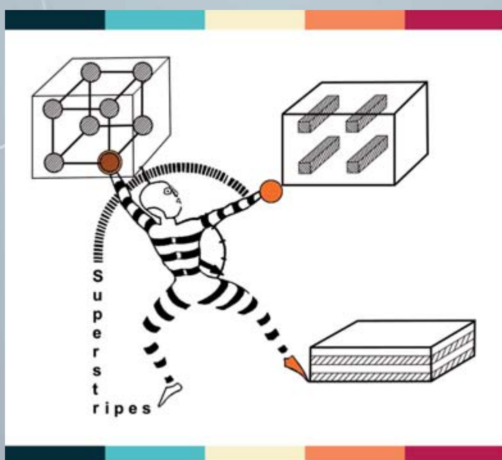
QUANTUM COMPLEX MATTER

edited by

Antonio Bianconi - Augusto Marcelli - Yasutomo Uemura



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Papers presented at the
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Antonio Bianconi – Augusto Marcelli – Yasutomo Uemura

Index

Spin Mechatronics-A. Einstein meets Spintronics-

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Keywords: Einstein-de.Haas effect, spin current, spin-rotation coupling,

A. Einstein and W.J. de Haas discovered experimentally the equivalence of magnetic moment and mechanical rotation in 1915 [1].
In the same year, S.J. Bernett showed that the mechanical rotation can generate a magnetic field, i.e., the so-called Bernett field, even in a body with no electric charge [2].
These phenomena are caused by the angular momentum conservation between electron spin and mechanical rotation, which has been proved in the general relativistic quantum mechanics [3].
We introduce mechanical effects in spintronics and propose a variety of novel spintronics phenomena. In particular, the coupling between nuclear spin and mechanical rotation is demonstrated [4]. Since the Bernett field is enhanced more than three orders of magnitudes in nuclei than electron spins, the mechanical nuclear-magnetic-resonance (NMR) may provide new applications of NMR.
We also observe the generation of spin current by the flow of liquid metals. Combining this effect with the spin Hall effect [5], the spin-hydrodynamic generation of electricity is obtained [6].
The mechanical generation of spin and spin current opens a door from “Spintronics” to “Spin-Mechatronics”.

References:

1. A.Einstein and W.J.de Haas, Verhandl.Deut.Physik.Ges, 17,154 (1915).
2. S.J.Bernett, Phys. Rev. 6, 239 (1915).
3. M.Matuo, J.Ieda and S.Maekawa, Phys. Rev. Lett. 106, 076601 (2011).
4. H.Chudo, M.Ono, K.Harii, M.Matsuo, J.Ieda, R.Haruki,S.Okayasu, S.Maekawa, H.Yasuoka and E.Saitoh, Appl. Phys. Express 7, 063004 (2014).
5. Spin Current, eds. S. Maekawa *et al.* (Oxford University Press, 2012).
6. R.Takahashi, M.Ono, K.Harii, S.Okayasu, M.Matsuo, J.Ieda, S.Takahashi, S.Maekawa and E.Saitoh, Nature Phys. 12, 52 (2015).

Triplet *p*-wave superconductivity with ABM state in Bi/Ni bilayers

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Most superconductors (SCs) are singlet s-wave SCs, whereas high T_C cuprates are singlet *d*-wave SCs. Few are triplet SCs. In addition to the unusual thermodynamic properties, we use Andreev reflection spectroscopy (ARS) to probe the Cooper pairs and measure the gap symmetry in Bi/Ni bilayer. We use ARS with unpolarized and polarized metals to conclude it is a triplet SC, ARS in all three dimensions to show it is a *p*-wave SC with the same gap structure as that of the Anderson-Brinkman-Morel (ABM) state in superfluid ^{3}He.

This work is in collaboration with G. J. Zhao, J. A. Gifford and T. Y. Chen (Arizona State University), and X. X. Gong, H. X. Zhou, Y. Chen and X. F. Jin (Fudan University).

