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Book of Abstracts

[The abstracts are presented in the alphabetic order according to speakers' last names.]

T_c-enhancement in $Fe_{1+\delta}Se$ by electrochemical lithium intercalation

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The superconducting transition temperature (T_c) of tetragonal $Fe_{1+\delta}Se$ can be enhanced from 8.5 K to 44 K by chemical structure modification resulting in significant increase of $[Fe_2Se_2]$-interlayer separation: from 5.5 Å in native $Fe_{1+\delta}Se$ to > 7 Å in $K_xFe_{1-y}Se$ and to > 9 Å in $Li_{1-x}Fe_x(OH)Fe_{1-y}Se$. Structure modification is achieved by the shift of the $[Fe_2Se_2]$-slabs and filling the interlayer space by solvated lithium and iron cations or by large alkaline cations like K.

We report the application of electrochemical approach to modification of $Fe_{1+\delta}Se$ superconducting properties. In contrast to chemical way the electrochemical approach allows to insert small amount of non-solvated Li^+ into $Fe_{1+\delta}Se$ structure keeping the native structure and $[Fe_2Se_2]$-layers arrangement. The amount of intercalated lithium is extremely small (about 0.07 Li^+ per f.u), however, caused slight change of carrier concentration results in enhancement of T_c up to ~ 44 K. The electrochemical intercalation provides the opportunity to get information about the "T_c vs carrier concentration" relation for this family of superconductors and open new possibilities for T_c-enhancement.

Competing nanoscale electronic inhomogeneities driven by *i)* short range CDW, *ii)* dopants and *iii)* strain: the roadmap for controlling the emergence of high temperature quantum coherence in complex out of equilibrium materials

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New experimental results using synchrotron radiation have provided compelling evidence for universal multiscale phase separation from nanoscale to mesoscale in all high temperature superconductors driven by *frustrated CDW transitions* [1-3] *short range interstitials self-organization* [4] *arrested phase separation* [7-8] driven *by misfit strain* [9,10] and proximity to a *Lifshitz transition* [11] where key ingredients are zero point motion amplitude and local lattice fluctuations in a double wells also in H_3S [12] and novel organic superconductors [13] . Here we show that high temperature superconductivity is characterized by a dome of Tc controlled by tuning the chemical potential near Lifshitz transitions in strongly correlated multi orbitals systems by *pressure, strain, and charge density*. A major step in the field has been the development of the theory of superconductivity driven by Fano Feshbach resonances near Lifshitz transitions [13]. The physics is getting very complex because of phase separation [14,15] forming percolating superconducting pathways in complex non Euclidean geometries [16] promoting the emergence of quantum coherence at high temperature which makes these systems like biological systems [17-20]. These results show the emerging of the proposed BPV -(Bianconi, Perali, Valletta) theory for the amplification of the critical temperature by Fano resonances [11,13] which is illustrated for a case of unidimensional organic superconductor doped p-Terphenyl [13].

References:

1. Campi, G., et al. Inhomogeneity of charge-density-wave order and quenched disorder in a high-Tc superconductor. **Nature** 525, 359 (2015) doi:10.1038/nature14987
2. Bianconi, A., Quantum materials: Shape resonances in superstripes. **Nature Physics** 9, 536. (2013) doi:10.1038/nphys2738
3. Poccia, N. et al. Optimum inhomogeneity of local lattice distortions in La2CuO4+y. **Proceedings of the National Academy of Sciences** 109, 15685 (2012) doi:10.1073/pnas.1208492109
4. Ricci, A. et al. Multiscale distribution of oxygen puddles in 1/8 doped YBa2Cu3O6.67. **Scientific Reports** 3, 2383 (2014) doi:10.1038/srep02383
5. Fratini, M., et al. Scale-free structural organization of oxygen interstitials in La2CuO4+y. **Nature** 466, 841 (2010) doi:10.1038/nature09260
6. Poccia, N., et al. Evolution and control of oxygen order in a cuprate superconductor. **Nature Materials** 10, 733 (2011) doi:10.1038/nmat3088
7. Ricci, A., et al. Nanoscale phase separation in the iron chalcogenide superconductor K_0.8Fe_1.6Se_2 as seen via scanning nanofocused x-ray diffraction. **Physical Review** B 84, 060511 (2011) doi:10.1103/physrevb.84.060511
8. Ricci, A., et al. Direct observation of nanoscale interface phase in the superconducting chalcogenide KxFe2−ySe2 with intrinsic phase separation. **Physical Review** B 91, 020503 (2015) doi:10.1103/physrevb.91.020503
9. Poccia, N., et al. Misfit strain in superlattices controlling the Electron-Lattice interaction via microstrain in active layers. **Advances in Condensed Matter Physics** 2010, 261849 (2010) doi:10.1155/2010/261849
10. Ricci, A., et al. Structural phase transition and superlattice misfit strain of RFeAsO (R=La, Pr, Nd, Sm). **Physical Review** B 82, 144507 (2010) doi:10.1103/PhysRevB.82.144507
11. Bianconi, A., Feshbach shape resonance in multiband superconductivity in heterostructures. **Journal of Superconductivity** 18, 625 (2005) doi:10.1007/s10948-005-0047-5
12. Bianconi, A., Jarlborg, T., Superconductivity above the lowest earth temperature in pressurized sulfur hydride. **EPL (Europhysics Letters)** 112, 37001 (2015) doi:10.1209/0295-5075/112/37001
13. Mazziotti, M. V., et al. Possible Fano resonance for high Tc multi-gap superconductivity in p-Terphenyl doped by K at the Lifshitz transition. **EPL (Europhysics Letters)** 118, 37003 (2017) doi:10.1209/0295-5075/118/37003
14. Kugel, K. I. et al. **Phys. Rev. B** 78, 165124 (2008)
15. Bianconi, A., Poccia, N., Sboychakov, A. O., Rakhmanov, A. L., Kugel, K. I., Intrinsic arrested nanoscale phase separation near a topological Lifshitz transition in strongly correlated two-band metals. **Supercond. Sci. and Technology** 28, 024005 (2015) http://dx.doi.org/10.1088/0953-2048/28/2/024005
16. Campi, G., Bianconi, A., High-Temperature superconductivity in a hyperbolic geometry of complex matter from nanoscale to mesoscopic scale. **Journal of Superconductivity and Novel Magnetism** 29, 627-631 (2016) http://dx.doi.org/10.1007/s10948-015-3326-9
17. Campi, G., Innocenti, D., Bianconi, A., CDW and similarity of the Mott Insulator-to-Metal transition in cuprates with the Gas-to-Liquid-liquid transition in supercooled water **J. of Superconductivity and Novel Magnetism** 28, 1355 (2015) doi:10.1007/s10948-015-2955-3
18. Poccia, N., Bianconi, A., Sep. 2011. The physics of life and quantum complex matter: A case of Cross-Fertilization. **Life** 1, 3-6. doi:10.3390/life1010003
19. Poccia, N., et al. Changes of statistical structural fluctuations unveils an early compacted degraded stage of PNS myelin. **Scientific Reports** 4, 5430 (2014) doi:10.1038/srep05430
20. Di Gioacchino, M., Campi, G., Poccia, N., Bianconi, A., Correlated disorder in myelinated axons orientational geometry and structure. **Condensed Matter** 2, 29. (2017) doi:10.3390/condmat2030029

