The $T_N$ decreases to below 200 K and the suppression of ferroelectric distortion below $T_N$ is reduced i.e., we have achieved displacive-type multiferroic with large spontaneous polarization.

## U24

# Charge density waves and magnetism in $RNiC_2$ family (R - rare earth metal)

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The ternary rare-earth nickel dicarbides $RNiC_2$ (R - rare earth metal) with a non-centrosymmetric type of crystal structure offer a unique opportunity to tune the ground state with varying R atom. The charge density waves (CDW) have been found for most of members of the $RNiC_2$ family (R = Pr − Lu) with the temperature scaling linearly with the unit-cell volume [1]. $LaNiC_2$ compound is an unconventional superconductor [2], $SmNiC_2$ undergoes a ferromagnetic transition and the rest of the compounds (apart from nonmagnetic $YNiC_2$ and $LuNiC_2$ exhibiting large positive magnetoresistance [3] and $PrNiC_2$ where only a weak magnetic anomaly is observed [5]) order antiferromagnetically.

In this presentation, the large diversity of physical phenomena occuring in $RNiC_2$ family will be discussed in terms of relations between various types of ordering. The main emphasis will be put on the CDW mutually interacting with magnetism in the polycrystalline $RNiC_2$ and their solid solutions [4], [5].

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**U25**

# Periodically driven quantum dot systems proximitized to superconducting lead

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We study the dynamics of a charge current in the single and double quantum dot systems, coupled between the superconducting and normal reservoirs. The quantum dot's energy levels are periodically driven by an oscillating gate potential. Within the Keldysh formalism extended on the Floquet dimension we study emergence of the higher order harmonics and investigate their contribution to the total current. We analyse an ongoing transfer of the spectral weights between the sub-gap bound states and their behaviour due to the driving power.

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**U26**

# Spin-dependent transport through Quantum Dot-Majorana Wire System

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We study theoretically the spin-dependent transport properties of a quantum dot coupled to a topological superconductor wire hosting Majorana zero energy modes (Majorana wire) and additionally coupled with metallic leads. Using the alternative equation of motion method (AEOM) we explore the signatures of a Majorana zero mode leaking into the quantum dot for a wide range of coupling between the quantum dot and Majorana wire. We observe the interplay between the Kondo effect and Majorana mode. The combination of spin-polarized tunneling amplitude between the quantum dot and Majorana wire and the application of an external magnetic Zeeman field causes the polarization of transport properties. We show that the spin-dependent zero-bias conductance and the Seebeck coefficient strongly depends on the polarization of tunneling amplitudes.

**U27**

# Description of interface between semiconductor and superconducting quantum computer

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Schrodinger [1, 2], tight-binding [1, 3] and Hubbard formalism on the lattice of coupled quantum dots are employed to study various physical properties of electrostatic semiconductor position dependent qubits [4] and the interface between CMOS quantum semiconductor electrostatic computer [2] and superconducting Josephson junction quantum chips [2]. Particular attention is also paid to quantum neural networks made from semiconductor CMOS quantum dots interacting to superconducting qubits in Bogoliubov de Gennes description. The concept of programmable quantum matter is illustrated with simulation results. The analogies between single electron devices and Josephson junction devices are given [5]. The strategy of circuit design and implementation is supported by experimental results. The construction software compatible to IBM QISKIT is presented basing on analogies between single electron devices and Josephson junctions [6].

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## U28

# Majorana phase gate based on geometric phase

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Majorana Zero Modes can be considered as a building blocks for topological quantum computers. Their non-abelian property is expected to enable performing topological protected operations—braids, with which basic quantum gates are related. Unfortunately, the gate set constructed using braiding operations is not complete, i.e. one cannot implement any algorithm with topological protection guaranteed. Namely, the problem is with standard phase gate implementation. We propose a new way for (topological unprotected) phase gate construction, which is based on geometric phase. For this purpose, we study extended Kitaev model with many-body interactions.

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**U29**

# Majorana Bound State leakage in nanoscopic structures.

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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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# Plakaty
# Posters

**P1**

# Mössbauer study of $YFe_2Ge_2$

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The $YFe_2Ge_2$ does not show long range magnetic order and crystallize isostructural to the $AFe_2As_2$ (A = Ca, Ba, Eu, K) iron-pnictide parent compounds and superconductors. Superconductivity with $T_c$ = 1.8 K is strongly dependent on the sample quality (disorder caused by Fe deficiency on the Fe site). Coexistence of ferromagnetic and stripe-type antiferromagnetic spin fluctuations within the Fe plane was recently found by neutron scattering.