Orbital Selectivity in Electron Correlations and Superconductivity of Iron-based Systems

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Keywords: Iron-based superconductivity

Identifying the key building blocks for the physics of the iron-based superconductors (FeSCs) remains a task in flux. The role of quantum fluctuations in the magnetic and nematic channels [1] has been addressed from early on. In more recent years, there has been a growing recognition that the underlying electron correlations manifest in an orbital-selective way [2,3], with an orbital-selective Mott phase anchoring this physics for the normal state. As a natural consequence for the superconducting state, an orbital-selective pairing has been advanced [4]. Most recently, these issues have been examined in the nematic state of FeSe [5,6]. I will summarize these issues and discuss their implications for the overall understanding of the FeSCs.

Supported by DOE and the Welch Foundation.

References:

1. J. Dai, Q. Si, J. X. Zhu, and E. Abrahams, PNAS 106, 4118, (2009).
2. Q. Si, R. Yu and E. Abrahams, Nature Rev. Mater. 1, 16017 (2016).
3. M. Yi, Y. Zhang, Z.-X. Shen, and D. H. Lu, Npj Quantum Materials 2, 57 (2017).
4. R. Yu, J.-X. Zhu and Q. Si, Phys Rev B89, 024509 (2014).
5. P. O. Sprau *et al.*, Science 357, 75 (2017).
6. R. Yu, J.-X. Zhu, and Q. Si, arXiv:1803.01733.

B-1

Ab initio studies and dark fermion theory of cuprate superconductors

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We derive ab initio and effective hamiltonians without adjustable parameters for several high-Tc cuprate superconductors [1] and discuss their properties especially about competitions between charge inhomogeneity and d-wave superconductivity. We further discuss the mechanism of cuprate superconductivity in terms of the dark and emergent fermions [2,3]

References:

1. M. Hirayama *et al.* arXiv:1708.07498
2. S. Sakai *et al.* Phys. Rev. Lett. 116, 057003 (2016)
3. M. Imada and T.J. Suzuki, arXiv:1804.05301

Modified form of the gap equation with pairing correlations beyond mean field and its equivalence to a Hugenholtz-Pines condition for fermion pairs

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Keywords: Superconducting gap parameter, non-local effects, Cooper pair size

The equation for the gap parameter represents the main equation of the BCS theory of super- conductivity. Although it is formally defined as a single-particle property, physically it reflects the pairing correlations between opposite-spin fermions. Here, we cast the gap equation in an alternative form which explicitly highlights these two-particle correlations, by showing that it is equivalent to a Hugenholtz-Pines condition for fermion pairs. Use of this alternative form makes it easier to include explicitly pairing fluctuations beyond BCS mean field. We implement this modified gap equation by considering the long-pending problem about the inclusion of the Gorkov-Melik-Barkhudarov correc- tion across the whole BCS-BEC crossover, from the BCS limit of strongly overlapping Cooper pairs to the BEC limit of dilute composite bosons, and for all temperatures in the superfluid phase. Our numerical calculations yield excellent agreement with the recently determined experimental values of the gap parameter for an ultra-cold Fermi gas in the intermediate regime between BCS and BEC.

References:

1. L. Pisani, A. Perali, P. Pieri, and G. C. Strinati, Phys. Rev. B (in press).
2. L. Pisani, P. Pieri, and G. C. Strinati (unpublished).

Loop Currents in Superconducting Cuprates and Iridates

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Keywords: HTSC,

There has been a long-standing debate among condensed-matter physicists about the origin of the pseudo-gap state in high-temperature superconducting cuprates. Polarized neutron diffraction has revealed the existence of an ordered magnetic phase, hidden inside the pseudo-gap state of underdoped $YBa_2Cu_3O_{6+x}$, $HgBa_2CuO_4$+d and $Bi_2Sr_2CaCu_2O_{8+d}$ [1]. Interestingly, the ordering temperature matches the pseudo-gap temperature T* deduced from resistivity measurements. The magnetic order can be described as an Intra-Unit-cell magnetic order, breaking time-reversal and C4 rotational symmetries. It corresponds to the symmetry predicted in the loop current theory of the pseudo-gap state where staggered current loops give rise to orbital-like magnetic moments within the CuO2 unit cell. I will review these observations in light of the loop current model. Other proposals, based on magneto-electric quadrupoles, will be presented as well. Recently, we observed similar magnetic signal in the antiferromagnetic iridates system $Sr_2(Ir,Rh)O_4$ [2] below a temperature different from TN suggesting the existence of loop-current electronic states in different oxides.