Resonant scattering studies of charge order in quantum solids

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The spontaneous self-arrangement of electrons into static and periodically modulated patterns, a phenomenon commonly termed as *charge order* or *charge-density-wave*, has recently resurfaced as a prominent, universal ingredient for the physics of copper oxide high-temperature superconductors. Its antagonist coexistence with superconductivity, together with a putative connection to a quantum critical point beyond optimal doping, are symptomatic of a very fundamental role played by this collective electronic state for the physics of cuprates.

Resonant x-ray scattering (RXS) has rapidly become the technique of choice for the study of charge order in momentum space [1], owing to its ability to directly identify a breaking of translational symmetry in the electronic density. We have used RXS in Bi-, Nd, and Y-based cuprates to detect charge-density-waves even in presence of short-ranged order [2-3], exploring a realm previously accessible only by STM. Using the information available from the full two-dimensional momentum space, we have taken this experimental methodology further to reveal the local (intra-unit-cell) symmetry in the charge distribution [4,5].
To conclude, I will discuss recent results and future perspectives concerning the study of the nanoscale (10-100 nm) texture of electronic orders using coherent soft x-ray scattering in scanning (RXS nanomapping) and imaging (ptychography and holography) mode.

[1] R. Comin and A. Damascelli, Resonant x-ray scattering studies of charge order in cuprates, *Annual Reviews of Condensed Matter Physics* (2016).
[2] R. Comin, *et al.,* Charge Order Driven by Fermi-Arc Instability in Bi2Sr2-xLaxCuO6+d, *Science* **343**, 390 (2014).
[3] E. da Silva Neto*, R. Comin*, *et al.*, Charge ordering in the electron-doped superconductor Nd2-xCexCuO4, *Science* **347**, 282 (2015).
[4] R. Comin, *et al.*, Broken translational and rotational symmetry via charge stripe order in underdoped YBa2Cu3O6+y, *Science* **347**, 1335 (2015).
[5] R. Comin, *et al.*, Symmetry of charge order in cuprates, *Nature Materials* **14**, 796 (2015).

Holographic maps of quasiparticle interference

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This talk will review a new approach to the analysis of Fourier-transformed STM images with subatomic resolution based on analysing overlaps between Fourier amplitudes that differ by reciprocal lattice vectors. The resulting holographic maps provide important information about the electronic structures of materials. When applied to superconducting cuprates this method solves a long-standing puzzle of the dichotomy between equivalent wavevectors. This analysis suggests that d-wave Wannier functions of the conduction band provide a natural explanation for experimental results that were interpreted as evidence for competing unconventional charge modulations.

Emergent fermions in solid state "universe"

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The universe, with a continuum space-time and Lorentz invariance, has only three possible types of fermions in theory, namely, Dirac, Weyl and Majorana fermions. In reality, only Dirac-type elementary particles have been discovered. While it is still under debate whether any elementary particle of Weyl or Majorana types exists, all three types of fermions have been proposed to exist as emergent quasiparticles in solid state "universe", which has discrete lattices without Lorentz invariance. Its 230 space groups in lattices can produce even more types of emergent fermions that are not allowed in the real universe. In this talk I will present our experimental discoveries of Weyl fermion, "hourglass" fermion, three-compoment "new fermion", and Majorana fermion in solid state "universe".

Pseudogap and Fermi surface in the presence of a spin-vortex checkerboard for 1/8-doped lanthanum cuprates

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The lanthanum family of high-temperature cuprate superconductors is known to exhibit both spin and charge electronic modulations around a doping level of 1/8. We assume that these modulations have the character of a two-dimensional spin-vortex checkerboard and investigate whether this assumption is consistent with the Fermi surface and the pseudogap measured by angle-resolved photoemission spectroscopy. We also explore the possibility of observing quantum oscillations of transport coefficients in such a background. These investigations are based on a model of noninteracting spin-1/2 fermions hopping on a square lattice and coupled through spins to a magnetic field imitating a spin-vortex checkerboard. The main results of this paper include (i) a calculation of the Fermi surface containing Fermi arcs at the positions in the Brillouin zone largely consistent with experiments, (ii) identification of factors complicating the observations of quantum oscillations in the presence of spin modulations, and (iii) an investigation of the symmetries of the resulting electronic energy bands, which, in particular, indicates that each band is doubly degenerate and has at least one conical point, where it touches another doubly degenerate band. We discuss possible implications these cones may have for the transport properties and the pseudogap[1].

[1] P. E. Dolgirev and B.V. Fine, Phys. Rev. B **96**, 075137 (2017).