$^{57}$Fe Mössbauer spectroscopy measurements were performed versus temperature down to 1.5 K for the $YFe_2Ge_2$ powdered single-crystal sample grown out of Sn flux. Spectra at room temperature (RT) and at 80 K have a shape of broadened pseudo-single line with quasi-continuous distribution of quadrupole doublets. A distribution is caused by the spatial modulation of the electric field gradient, which can be interpreted as consequence of the incommensurate modulation of the charge density on the Fe nuclei, i.e., the charge density wave (CDW). The isomer shift at RT is equal to 0.34 mm/s, which is significantly less than 0.43 mm/s for $BaFe_2As_2$. It means that d-electrons density is significantly lowered in $YFe_2Ge_2$ in comparison to mentioned parent compound, so the system can be considered as strongly hole-doped, like $KFe_2As_2$ superconductor. Spectra at 4.2 K and 1.5 K have wide broadening caused by the spatial modulation of a weak hyperfine magnetic field with the average values about 1.3 and 1.5 Tesla, respectively. The magnetic nature of the spectra close to the ground state can be interpreted as consequence of the spin fluctuations and indicates that the system is close to magnetic instabilities.

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**P2**

# Enhancement of electron doping by iron vacancies in Ni-substituted $FeTe_{0.65}Se_{0.35}$ single crystals

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The structural disorder, frequently present in crystals of iron chalcogenides, sometimes leads to unexpected improvement of superconducting properties, as reported in the case of iron-deficient $FeTe_{0.65}Se_{0.35}$ crystals [1]. In an effort to find the origin of such behavior, here we study the properties of two types of $Fe_{1-y}Ni_yTe_{0.65}Se_{0.35}$ crystals ($0 \leq y \leq 0.11$), grown by Bridgman method with different cooling rates, slow cooling (SC) and fast cooling (FC). The SC crystals with single, tetragonal phase show inferior superconducting properties to properties of the FC crystals, in which considerable admixture of nanometer-size monoclinic inclusions is found due to presence of iron vacancies.

Using matrix formalism for multicarrier systems we extract carrier concentrations and their mobilities from the low-temperature Hall effect data for crystals with $y > 0.03$, in which superconductivity is suppressed. In both types of crystals the evolution of the majority carriers with increasing $y$ is similar, from holes for $y < 0.06$ to electrons for $y > 0.06$, indicating electron doping by Ni substitution. However, at low temperature the concentration of holes in FC crystals with $y < 0.06$ is strongly suppressed, while their mobility is enhanced in comparison to SC crystals. Moreover, while the minority carriers in FC crystals are electrons, in SC crystals these are holes, and electrons appear only at the lowest temperature with increasing $y$. We conclude that inhomogeneity induced by iron vacancies enhances electron doping in FC crystals, what most likely contributes to the enhancement of superconducting fluctuations.

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**P3**

# Why is $Eu(Fe_{1-x}Ni_x)_2As_2$ not a superconductor? - $^{57}$Fe and $^{151}$Eu Mössbauer study

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The $EuFe_2As_2$-based compounds are unique laboratory for investigations of interplay between magnetism and superconductivity. The parent compound $EuFe_2As_2$ undergoes $3d$ itinerant spin density wave (SDW) order at 190 K and $4f$ localized antiferromagnetic order at 19 K. Superconductivity (SC) is induced by substitutions on either one of the three lattice sites as well as by pressure. There are many possibilities for hole and electron doping leading to SC (e.g. $Eu_{1-x}A_xFe_2As_2$ with A = K, Na, La and $Eu(Fe_{1-x}T_x)_2As_2$ with T = Co, Ru, Ir) or isovalent substitution e.g. $EuFe_2(As_{1-x}P_x)_2$. The electron doping is achieved by partial substitution of Fe by Ni in $Eu(Fe_{1-x}Ni_x)_2As_2$ system with structural stability up to x = 0.2. Substitution causes suppression of the SDW, but SC is not observed down to 1.8 K. $^{151}$Eu Mössbauer spectra indicate that $Eu^{2+}$ magnetic moments order below 20 K and $^{57}$Fe Mössbauer spectra detect the hyperfine magnetic transfer field on the Fe nucleus from the Eu magnetic order. Generally speaking, the Mössbauer hyperfine parameters are almost the same as for SC $EuFe_2As_2$-based compounds. This indicates a similar magnetic structure regardless of whether the system is normal conducting or SC, so the absence of SC in $Eu(Fe_{1-x}Ni_x)_2As_2$ is an open question.