References:

1. P. Bourges and Y. Sidis, C. R. Physique, 12, 461, (2011). Y. Sidis and P. Bourges, J. Phys.: Conf. Ser. 449, 012012 (2013). L. Mangin-Thro *et al.*, Phys. Rev. B 89, 094523 (2014). L. Mangin-Thro *et al.*, Nat. Comms. 6, 7705 (2015) & Phys. Rev. Lett., 118, 097003, (2017).
2. Jaehong Jeong *et al.*, Nat. Comms., 8, 15119 (2017).

Superconductivity and phase separation in layered high-Tc superconductors

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Keywords: superconductivity, phase separation, high-Tc superconductors

The issues concerning the nature and the role of inhomogeneities in high-Tc superconductors and their correlation with superconductivity are addressed. The study of cuprates has shown that their anisotropy is extremely high and the coherence length is very short so, the material is entirely nonhomogeneous. Temperature dependent anisotropy was observed in MgB_2, and was explained as a consequence of the presence of two superconducting gaps. Similar temperature dependence was observed in iron-based superconductors. It was shown that the inhomogeneous spatial distribution of ions with nanoscale phase separation seems to enhance the superconductivity in superconducting Fe-Te-Se chalcogenides. It was shown that the microstructure of $Rb_xFe_{2-y}Se_2$, caused by mesoscopic phase separation, is modified by annealing, leading to an improvement of the superconducting properties and an enhancement of Tc.

Rashba spin-orbit coupling: a journey from the two-dimensional electron gas to graphene with spin-orbital proximity effects

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Graphene combined with other monolayer materials such as transition metal dichalcogenides is currently investigated as a very promising platform for spintronics applications. In this talk I will focus on Rashba-Dirac models, where the relativistic electron dispersion interplays with the spin-orbit due to the structure inversion asymmetry. In analogy with the case of the non relativistic quadratic spectrum for the two-dimensional electron gas, I will introduce the SU(2) gauge field description for the Rashba spin-orbit coupling. Such a description, when used together with the Ward identities of quantum field theory, provides a full solution to the problem in the presence of disorder scattering. This is shown to be a powerful approach to unveil the diagrammatic structure of the theory.
This will be used to discuss results for both the spin Hall and spin galvanic effects in the Dirac-Rashba models with generalized valley-spin interactions.

References:

1. "Optimal charge-to-spin conversion in graphene on transition metal dichalcogenide" Manuel Offidani, Mirco Milletarí, Roberto Raimondi, Aires Ferreira, Physical Review Letters 119, 196801 (2017).
2. "Covariant conservation laws and spin Hall effect in the Dirac-Rashba model " Mirco Milletari, Manuel Offidani, Aires Ferreira, Roberto Raimondi, Physical Review Letters 119, 246801 (2017).

C1-2

The Synthesis, NMR and μSR Investigation of Novel Diluted Ferromagnetic Semiconductors

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Keywords: Diluted magnetic semiconductors, NMR, muSR

We recently extended the research from Fe-based superconductors into bulk form diluted ferromagnetic semiconductors (DMS). In this talk, I will show a series of bulk form DMS materials synthesized by our collaboration team. Among them, the Curie temperature TC of 122-type bulk form $(Ba,K)(Mn,Zn)_2As_2$ DMS has reached to 230 K [1,2], which is higher than the record value 200 K of (Ga,Mn)As. Furthermore, through the doping of Co onto Zn sites in $BaZn_2As_2$, we obtained an n-type DMS with TC as high as 45 K[3].
The availability of bulk form DMS specimens enables us to measure the bulk magnetism by volume sensitive probe μSR and site-selective probe NMR. μSR measurements confirm that the ferromagnetism is homogenous in these bulk form DMSs, and indicate that the mechanism responsible for ferromagnetic ordering in $(Ba,K)(Mn,Zn)_2As_2$ and other bulk DMSs is the same as that of (Ga,Mn)As [1,2,4,5]. This opened up a new window to look into the ferromagnetism in DMSs that has been debated for long time. On the other hand, through the measure of NMR, we successfully identified a new 7Li NMR peak induced by Mn doping in $Li(Zn_{1-x}Mn_x)P$ [6] and $Li(Cd_{1-x}Mn_x)P$. We present unequivocal experimental evidences that the ferromagnetic ordering is indeed caused by randomly substituted Mn in Zn sites, instead of Mn cluster or other magnetic impurities. Through the measurement of spin-lattice relaxation rate 1/T1, we also established that Mn-Mn ferromagnetic interactions are not limited to the near-neighbor sites but extend over many unit cells, mostly likely due to the p-d Zener interactions.