Charge and current modulations in a spin-fermion model with overlapping hotspots and physics of cuprates.

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Several well-known phenomena in the hole-doped cuprates like breaking the rotational invariance, appearance of the pseudogap, charge modulation and d-wave superconductivity occur on a low energy scale of hundreds Kelvin. As it is not quite clear how to obtain these phases in an unified way from microscopic models of cuprates, we consider a low-energy model of fermions interacting with close to critical antiferromagnetic excitations. In contrast to a standard spin-fermion model, we assume in agreement with ARPES data that the fermion spectrum in the antinodal region is shallow, such that the 8 hotspots merge at not very weak interaction into 2 antinodal hot regions. In addition to the interaction via antiferromagnetic fluctuations, a long range part of the Coulomb interaction reducing the superconducting transition temperature is taken into the consideration.

It is demonstrated in the mean field approximation that a variety of phase transitions are possible depending on the chemical potential and details of the electronic spectrum near the antinodes. In addition to the d-wave superconductivity and charge density wave with the diagonal modulation, we find a nematic transition (Pomeranchuk instability) followed by a transition to a charge density wave with a modulation along the bonds and d-wave formfactor.

Moreover, it is found that an electron-hole pairing with a vector connecting to neighboring antinodes (antiferromagnetic vector of cuprates) is also possible. Remarkably, this pairing leads to circulating currents rather than to a charge modulation. These currents are similar to those proposed in DDW (d-density wave state). Depending on the parameters of the electron spectrum one can also obtain an incommensurate structure of circulating currents.

The nematic transition does not lead to formation of the gap but the circulating currents do. This gap is located at the antinodes and we associate this state with the pseudogap state.

The results of our theory can serve as an explanation of recent experiments on cuprates performed with the help of STM, NMR, hard and resonant soft X-ray scattering, neutron scattering, sound propagation, and with some other techniques.

High temperature conventional superconductivity

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We will overview conventional superconductivity with high critical temperatures. Major attention will be devoted to sulfur hydride with the record Tc=203 K1. This superconductivity was well established and the high Tc proved by observation of zero resistance, isotope effect, and X-ray diffraction studies2. Meissner effect was proved by direct measurements with SQUID magnetometer1, and ac magnetic susceptibility3. Infrared data also will be presented4. Hydrogen sulfide demonstrated complex behavior with pressure and temperature. We found a way of transformation of H2S to H3S. The cubic phase of H3S is responsible for the highest Tc. Pure H3S was recently synthesized directly from sulfur and hydrogen.
The observed apparently conventional superconductivity was analyzed in numerous theoretical works. In particular, it was found that the major input (~90%) in the superconductivity is from hydrogen part of the phonon spectrum and therefore H3S can be considered as doped atomic metallic hydrogen. As for pure hydrogen, we will present our data on electrical and optical measurements at pressures above 400 GPa5.
We will discuss other materials with Tc>80 K (PH3, Si2H6) and prospects for achieving Tc>203 K.

1 Drozdov, A. P., Eremets, M. I., Troyan, I. A., Ksenofontov, V. & Shylin, S. I. Conventional superconductivity at 203 K at high pressures. *Nature* **525**, 73-77, doi:doi:10.1038/nature14964 (2015).
2 Einaga, M. *et al.* Crystal Structure of 200 K-Superconducting Phase of Sulfur Hydride. *Nature Physics*, doi:DOI: 10.1038 (2016).
3 Huang, X. *et al.* Direct Meissner Effect Observation of Superconductivity in Compressed H2S *arXiv:1610.02630* (2016).
4 Capitani, F. *et al.* Spectroscopy of H3S: evidence of a new energy scale for superconductivity. *Nature Physics* **13**, 859–863 (2017).
5 Eremets, M. I., Drozdov, A. P., Kong, P. P. & Wang, H. Molecular semimetallic hydrogen. *arXiv:1708.05217* (2017).

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

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

Emergence of a new interpretation of NMR of cuprates superconductors

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In recent years, with a number of experiments on different materials we established that a single spin component is not able to explain the NMR shifts, pointing to a different magnetic hyperfine scenario. Driven by these finding we compiled all literature NMR shift data for planar Cu from which it becomes obvious, now, that the hitherto adopted interpretation of the shifts is wrong, e.g., a large isotropic shift reigns on the strongly overdoped, Fermi liquid side of the phase diagram and starts disappearing as doping and/or temperature are lowered. Also recently, we showed that the charges in the CuO2 plane can be quantified with NMR, which led to the discovery that the sharing of holes between Cu and O (not the doping) is responsible for various cuprate properties, e.g., their maximum Tc. In yet another set of experiments we solved a long-standing NMR conundrum that considered Y-1237, and Y-1248 very 'homogeneous' materials, while most other cuprates show large electric field variations in the plane. We find that these homogeneous systems are highly charge ordered systems, with nearly commensurate charge ordering, responding to pressure, temperature, and magnetic field. This charge ordering, as compiled literature data show, is likely to be ubiquitous to the CuO2 plane.

High-T_C superconductor-semiconductor devices

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We demonstrate experimentally the effect of superconducting proximity to semiconductor light- emitting structures proposed by us for enhanced two-photon gain, electrically-driven entangled-photon generation and Bell state analyzers. We show the effect of high-temperature superconductor proximity to topological insulators such as Bi_2Se_3 and Bi_2Te_3 and devices based on technologically important semiconductors such as Si and GaN.

We proposed an efficient approach for generation of entangled photons, based on Cooper-pair luminescence in conventional semiconductors without the requirements of isolated emitters [1] and analyzed a new effect of enhanced light amplification in electrically-driven semiconductor- superconductor structures, including Cooper-pair based two-photon gain [2].