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## P4

# London penetration depth anisotropy of electron-irradiated $Ba_{1-x}K_xFe_2As_2$ single-crystals

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We have characterized an electron-irradiated $Ba_{1-x}K_xFe_2As_2$ single-crystal (with x = 0.53) using two different experimental techniques: microwave measurements and magneto-optic measurements. The 122 pnictide crystal has been measured before and after the 2.5 MeV electron irradiation process [1]. After irradiation it was annealed in a number of steps, each of them lasting 1 h, at temperatures increased stepwise by 10 °C, between 90 °C and 180 °C, and measured after each annealing step. Microwave measurements were performed by means of a cylindrical copper cavity, taking advantage of the $TE_{011}$ and $TM_{110}$ modes, allowing for the determination of the London penetration depths changes $\delta\lambda_{ab}(T)$ and $\delta\lambda_c(T)$, i.e. perpendicular and parallel to the sample $c$-axis. The sample showed a full recovery of its $T_c$, however the observed behavior of $\delta\lambda_c$ and $\delta\lambda_{ab}$ was not monotonic *vs* annealing temperature, showing a minimum in $\delta\lambda_c$ and $\delta\lambda_{ab}$ around 120 °C.

This finding was confirmed by magneto-optic measurements, were besides verifying the sample uniformity and the absence of visible defects, the lower critical field $H_{c1}$ of the $Ba_{1-x}K_xFe_2As_2$ single-crystal was obtained and its $\lambda_{ab}^0$ value was calculated. However, above the annealing temperature of 160 °C, only very small changes could be sensed by the magneto-optic method whereas the microwave measurements did show a substantial change of sample properties.

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**P5**

# Hall effect in heavy-fermion antiferromagnetic superconductor $Ce_3PtIn_{11}$

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Recently, the heavy-fermion compound $Ce_3PtIn_{11}$ has been revealed to exhibit ambient pressure long-range antiferromagnetic order ($T_{N1}$ = 2.08 K, $T_{N2}$ = 1.93 K) and superconductivity ($T_c$ = 0.23 K) [1]. Here, we describe the results of our Hall effect study performed in the normal state of single-crystalline $Ce_3PtIn_{11}$ with electric current flowing within the basal plane of its tetragonal unit cell. The Hall coefficient ($R_H$) is negative in almost entire temperature range covered, except for a very narrow temperature interval around the coherence temperature ($T_{coh} \approx 20$ K), where $R_H$ changes sign to positive probably due to a fairly large contribution arising from incoherent skew-scattering effect. The latter feature was hardly observed in $R_H(T)$ determined for related heavy-fermion superconductors, like $CeCoIn_5$ [2] and $Ce_2PdIn_8$ [3], where the incoherent Kondo scattering probed by electrical resistivity is much smaller. Interestingly, in the coherent Kondo regime $(T < T_{coh})$ both the magnitude and the temperature dependencies of the Hall effect are similar in all three materials, with a maximum in $|R_H|(T)$ occurring at almost the same temperature $T^*$ = 6 K. Only in the case of $Ce_3PtIn_{11}$, a non-Fermi liquid like logarithmic decrease of $|R_H|$ below $T^*$, is interrupted by a sudden enhancement of $R_H$ near the onset of the antiferromagnetic state.

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**P6**

# Short-range order in superconducting $(TaNb)_{0.67}(HfZrTi)_{0.33}$ high entropy alloy

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New class of intermetallic compounds, high entropy alloys [1], at the beginning were perceived as one-phase solid solutions. Highly precise experimental studies, using i.e. synchrotron XRD methods, showed, that many high entropy alloys exhibits coexistence of many phases with different atom concentrations. In this work, we study short-range order and lattice distortion influence on electronic structure and superconducting properties of $(TaNb)_{0.67}(HfZrTi)_{0.33}$ (TNHZT) [2, 3], also at high pressures (up to 100 GPa). First-principles calculations have been performed using KKR method with implemented Coherent Potential Approximation (CPA). Short range order within KKR-CPA calculations have been approximated with two models of unit bcc cell with following atom arrangements : $(Ta_3Zr_2Ti)(Nb_3Hf_2Ti)$ and $(Ta_3Hf_2Ti)(Nb_3Zr_2Ti)$. Next, we constructed two supercells – one containing 18 and second 54 atoms. In both cases relaxation calculations have been also performed. Since TNHZT alloy is conventional superconductor, we were able to calculate critical temperature using RMTA approximation. Phonon contribution have been determine using method described in [4].

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**P7**

# The Opportunities for the Magnetic Energy Storing in the High Temperature Superconducting Winding

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Modern power grids are undergoing major changes with increased amount of distributed generation units, such as the solar photovoltaic systems and wind farms integrated in the power grids. However, the integration of these clean sources of energy often imposes adverse effects, such as the midday voltage rise due to a reverse power flow.Various new energy storage technologies to mitigate these problems have been proposed in recent years. New solutions consist in storing energy generated in local sources in the period of excess production and using stored energy to reduce the peak in order to achieve a better balance of supply and demand.

In the paper was pointed out the relevance of the superconducting winding in the energy storage technology. The storage system uses the superconducting coil to accumulate energy in the form of electromagnetic energy. The main features of Superconducting Magnetic Energy Storage (SMES) systems and the evolution of devices designed in the world are presented. This paper shows the magnet design for HTS SMES, including performance analysis, energy increasing method and the impact of the SMES system on the environment. Possible cases of the winding were analysed with particular focus on the solenoid and the toroidal configuration. The considered problem concerns the choice of the solenoid winding configuration for the required energy value with limited space of the strong magnetic field. For the tested device with energy of 34 kJ @ 13 K, it is possible of construction of the magnetic shield to limit the magnetic field zone to allowed values while increasing the energy value by 14 percent.

**P8**

# Analysis of the high temperature superconductivity state in the $PbH_4(H_2)_2$

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Plumbane is the first compound which belongs to the plumbane homologous serie. This serie is similar to the alcanes homologous serie but the main chain isn't composed of carbons but is made of lead atoms. Bonds between two atoms of lead are 3.5 times weaker than the C-C bonds in alcanes. Connection one of the heaviest metals with hydrogen seems very promising to accomplishment a high-temperature supervonductor in relatively low value of pressure.

The main request of these reserch was to calculate what is the critical temperature value (Tc) at which $PbH_4(H_2)_2$ became a superconductor under the pressure 200 GPa. Using the Eliashberg formalism helped to calulate the Tc temperature with consideration high value of electron-phonon coupling constant ($\lambda = 1.3$) in these system. It was also calculated the dimensionless coefficient $R_\Delta$, thermodynamic critical field, free energy and the specific heat for all three values of the Coulomb pseudopotential $\mu^* \in \langle 0.1, 0.3 \rangle$.

**P9**

# Superconducting state in sulfur-hydrogen systems

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We took into account a few selected compressed sulfur and hydrogen systems. In particular for $H_5S_2$ calculations were carried out in Classical Eliashberg Equations scheme and next in Vertex Corrected Eliashberg Equations scheme, which takes account the lowest-order vertex correction to the electron-phonon interaction. We have shown that the superconducting state induced under pressure 112 GPa in this compound is characterized by anomalously high value of Coulomb pseudopotential in both considered schemes. We also took into account the thermodynamic properties of superconducting states which are induced in $H_4S_3$ and $H_2S$ compounds. We proved that thermodynamic parameters of the superconducting state induced in $H_2S$ and $H_5S_2$ calculated in the Classical Eliashberg Equations scheme have similar values. On the other hand, we showed that BCS type superconducting state is induced in $H_4S_3$. However, it is characterized by a very low critical temperature value. For this reason in our opinion in experiment was observed the superconducting state in the $H_2S$ compound, which is kinetically protected in the samples prepared at the low temperature.

**P10**

# Analysis of superconducting fault current limiter 6 kV / 0.14 kA

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The 6 kV / 0.14 kA superconducting fault current limiter (SFCL) is cooled using a cryocooler. The operating temperature of the limiter can be changed, which entails a change in the operating current of the 6 kV / 0.14 kA SFCL. An analysis of the effect of working temperature (from 40 K to 85 K) on the limiter's work has been presented.

## P11

# Electronic structure and electron-phonon coupling in noncentrosymmetric $ThCoC_2$ and $ThCo_{1-x}Ni_xC_2$

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Superconductors lacking inversion symmetry in their crystal structure are know to show unconventional properties. In a recently characterized noncentrosymmetric $ThCoC_2$ there was reported deviation from exponential temperature dependence in the electronic specific heat and non-BCS behavior of the magnetic upper critical field [1]. A following study found that substituting Ni for Co greatly enhances superconducting critical temperature in $ThCo_{1-x}Ni_xC_2$ (from 2.6 K to 11.9 K for $x = 0.4$) [2]. In this work electronic structure, phonons and electron-phonon interaction was studied in $ThCo_{1-x}Ni_xC_2$ basing on *ab anitio* computations, using plane wave pseudopotential [3, 4], as well as KKR-CPA methods [5]. Effect of the spin-orbit interaction on the electronic structure and electron-phonon coupling was investigated. Theoretical results are discussed in veiw of the experimental findings.