Hybrid high-T_C superconductor-semiconductor tunnel junctions were demonstrated by us using two techniques. Macroscale device by the newly-developed mechanical bonding technique [3] and nanoscale planar device using PLD deposition. Tunneling-spectra characterization of the Macro-hybrid junctions of BSCCO combined with bulk GaAs, and GaAs/AlGaAs quantum well, exhibits excess voltage and sub-gap nonlinearity. We also demonstrated the first ever nanoscale super-Schottky diode based on a high-Tc superconducting tunnel junction. A buffer-free direct growth of nanoscale YBCO thin films on heavily doped GaN was performed to realize a high-T_C superconductor-semiconductor junction. A strong sub-gap nonlinearity, which is the hallmark of super Schottky diode, was observed in these devices, which have various applications as rf-detectors and mixers.

We further proceeded to demonstrate the effect of photon-assisted tunnelling in these hybrid structures for their application as light sensors. We show a clear shift in tunneling spectra to higher energies under pulsed laser excitation due to the effect of photon-induced carrier transient population change of superconductor quasiparticles. Our approach can provide unexplored information about the deep band structure of the HTS, and give new insights into the physics of high-T_C superconductors.

Lastly, the superconducting proximity to topological insulators such as Bi_2Se_3 and Bi_2Te_3 was demonstrated. It is shown to persist up to at least 80K – a temperature an order of magnitude higher than any previous observations. Moreover, the induced superconducting gap in these devices reaches values of 10mV, significantly enhancing the relevant energy scales. Andreev reflection is observed as an excess current and an increase in differential conductance maxima.

These results open new directions for fundamental studies in condensed matter physics and light-matter interaction and enable a wide range of applications in optoelectronics and quantum information processing.

[1] A. Hayat, et al, Phys. Rev. B 89, 094508 (2014). [2] R. Marjieh, E. Sabag and A. Hayat, New J. Phys. 18, 023019 (2016); [3] A. Hayat et al. Phys. Rev. X 2, 041019 (2012). [4] P. Zareapour, A. Hayat, et al. Nature Commun. 3, 1056 (2012).

Spin and charge-density-wave fluctuations in cuprates

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Charge density-wave (CDW) order or more precisely 2-D charge-density-wave fluctuations have now been established as a ubiquitous property of under-doped cuprate superconductors. These low-energy fluctuations exist near doping $p \sim 1/8$ in the cuprate phase diagram. My talk will be in two parts. In the first part I will present x-ray studies of the structure of the charge density wave in $YBa_2Cu_3O_{6+x}$ near $p=1/8$. I will show how the application of a magnetic field supresses superconductivity and leads to a 2D to 3D crossover in the CDW structure. With long coherence lengths being achieved at high field. In the second part of the talk I will present inelastic neutron scattering measurements of the collective spin excitations in CDW ordered $La_{2-x}Sr_xCuO_4$ (x=1/8). The excitation spectrum is highly structured with a strong response near (1/2,1/2) in the energy range 40-100 meV. I will show how this spectrum evolves through optimal doping and may relate to superconductive pairing.

Doping-dependence of charge-de Order in Bi2201

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The cuprate superconductor phase diagram is characterized by the interplay of multiple broken symmetry phases. Charge density wave (CDW) order has been observed in the under-doped regions of many cuprate families. It is also widely accepted that near optimal doping, cuprates undergo a reconstruction from Fermi arcs to a large Fermi surface. In the particular cuprate $Bi_2Sr_2CaCu_2O_{8+d}$ (Bi2212), scanning tunneling microscopy (STM) studies have characterized a *d* form factor CDW that exists on the under-doped side of this reconstruction. Here, we use STM to examine the role of charge order in $(Bi,Pb)_2(Sr,La)_2CuO_{6+d}$ (Bi2201), to test the universality of conclusions drawn from earlier Bi2212 studies. Remarkably, in Bi2201, we observe *d* symmetry CDW order *coexisting* with the large Fermi surface in the over-doped regime. We use the nanoscale inhomogeneity within each sample to track the doping dependence of the wavevector and spectroscopic signature of the CDW.

Is magnetism relevant to cuprate superconductivity: lanthanides versus charge compensated 123?

Amit Keren

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Many theories suggest that the mechanism for cuprate superconductivity is based on super-exchange interaction between electrons. The most obvious test of these theories is a measurement of the correlation between Tc and the super-exchange parameter J. Alteration of J is achieved by chemical modifications or external pressure. Measurements of J are done with: Neutron scattering, muon spin rotation (mSR), two magnon Raman scattering or resonant inelastic x-ray scattering. However, the experimental data is confusing. A recent Raman study showed an anticorrelation between Tc and J in the set of $LnBa_2Cu_3Oy$ compounds with Ln=(La,..Lu,Y) [B.P.P. Mallet et al., Phys. Rev. Lett. 111, 237001 (2013)]. On the other hand, experimental measurements on the charge compensated 123 material (CaxLa1-x)(Ba1.75-xLa0.25+x)Cu_3Oy (CLBLCO) inferred an overall positive correlation between Tc and J [D.S. Ellis et al., Phys. Rev. B 92, 104507 (2015)]. Thus, the effect of J on Tc is not established experimentally. In this talk I will review the experimental situation and shed light on this controversy.

Amplitude and phase dynamics in a photoinduced charge density wave transition

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The charge density wave transition in low dimensional metals gives rise to an order parameter quantified by an amplitude and a phase. Because of the reduced dimensionality of these materials, the transition temperatures are reduced from their mean field value, and fluctuations are often observed above the experimentally obtained transition temperature. In this study, we use light to perturb and destroy the charge density wave in the rare-earth tritelluride compound LaTe3 and are able to separately monitor the amplitude and phase dynamics during the recovery of the charge density wave on the femto- to picosecond timescale. We observe that while the amplitude recovers on an ultrafast timescale locally, global phase coherence sets in on a much longer timescale due to persistent phase fluctuations. Comparisons will be drawn to the thermodynamic phase transition in similar compounds.

Role of disorder in superconductivity of Fe-based systems

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Disorder can result in interesting and sometimes unexpected effects in multiband superconductors. Especially if the superconductivity is unconventional like in iron-based pnictides and chalcogenides. I'm going to discuss how the impurity scattering affects superconducting states with s+- and s++ gaps, and show that disorder causes the transitions between s+- and s++ states and examine observable effects these transitions can produce.