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**P12**

# Overcurrent testing of second generation HTS tapes in liquid nitrogen

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Fault current is one of the basic threats to the elements of power systems. Short-circuits in power systems are usually caused by atmospheric overvoltages, faulty operations in power substations, mechanical damage to cables and poles, moisture or damage to insulation. Fault current in a shorted circuit is usually many times greater than the current occurring during normal operation of the network equipment. Fault current flow can cause thermal and dynamic harmful effects on the operation of power equipment. Overcurrent performance of high-temperature superconducting (HTS) tapes is one of the most crucial parameters for industrial applications because the superconducting fault current limiters (SFCLs) and transmision cables are very often subject to short-circuit overcurrent. After quench the fault current may generate too much heat in HTS tapes of these devices and, consequently, lead to the destruction of the entire device. In this paper, the experimentally determined of transient responses of second generation (2G) high-temperature superconducting (HTS) tapes under overcurrent was presented. The series of measurements was performed for the second generation HTS tapes produced by Superpower Inc. The measurements in a liquid nitrogen bath were performed for a few values of currents exceeding the critical value of superconducting tapes.

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## P13

# Theoretical description of the extra large specific heat experimentally observed in the topological insulator $SmB_6$

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Samarium hexaboride ($SmB_6$) is now considered as a topological isolator. The wide interest of the scientific community in this class of compounds results in a large number of experimental papers discovering a series of non-trivial phenomenona.

One of the newly rediscovered phenomenon is the extra large specific heat experimentally observed by Orendáč in $SmB_6$ [1].

In this contribution, we will present a theoretical explanation of this phenomenon.

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**P14**

# Self-organized cascades of giant thermomagnetic avalanches in superconducting plate

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Magnetic flux jumps are one of the phenomena commonly observed both in conventional and in high temperature superconductors [1]. On a bulk $YBa_2Cu_3O_{7-\delta}$ single crystal the inversion of giant trapping moment as a result of thermomagnetic avalanche was discovered [2] at temperature 2K. Our research at low temperatures of the catastrophic dynamics of the magnetic flux $\Phi(t)$ ($t$ is time) as a result of avalanches in massive plates (with thickness of 2-6 mm) of conventional superconductor Nb-Ti (at.%50) alloy has revealed the self-organized cascades of avalanches. The avalanches of the magnetic flux in sample during a sweep of the external magnetic field (parallel to the plate) was studied with the aid of a pickup coil which was wound around the superconductor. When the self-organized cascades of avalanches happens, the magnetic flux enters (screening regimes) or leaves (trapping regimes) in "steps-like" manner. Those, the magnetic flux enters (leaves) in approximately equal successive portions, the number of which can reach value of ten. The width of steps in dependency $\Phi(t)$ is increases with a increase of the plate thickness or with the increase of the magnetic field at which the flux jumps occur. The main peculiarities of "steps-like" avalanche flux movement were studied. The model of the self-organized cascades of avalanches was proposed.

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## P15

# Magneto-optical visualization of the mechano- thermal effect on the pinning structure in the NbTi

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The flux pinning centers in the NbTi alloy are produced by the thermo-mechanical cycling consisting of a series of material drawing and heat treatments. Transmission electron microscopy allows the images of alloys nanostructure on the scale of 100 nm and estimates size of the pinning centers [1]. Magneto-optical (MO) imaging technique was used in superconducting (SC) large grain (50 mm) Nb ingot slice for detection of bulk defects, which are visible as features on MO images [2]. In this report, MO registration of the magnetic flux penetration was used in the Nb50Ti SC for visualization of the mechano-thermal effect on the pinning structure as key element of high critical current density. The disc shape sample was cut from a rod of NbTi after extrusion. The structure of the boundary between the Meissner and critical states was studied during external magnetic field penetration into alloy a) after the extrusion and b) after the heat treatment stages. The magnetic induction distribution in the extruded material exhibits a complicated 3D-structure. Based on the analysis of the correlation function, it was found that: the fractal Housdorff dimension of flux front amounts to about 1.5; the fractal dimension increases a) with increasing external magnetic field and b) in fixed external magnetic field with increasing level of induction at which the analysis was done. MO patterns make it possible to reveal the directions of plastic flow in a material under mechanical stresses at the extrusion. The heat treatment stage leads to significant changes of fractal Housdorff dimension of flux front and the value of critical current density. Other features of magnetic field penetration into SC were discussed.

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## P16

# Structural characterization of $RE\mathrm{Ba_2Cu_3O_{7-\delta}}$ high-temperature superconductors

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Cuprate superconductors are materials of huge technological importance. With the quest of room-temperature superconductivity still unfulfilled, these high-temperature superconductors have emerged as champions for real-world applications. Their main applications currently range from cabling for energy transportation to ambitious projects involving engines based on high-temperature superconductors.

One of the methods for preparation of ceramic high-temperature superconductors of $RE\mathrm{Ba_2Cu_3O_{7-\delta}}$ (*RE* - rare earth element) is the solid-state synthesis method. This method is based on the thermal treatment of a mixture of cooper oxide (CuO), barium carbonate ($BaCO_3$) and rare earth oxide ($RE_2O_3$) powders.

The superconducting materials produced were investigated for microstructural and physicochemical properties. The granulation analysis of the raw materials were performed using a Low-Angle Laser Light Scattering method. Qualitative and quantitative phase analysis of the superconducting materials after synthesis in air atmosphere and annealing in oxygen have been performed by X-Ray Diffraction. A microstructural analysis were carried out by Raman spectroscopy and the morphology of $RE\mathrm{Ba_2Cu_3O_{7-\delta}}$ materials was studied by Scanning Electron Microscopy and Atomic Force Microscopy. Magnetic properties of the samples were examined by means of Vibrating Sample Magnetometer. Magnetic moment measurements were provided in wide temperature range, from 5 to 100 K, in external magnetic field from -15 kOe to 15 kOe. Phase transition from normal to superconductor state was investigated by ZFC/FC curves, measured in external magnetic field of about 10 Oe. Structural properties and electronic structure calculations were performed based on Density Functional Theory model.

## P17

# Effective control of $Y_2BaCu_3O_5$ particles morphology and infiltration growth processing of single grain bulk $Y_2BaCuO_3O_{7-\delta}$ superconductors

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The morphological features and the initial size of the precursor powder significantly influence the growth and the physical properties of bulk high-$T_c$ superconductors. The infiltration growth (IG) process is a superior method for fabricating near-net and high-quality, bulk single grain $RE$Ba$_2$Cu$_3$O$_{7-\delta}$ (*RE*BCO) superconductors. In the present work, we will demonstrate the successful manipulation of the $Y_2BaCuO_5$ (211/Y-211) precursor powders irradiated with high energy ultrasound to control the particle size. By increasing the irradiation power, individual and nanometer-sized (about 300 nm – 500 nm) particles were produced with surface damages and sharp edges. Utilizing the pretreated 211 powders, high- quality single grain samples were fabricated via the IG process. The non-superconducting Y-211 particle size and the content in the bulks were reduced with ultrasonic irradiation power as evinced from microstructural investigations by optical and field emission scanning electron microscopy. The structural modifications in the YBCO samples were studied using RAMAN and X-Ray Diffraction. The superconductivity transition was found at about 92 K, which is not affected by the irradiation of high energy ultrasonic waves. The field dependence of critical current density of the YBCO sample was improved by a factor of 2 at 77 K due to the effective Y-211 grain refinement without any addition of dopants or grain refiners such as Pt and $CeO_2$. The present method is novel, cost-effective, and very convenient to maintain high homogeneity, and is free of chemical contaminants as compared to other methods. The treatment is general to a wide variety of materials, where it can significantly affect the final properties.

**P18**

# Cobalt doping in $CaFe_2As_2$: evolution of the electronic structure

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Despite the fact that more than 10 years have passed since the discovery of iron-based superconductors, these systems are still a subject of intensive research. The key method to reveal phase diagrams of these materials is chemical doping, however its influence on the transport properties raises further questions. $CaFe_2As_2$ is the example of the system wherein Co doping induces superconductivity with critical temperature equal to 20 K. That gives a unique opportunity to perform systematic investigations of a set of samples corresponding to the region of the superconducting dome at the phase diagram.

We studied $CaFe_2As_2$ and $CaFe_{1.93}Co_{0.07}As_2$ systems by means of angle-resolved photoemission spectroscopy (ARPES) at UARPES beamline of the Solaris synchrotron and at in-house laboratory. The Fermi surface of each compound was mapped with application of four different energies of incident radiation corresponding to the four different planes in k-space. Each of the scans was performed using two polarizations of the incident light in order to observe bands with different orbital characters.

Our data indicate the strong dependence of the band structure on the polarization of the exciting radiation what indicates different orbital characters of the bands. We also observed deviation from fourfold symmetry at the Fermi surfaces measured using radiation with different polarizations. The clear effects of electron doping on band shifts were not observed, which indicates that the main influence of Co substitution is not a carrier doping.