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Doping the holographic Mott insulator

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Mott insulators are central to the physics of strongly correlated electron systems. If the normal state of the system is a Fermi liquid, characterized by the short range entanglement and well defined quasiparticles, the Mott insulator formed after introducing strong enough background lattice is easily understood as a classical "traffic jam" of repulsive quasi-electrons.
But what if the normal state is instead the densely entangled strange metal? Then one gets the most notorious Mott insulator, observed in under-doped cuprate high-Tc superconductors. This state violates some of the simple logic which follows from classical "traffic jam" picture.

The holographic duality, discovered in string theory, describes generic properties of certain classes of such densely entangled quantum matter. Using holography, we build the "strange metal" version of the Mott insulator as a commensurate state between spontaneous intertwined charge density wave and a lattice. We show that this state shares many properties with the conventional Mott insulator, but is different in several aspects. Crucially, these differences can shed light on the unconventional features of the Mott state in the under-doped cuprate.

Multiple Andreev reflection effect spectroscopy of iron-based superconductors

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Here we present a comprehensive study of the structure of the superconducting order parameter in various Fe-based pnictides and chalcogenides. We using a "break-junction" technique in order to form clean SnS junctions (S is superconductor, n is thin and high-transparent layer of normal metal) and natural SnSn-…-S stack structures [1]. The (intrinsic) multiple Andreev reflections effect (IMARE) occurring in these contacts causes a set of dynamic conductance features which position is directly determined by the superconducting gap(s) energy at temperatures $0 < T < T_c$ [2,3]. The used IMARE spectroscopy of the break junctions is unique and advantageous, since provides direct and high accurate measurement of the most important energy parameters of superconductor in bulk and their temperature dependences.

We determined the values of the large and the small superconducting gaps in 1111, 122, 111, 11, and 122-Se families of iron-based superconductors (for a review, see [1,4-8] and refs. therein). Although a moderate in-plane gap anisotropy was detected in 122 pnictides, we have not detect any nodes present in the $k_x k_y$ plane. The gap temperature dependences deviate from standard single-band BCS-like curves, being typical for a weak interband interaction in k-space. For all the studied compounds, the BCS ratio for the large gap $2D_L/kT_c = 5\text{-}6$ exceeds the weak coupling BCS limit 3.5, which is caused by a strong coupling. Within the critical temperatures range $T_c = 9\text{-}53$ K, the BCS ratios for both gaps remain almost constant.

Literature

[1] S.A. Kuzmichev, T.E. Kuzmicheva, Low Temp. Phys. **42**, 1008 (2016)
[2] M. Octawio, *et al.*, Phys. Rev. B **27**, 6739 (1983)
[3] R. Kümmel, *et al.*, Phys. Rev. B **42**, 3992 (1990)
[4] T.E. Kuzmicheva, *et al.*, EPL **102**, 67006 (2013)
[5] T.E. Kuzmicheva, *et al.*, Physics Uspekhi **57**, 819 (2014)
[6] M. Abdel-Hafiez, *et al.*, Phys. Rev. B **90**, 054524 (2014)
[7] T.E. Kuzmicheva, *et al.*, Phys. Rev. B **95**, 094507 (2017)
[8] T.E. Kuzmicheva, *et al.*, Physics Uspekhi **60**, 419 (2017)

Insights into spin excitation spectrum of high-temperature cuprate superconductors from finite cluster simulations

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We theoretically study spin excitations in cuprate superconductors under the assumption that the system is divided into weakly interacting finite clusters of spins 1/2, possibly forming a checkerboard or a more disordered superstructure. The energy spectrum of a small cluster depends dramatically on the shape and the size of the cluster. In particular, the ground state of the cluster can be either a spin singlet or a multiplet, depending on the parity of the number of spins in the cluster and on how the cluster can be divided in two sublattices. This fact, supplemented by selection rules, leads to profound consequences for the magnetic response computed on the basis of the cluster model. The patterns of the response functions exhibit a remarkable variability which agrees with the experimental observations. At the same time, some features of the response established in neutron scattering experiments to be common for a range of compounds and doping levels are robustly reproduced in our calculations. One such feature is a broad maximum of the local susceptibility at the frequency (40-70) meV.

Superconductor applications in the electric power grid

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The first commercial superconductor application for the electric power grid was SMES, Superconductor Magnetic Energy Storage, for compensation of voltage dips and sags. These products, introduced around 2000 and using low temperature superconductor magnets with around 2 MJ of energy storage, have been completely displaced by reactive-power STATCOM equipment using power semiconductors, illustrating the highly competitive commercial environment for electric power equipment. Early efforts to develop rotating machinery, power cables, transformers and fault current limiters based on low temperature superconductors never even reached the commercial stage. Yet pressures from ongoing load growth, siting barriers, environmental and safety issues, and need for more reliability and higher power quality are pushing the electric power utilities to seek new solutions. More recently, the successful development of high-performance high temperature superconductor (HTS) wire has reignited opportunities for many of these applications to address utility needs, with prospects of more compact and efficient systems, lower impedance, higher safety and environmental sustainability, and novel ways to protect and stabilize the grid. Presently, the two most promising applications are AC power cables and "resistive" superconductor fault current limiters, where significant numbers of government- sponsored demonstrations have been successfully installed in the grid, and the first commercial (not government-funded) projects have just recently started. This presentation will review the factors which have enabled these applications to achieve some initial success, and also the obstacles holding back these and many other possible applications, such as cost of wire and refrigeration, need for standardization, and utilities' natural aversion to novelty. All in all, the future looks hopeful as these obstacles are gradually being overcome.

Reference

[1] A. P. Malozemoff, The power grid and the impact of high-temperature superconductor technology: an overview, in Superconductors in the Power Grid, ed. C. M. Rey (Woodhead Publishing, Cambridge UK, 2015), pp. 3-28.

Production of 2G HTS wire and development of HTS devices at SuperOx

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SuperOx is an international group of companies headquartered in Russia and active in the production of HTS materials and development of HTS devices.
The company growth path involved three main steps: (1) establish the production of 2G HTS wire of the world competitive quality and price, (2) differentiate the company among other wire manufacturers by providing advanced wire customisation options tailored to specific applications, and (3) promote the demand on wire and capture more value by developing own HTS device projects.
SuperOx has established the production of customised 2G HTS wire based on the IBAD-MgO and PLD-GdBCO technologies. Key processing steps in SuperOx wire production sequence will be described in the talk. At present, we market 2G HTS wire 12, 6 and 4 mm wide with single piece lengths up to several hundred metres and critical current at 77 K in self-field in the range of 200-400 A/cm. Among available customisation options are silver, copper, solder, and polyimide coatings, as well as filamentisation, lamination and wire stacks.
Evolving beyond the HTS material production, SuperOx has been developing HTS devices such as fault current limiters, cables, coils, rotating machines, current leads, and 2G HTS composite bulk. We will present examples of SuperOx HTS device activities in the talk.

Topological structures in a model cuprate

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The origin of high-T_c superconductivity and other unconventional properties of cuprates is presently still a matter of great controversy mainly due to a complex interplay of charge, orbital, spin, and lattice degrees of freedom. Recently we have introduced a minimal model to describe the charge degree of freedom with the on-site Hilbert space reduced to only the three effective valence centers $[CuO_4]^{7-,6-,5-}$ (nominally $Cu^{1+;2+;3+}$), where the electronic and lattice degrees of freedom get strongly locked together, and made use of the S=1 pseudospin formalism[1]. The conventional spin degree of freedom seems to play merely negative effect in high-T_c superconductivity due to anticorrelation or intertwinning effects of spin and charge/superconducting degrees of freedom. Despite its seeming simplicity the model is believed to capture the salient features both of the hole- and electron-doped cuprates. The pseudospin formalism elucidates an unique fermion-boson duality of the doped cuprates, does provide an unified standpoint for classification of the "myriad" of electronic phases in cuprates and the evolution of the CuO_2 planes under a nonisovalent doping, introduces the on-site mixed valence quantum superpositions and order parameters to be novel features of the cuprate physics, does provide a comprehensive description of the correlated one- and two-particle transport, coexistence of p- and n-type carriers, electron-hole asymmetry, anticorrelation of conventional spin, charge, and superconducting order parameters.

The 2D pseudospin system is prone to creation of different topological structures from domain walls, in-plane and out-of-plane vortices to single-centered and multi-centered skyrmions which form topologically protected inhomogeneous distributions of the eight local S=1 pseudospin order parameters including charge density and superfluid order parameters.

In the talk we focus on analytical descripton of different nontrivial skyrmion-like topological defects typical for 2D (pseudo)spin S=1 systems [2] and results of computer simulations of topological structures on large (256x256, 512x512) square lattices performed with a special algorithm for CUDA architecture for NVIDIA graphics cards including a nonlinear conjugate-gradient method to minimize energy functional and Monte-Carlo technique to directly observe the forming of the ground state configuration. The technique allowed us to uncover novel features of the phase transitions, in particular, look upon the nucleation of odd domains and the emergence of topological structures, their evolution with lowering the temperature and under deviation from half-filling.

References

1. A.S. Moskvin, Phys. Rev. B **84**, 075116 (2011); J. Phys.: Condens. Matter **25**, 085601 (2013); J. Phys: Conf. Ser. **592,** 012076 (2015); JETP, **121**, 477 (2015); A.S. Moskvin, Yu.D. Panov, F.N. Rybakov, A.B. Borisov, J. Supercond. Nov. Magn., **30**(1), 43 (2017).
2. N.A. Mikushina, A.S. Moskvin, Phys. Lett. **A 302/1**, 8 (2002).

Eliashberg equations with pairing boson induced by antiferromagnetic `hidden order' in cuprates

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An emergence of the 'magnetic boson' providing Cooper-pairing 'glue' is considered in the model of superconducting cuprates with semi-classical antiferromagnetic fluctuations that defy the antiferromagnetic ordering, but become a coherent 'instantonic crystal' simultaneously with condensation of the Cooper pairs. The "crystal" manifests broken Matsubara time translational symmetry of the correlated Fermi-system and plays the role of its 'hidden order'. The instantons are bound with the Cooper pair condensate and form the Cooper pairing 'glue' in the initially repulsive Fermi-system. Thus, the two competing orders: antiferromagnetic and superconducting coexist (below some Tc) in the form of superconductor with 'hidden' antiferromagnetic 'instantonic crystal'. The 'hidden order' scenario based on the Euclidean 'crystallization' was proposed earlier in [2]-[4], where a spin density wave (SDW) with Matsubara time-periodic amplitude was considered. It was demonstrated analytically in [2], that the SDW with an amplitude that behaves as a snoidal Jacobi function of the Matsubara time, leads to zero scattering cross section for weakly perturbing external probes, like neutrons, etc., thus representing 'hidden order'. In the present work the set of extended Eliashberg-like equations with bosonic 'glue' of antiferromagnetic instantons is derived and solved self-consistently. This new picture is discussed in relation with the different experiments in high- Tc superconductors.

[1] A.M. Polyakov, "Gauge fields and strings", Harwood Academic Pub., 1987.
[2] S. I. Mukhin, J. Supercond. Nov. Magn. **24** (2011) 1165-1171.
[3] S. I. Mukhin , Physica B: Physics of Condensed Matter **460** (2015) 264-267.
[4] S. I. Mukhin, J. Supercond. Nov. Magn. **27**(2014) 945-950.