**P19**

# Dirac-like electronic-band dispersion of $LaSb_2$ superconductor and its counterpart $LaAgSb_2$

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In condensed matter physics great attention has recently been paid to topological features of electronic band structures of various crystalline systems and, in particular, a possible coexistence of superconductivity and topologically protected states. In this work, we focus on such a kind of non-symmorphic and centrosymmetric intermetallic systems. These are superconducting $LaSb_2$ ($T_{SC} \sim 1$ K) [1] and its analogue $LaAgSb_2$. Particularly interesting is the former one, which reveals also charge density waves and large non-saturated linear magnetoresistivity [2, 3]. Despite several experimental reports, $LaSb_2$ has not yet been studied theoretically.

We present here results of our DFT calculations of both bulk and surface slab electronic band structures of the titled layered compounds. The obtained band structures exhibit strongly dispersive two-dimensional (2D) Dirac-like electronic bands in the vicinity of the Fermi level. These bands are created predominantly by the $5p$-orbitals of the Sb quasi-2D atomic layers [4]. For each system, considered here, the calculated slab Fermi surface (FS) differs significantly from the corresponding bulk FS. This may suggest that certain planes in the Brillouin zone provide topologically protected non-trivial surface states due to non-symmorphic symmetry.

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**P20**

# Self-consistent analysis of anisotropic and isotropic superconducting state on a square lattice

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In the framework of Eliashberg formalism [1, 2], we have characterized the tendency to induce superconducting state on a square lattice. We took into account the pairing mechanism based on the linear electron–fonon interaction [3] and we solved Eliashberg equations approximately isotropic and anisotropic. We have shown superconductong state cannot be created when the order parameter depend on the wave vector (**k**). However, for value of unbalanced parameter ($\gamma$) smaller than $\gamma_C = 0.93$, the linear electron-phonon interaction can induced superconducting state with thermodynamical parameters significantly different from predictions of the standard BCS theory. In the system we have observed anomalous increase in electron effective mass with increasing the unbalanced parameter. In isotropic superconducting state we found unbalanced state for $\gamma > 1$.

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## P21

# $GdFe_{1-x}Co_xAsO$ magnetic superconductors

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In this contribution we present synthesis and physical properties of newly obtained Co-doped GdFeAsO magnetic superconductors.

Due to the specific "composition", GdFeAsO-based superconductors are expected to exhibit similar intriguing features (e.g. magnetic field induced superconductivity) as the intensively investigated $EuFe_2As_2$-based compounds. [1, 2]

At room temperature, compounds form both families are paramagnetic and crystalize in tetragonal structure. Below certain temperature ($< T_{SDW}$) they undergo tetragonal to orthorhombic structural phase transition accompanied by a spin density wave order on iron sublattice; and at $T_N$ they exhibit localized (antiferro)magnetic order associated with $f$-electrons of the lanthanide ion (Eu or Gd). With Co-doping it is possible to tune the $< T_{SDW}$ and introduce superconductivity in these systems. [1–4] Therefore, $GdFe_{1-x}Co_xAsO$ compounds have promising properties, where interplay of superconductivity and $f$-electron magnetism is expected, similarly as in the $EuFe_2As_2$-based superconductors.

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**P22**

# Additional losses in the windings of the HTS transformers made of 2G parallel tapes in the context of the equalization currents

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In a case where a rated current of the transformer windings is higher than the critical current of the used superconducting tape, it is necessary to use parallel tapes. As a result, the currents flow in individual parallel tapes is uneven. The effect of the uneven current distribution is the flow of equalization currents which violate the distribution of the current in the winding as well as additional losses in the windings.

In order to determine the values of equalization currents as well as additional losses in the windings, a comparative analysis of the distribution of these currents were carried out for the 3-phase 63 MVA, 10 MVA and 630 kVA conventional transformers and a 3-phase 50 MVA superconducting transformer with windings made of Roebel cable, representing transformers for high, medium and low voltage power network. For each of the considered Cu transformers a transformer with HTS 2G superconducting windings of the same power rated was designed, and for the transformer with windings made of Roebel cable - transformer with windings made of HTS 2G superconducting tape and with copper windings

The analysis showed that even despite the use of many parallel 2G HTS tapes in the LV windings of the transformers, the value of additional losses in the windings is small, which basically eliminates the need of a tape transposition or an application of Roebel's cable.