Factors supporting d-pairing and high Tc in cuprates

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In this talk we will analyze and discuss different peculiarities of the crystal structure, magnetic and electronic properties of cuprates supporting d-pairing and high Tc values. The quasi-2d crystal structure and strong electron correlations result in strong local antiferromagnetic short order. It is decreasing with hole doping and results in two Lifshitz transition changing the topology of the Fermi surface. Pairing due to magnetic fluctuations and electron-phonon coupling simultaneously forming d-wave gap and doping dependent isotope effect if electron-phonon coupling with buckling phonon mode is stronger than with breezing one. Pressure effect on critical temperature is discussed. Increasing the exchange coupling in La_2CuO_4 under intensive light irradiation is predicted and its effect on Tc is discussed. Discussion is based on our calculations within the mulielectron hybrid scheme LDA+GTB [1] and its polaronic extension P-GTB [2]. This work has been done under financial support of the President's of Russia program "Support of the leading scientific schools", Grant **2016** NSh-7559.2016.2

[1]. Elena I.Shneyder, Sergei G.Ovchinnikov, Maxim.M. Korshunov, Sergei V.Nikolaev; JETP Letters .2012. **96**, Issue 5, pp 349-360.

[2]. Makarov I.A., Shneyder E.I., Kozlov P.A, and Ovchinnikov S.G.. Physical Review B. 2015, **92**, 155143

Quantum nano-engineering of highest-Tc superconductivity

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All my research was primarily focussed to (ever higher-T_c) superconductivity, so first I will outline some of the important early developments, from elemental metals to alloying or pressure/chemical effects and T_c enhancements. Subsequently I will discuss our systematic experiments on doping, strain, electric field effect in high-T_c cuprates and related quantum materials[1-7]. Finally, I will address the ongoing challenge to deliver the room temperature superconductor. Several scenarios are plausible, ranging from BCS-like approach with pressure experiments (like M. Eremets et al.), to selected small clusters (V. Kresin et al.), to ingenious sandwitch structures ('ginzburgers'), to artificially layered materials (I. Bozovic et al.) and creative 'ionic' nano-engineering and/or various combinations. Some relevant recent experiments and latest insights into high-T_c superconductivity will also be critically discussed.

References

1. M. Abrecht et al. PRL **91**, 057002 (2003); EPFL Thesis no. 2792 (2003)
2. D. Cloetta et al., Phys. Rev. B**74**, 014519 (2006); EPFL Thesis no. 3333 (2005)
3. D. Pavuna et al., Journal of Physics **108**, 012040 (2008) and references therein
4. C. Cancellieri et al., Phys. Rev. B**76**, 174520 (2007); EPFL Thesis no. 4120 (2008)
5. D. Ariosa et al. Appl. Phys. Lett. **92**, 092506 (2008) and references therein
6. D. Oezer, M.Sc. Thesis, EPFL (2009); N. Wooding, Ph.D. Thesis (2013)
7. A.T. Bollinger et al. Nature **472**, 458 (2011) ; G. Dubuis, EPFL Ph.D. Thesis (2014).

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Perspective applications of iron-based superconductors

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Iron-based superconductors discovered in 2008 are still point of interest due to its high critical parameters such as H_{c2} and J_c, and low anisotropy. There are a number of compound "families" such as $LnFeAsO_{1-x}F_x$ (1111), AFe_2As_2 (122), Li_xFeAs (111), FeSe (11), $AFeAs_2$ (112), recently discovered $A^1A^2Fe_4As_4$ (1144) and so on. The highest critical temperature is about 56K for Sm-1111 but synthesis difficulties strongly limit the vast application of this "family". 122-compounds forms easily under ambient conditions, are stable in atmosphere's oxygen and moisture and has no phase transitions at high temperatures. T_c for Ba-122 doped with potassium is a little bit lower than for 1111 and reaches 39K that is comparable with T_c for MgB_2, but H_{c2} for $BaFe_2As_2$ compound with different dopant exceeds 80T and J_c is up to 10^6 A/cm^2. That makes them perfect candidates for high-field and high-current application such as superconducting wires, magnets, fault current limiters, etc.

Probing optically silent superfluid stripes in c uprates

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Unconventional superconductivity in the cuprates emerges from, or coexists with, other types of electronic order. However, these orders are sometimes invisible because of their symmetry. For example, the possible existence of superfluid charge stripes in the normal state of single layer cuprates cannot be validated with linear infrared optics, because interlayer Josephson tunneling fluctuations are expected to vanish on average [1].

I will present the c-axis nonlinear optical response of the $La_{2-x}Ba_xCuO_4$ cuprate family, at TeraHertz frequencies (1 THz) [2]. Nonlinear third harmonic generation (THG), characteristic of Josephson coupling between superconducting layers in cuprates, promptly disappear at T_c for weakly charge ordered compounds (x=9.5% and 15.5%). Remarkably, in the case of $La_{1.885}Ba_{0.115}CuO_4$ (x=11.5%), third harmonic generation was observed above T_c=13 K, throughout the striped and charge order phases (T_{co}=55 K) [3]. I will discuss the nonlinear response of a pair density wave condensate agrees well with the experimental measurements. These results provide compelling experimental support for the presence of hidden superfluid order in the normal state of cuprates.

References

[1] Berg, E. et al. *Phys. Rev. Lett*. 99, 127003 (2007).
[2] Rajasekaran, S. et al. *Nat. Phys.*, 12, 1012–1016 (2016).
[3] Rajasekaran,S. et al. arXiv:1705.06112 (2017).

Electron-phonon interaction in copper-oxide superconductors

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It is well known that electron-phonon coupling is responsible for superconductivity in conventional superconductors, but the prevailing view is that it is not important in high temperature superconductivity. Yet, evidence that electron-phonon coupling is very strong for certain phonons in the copper oxides has been building. In particular, Cu-O bond-stretching phonons at 65-85meV in $La_{2-x}Sr_xCuO_4$ are known to show anomalously large broadening and softening near the reduced wavevector q=(0.3,0,0). The magnitude of the anomalous broadening follows the superconducting dome so this phenomenon may be important for superconductivity. Furthermore, a similar phonon anomaly in $YBa_2Cu_3O_7$, becomes greatly enhanced in the superconducting state. I will discuss these results as well as their relationship to features in the electronic spectra measured by angle resolved photoemission (ARPES). The remainder of the talk will focus on new work focused on low-energy phonons in BSCCO as possible candidates for the mechanism behind enigmatic low-energy kinks observed in electronic dispersions.