**P23**

# Inter-subband paring in doped 2D superconductors with asymmetric confinement

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Among the wide class of multiband superconductors the special attention is recently paid on the $LaAlO_3/SrTiO_3$ interface that exhibits gate tunable superconductivity with the critical temperature of about 100 – 200 mK [1]. Superconducting properties of $LaAlO_3/SrTiO_3$ interface still remain unclear and are the subject of the ongoing debate, which mainly concentrates around the role of the spin-orbit interaction and electronic correlations. Interestingly, the superconducting transition temperature $T_c$ of the interfacial 2DEG created in the considered system displays a domelike shape as a function of the gate voltage [2], which has been experimentally established to appear slightly above the Lifshitz transition, when an additional band crosses the Fermi level.

Here we show that similar domelike shape of $T_c$ can be observed in asymmetric 2D doped superconductors as a result of the inter-subband pairing induced by the change of the interaction matrix elements. Although the presented model is far from the realistic model of the $LaAlO_3/SrTi_3$ interface, some important similarities suggest that the observed domelike shape of $T_c$ at $LaAlO_3/SrTiO_3$ interface results from the change of the overlap between the orbitals induced by the gate voltage. This, in turn, leads to the enhancement of the inter-subband (inter-orbital) pairing across the Lifshitz transition which generates characteristic domelike shape.

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## P24

# Phonon-mediated superconductivity in the presence of spin-orbit interaction

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Research on superconducting properties in the presence of spin-orbit coupling is the subject of many scientific articles published in recent years. However, understanding of the problem is inadequate due to the fact that the theoretical results have been obtained using too simplified models.

The main purpose of the research is to derive full thermodynamic equations for phonon-mediated superconducting state in the presence of Rashba-type spin-orbit interaction. Conventional Eliashberg approach, does not take into account thermodynamic functions related to the spin-orbit interaction. Currently, even the most advanced works on phonon-mediated superconductivity, formed in the presence of spin-orbit coupling, use classical Eliashberg equations, while the spin-orbit interaction is included only in the Eliashberg function. The additional interaction also changes the very form of Eliashberg equations, therefore, the analysis of the problem is incomplete.

The starting point of our generalized formalism is the Frohlich Hamiltonian complemented by the spin-orbit coupling operator. The main element of the analysis is the definition of the four-component Nambu spinors. It allows to create a 4x4 matrix Green's function, which takes into account Green's scalar functions corresponding to the spin-orbit interaction. No additional approximations were used during the calculations, except those that are normally used in the derivation of classical Eliashberg equations, i.e. the Wick's and Migdal's theorems.

## P25

# Magnetic and transport properties of YBCO superconductors fabricated by MG and IF methods

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YBCO superconductors were preparated by inflitration-grow and melt-grow methods. The XRD patterns and SEM pictures of the samples are presented and analysed. The critical current density was calculated from the a.c. suseptibility versus temperature measurements using the Bean's critical state model. Samples were obtained as a result of slow cooling from the temperature 1015 °C down to the temperature 970 °C. The properties of the samples for different cooling rates are compared.

**P26**

# High pressure treatment of Fe-122 and Fe-1144 wire cores-phase stability

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The high pressure, especially hydrostatic (CIP or HIP) have a wide potential to modify microstructure of materials. They can change the thermodynamic properties during synthesis. The high pressure annealing have been used mainly to the $MgB_2$ family wires pristine and doped and also for Fe-122, Fe-1144 and $KFe_2Se_2$ materials.

The HIP treated family of new superconductors as: FeAs-122 or FeAs-1144 reach $T_c$ of 40K and $J_c$ slightly lower to $MgB_2$. The $H_{c2}$ up to 80T were found (applicable in near future for high energy SMES-s). All of these superconductors require HIP technology and nano grains of substrates (20-30 nm), high compaction during synthesis and annealing, for obtaining great improvement of pinning force density ($F_P$).

We show the comparison between the results of samples annealed at ambient pressure and at high pressure (up to 1.4 GPa) of either eutectic salts liquids, liquid glasses or at argon gas media.

**P27**

# Improved electrical properties in Fe-based and $MgB_2$ superconductors due to high pressure synthesis and sintering. Perspectives for large scale high pressure wire production.

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One of the main challenges in development of high $j_c$ $MgB_2$ or Fe-based wires and bulks is to improve packing factor and electrical connectivity of those polycrystalline materials. This is often realized through sample pressing that leads to material densification. Such process can be conducted before (cold pressing) or during material synthesis (hot pressing). It is important to determine available density range for each material and possibility to obtain high transport properties in long lengths of superconducting wires under dedicated high pressure machines.

We have performed synthesis and sintering of such superconductors under high pressure, both using axial and isostatic pressing up to 1 GPa, on bulk and thick monofilamentary wires. We report changes in RRR and electrical connectivity K leading to increase in critical current density $j_c$ in both types of superconductors. Perspectives of application in large scale on wires is presented.

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