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[The title and the abstract were not available at the time of printing this program.]

Actinide hydrides as perspective high-temperature superconductors

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Since the experimental observation of H_3S phase with critical temperature of transition to superconducting state of 203 K at 120 GPa the hydride phases of different elements can be considered as a perspective way to approaching the room-temperature superconductivity in 2 or 3 component hydrogen-rich systems.
Recent theoretical investigations of strong electron-phonon coupling in CaH_6 (SC transition at 220 K), $S_{0.925}P_{0.075}H_3$ (280 K), LaH_{10} (286 K), YH_{10} (326 K)[1-3] motivated us to study hydrides of lanthanides and parts of actinides with a half-life > 10 years. Unexpectedly lanthanides hydrides (except of La) do not show high critical temperature, while actinides hydrides pose much more interesting class of materials as high-T_C materials.
We performed variable-composition evolutionary search for new stable hydrides in the U-H, Th-H systems. Several new phases were found to be thermodynamically stable at different pressures namely $P6_3/mmc$ -UH_7 (Tc = 100 K), $P\bar{6}m2$ -U_2H_{13} (Tc = 115 K), $Fm\bar{3}m$ -UH_8 (Tc = 193 K), $\bar{4}m2$ -U_2H_{17} (Tc = 119 K), , $P6_3/mmc$ -UH_9 (Tc = 86 K).[4] Experimental observation confirms the formation of UH_9 and UH_7 phases at high pressure. In the Th-H system we found two new superconducting phases: $P2_1/c$-ThH_7 (Tc =65 K), $Fm\bar{3}m$-ThH_{10} (Tc = 194 K). Critical temperature of the ThH_{10} phase may approach ~200 K at lower pressures.
Other actinide hydrides were studied as well, where we found superconducting PaH7, PaH8 phases in the Pa-H system, PuH_7, PuH_8, PuH_9 and extremely hydrogen-rich PuH_{18}, PuH_{20} phases in Pu-H system. We also studied the Ac-H, Am-H, Cm-H, Np-H systems in order to find superconducting phases. The dependence of EPC parameter, TC and ω_{log} on the pressure in the range 0-500 GPa was studied for the most promising phases.
The possibility to increase critical temperature by doping of predicted phases was also comprehensively studied. The best results were found for the doped phases U_3NdH_{24}, U_3TmH_{24}, U_3EuH_{24}, U_3GdH_{24}
In the conclusion, the investigation of the actinide hydride phase along with doped phases could be considered as an important step towards the hydride high-T_C superconductors.

References.
1. Wang, H.; Tse, J. S.; Tanaka, K.; Iitaka, T.; Ma, Y. Superconductive Sodalite-like Clathrate Calcium Hydride at High Pressures. *Proc. Natl. Acad. Sci.* **2012**, *109* (17), 6463–6466.
2. Yanfeng Ge, Fan Zhang, and Yugui Yao, First-principles demonstration of superconductivity at 280 K in hydrogen sulfide with low phosphorus substitution, Phys. Rev. B 93, 224513 (2016).
3. Liu, H.; Naumov, I. I.; Hoffmann, R.; Ashcroft, N. W.; Hemley, R. J. Potential High-Tc Superconducting Lanthanum and Yttrium Hydrides at High Pressure. *Proc. Natl. Acad. Sci.* **2017**, 201704505.
4. Kruglov, I. A.; Kvashnin, A. G.; Goncharov, A. F.; Oganov, A. R.; Lobanov, S.; Holtgrewe, N.; Yanilkin, A. V. High-Temperature Superconductivity of Uranium Hydrides at near-Ambient Conditions. *ArXiv170805251 Cond-Mat* **2017**.

The interplay of holes and electrons in the superconducting cuprates

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In the search for mechanisms of High-T_c superconductivity it is critical to know the electronic spectrum in the pseudogap state from which superconductivity evolves. The lack of ARPES data for every cuprate family precludes an agreement as to its structure, doping and temperature dependence and the role of charge ordering. No approach has been developed yet to address the issue theoretically, and we limit ourselves by the phenomenological analysis of the experimental data.

We argue that, in the pseudogap state ubiquitous in underdoped cuprates, the spectrum [1] consists of holes on the Fermi arcs and an electronic pocket in contrast to the idea of the Fermi surface reconstruction via charge ordering. At high temperatures the electrons are dragged by holes while at lower temperatures they get decoupled. The longstanding issue of the origin of the negative Hall coefficient in YBCO and Hg1201 at low temperature is resolved: the electronic contribution prevails as its mobility becomes temperature independent, while the mobility of holes, scattered by the short-wavelength charge density waves, decreases.

To reveal the origin of the electron pocket we analyse the cuprates’ energy spectrum in frames of the Varma pseudogap state picture [2] using the minimal model Hamiltonian on the basis of *d, p* orbitals per unit cell. We show that for the pseudogap phase, resulting from time reversal violation by the strong local *d-p* correlations [2], within the certain doping range one should expect an opening of the small electronic pocket at the center of the Brillouin zone. In conclusion we discuss the influence of the lattice structural changes on such transformation of the energy dispersion.

[1] L. P. Gor’kov & G. B. Teitel’baum, Sci. Rep. **5**, 8524 (2015)
[2] C. M. Varma, Phys. Rev., **B 55**, 14554 (1997); **B 73**, 155113 (2006)

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Topological quantum critical fluctuations in cuprates and in Fe-based high temperature superconductors

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The model which describes the quantum critical fluctuations in both cuprates and Fe based supercondutors, despite the differences in their microscopic physics, is the dissipative quantum xy model. The solution of this model reveals a new class of criticality due to the proliferation of topological excitations in time. Singular Fermi-liquid properties, such as linear in temperature resistivity, as well as d-wave superconductivity are shown to follow.