References:

1. K. Zhao *et al.*, Nature Communications 4, 1442 (2013).
2. K. Zhao *et al.*, Chin. Sci. Bull. 59, 2524 (2014).
3. S.L. Guo and F.L. Ning* *et al.*, Submitted.
4. C. Ding and F.L. Ning* *et al.*, PRB 88, 041008(R) (2013).
5. F.L. Ning* and H.Y. Man *et al.*, PRB (2014).
6. C.Ding and F.L. Ning* *et al.*, PRB 88, 041002(R) (2013).

The Coherent Polaron Quantum Phase in Uranium Dioxide

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Keywords: condensation, non-equilibrium condensate, Fano-Feshbach resonance

Results from a large number of experiments on O- and photo-doped $UO_{2(+x)}$, a 5f Mott insulator, are best and perhaps only interpreted as demonstrating that the polarons aggregate and self organize into a Bose-Einstein condensate. The basis for this is Fröhlich's prediction of a non-equilibrium condensate composed of specific phonons that become coherent because of dipole interactions that are enhanced by anharmonicity. The charge-transfer that we have observed in UO_2 would be an extreme case of that. An evaluation of the electronic density-of-states also shows that the polaronic quantum phase meets the conditions for stabilization by a Fano-Feshbach resonance. Evidence will be presented for typical condensate properties as well as several that have not been predicted.

References:
1. H. Frohlich, Phys. Lett. A A 26, 402 (1968).
2. A. Bianconi, Nature Phys. 9, 536 (2013).
3. S. D. Conradson, *et al.*, Phys. Rev. B 88, 115135 (2013).
4. S. D. Conradson, *et al.*, Sci. Rep. 5, 15278 (2015).
5. S. D. Conradson, *et al.*, Phys. Rev. B, (2017) submitted.

New DMS with Independent Doping of Spin & Charges

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We report progress on recently discovered new type diluted magnetic semiconductor(DMS) $(Ba,K)(Zn,Mn)_2As_2$ (BZA)1 featured with independent spin and charge doping mechanism different from the integrated doping for most of previous studied diluted magnetic semiconductor2~6. This leads BZA to such quite prominent properties comparing to classical diluted magnetic semiconductor $(Ga,Mn)As_{4\sim6}$, as 230K very high Cure temperature6, the ideal playground to theoretical understanding7, etc. More interestingly BZA is isostructural to 122 iron based superconductor $BaFe_2As_2$ & the $BaMn_2As_2$ AFM with lattice mismatch less than 5%, making it promising for spintronics devices3. Based on successful growth of BZA single crystal, the primitive Andreev reflection junction was fabricated, showing 66% spin polarization in BZA single crystal8.

Acknowledgements:
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References:

1. K. Zhao *et al.* Nature communications 4, 1442 (2013)
2. T. Dietl *et al.* Reviews of Modern Physics 86, 187(2014)
3. A. Hirohata *et al.* IEEE Trans. Magn. 51, 1 (2015)
4. I. Zutic *et al.* Reviews of Modern Physics 76, 323 (2004)
5. T. Jungwirth *et al.* Reviews of Modern Physics 86, 855 (2014)
6. K. Zhao *et al.* Chin. Sci. Bull. 59, 2524 (2014)
7. J. K.Glasbrenner *et al.* Phys. Rev. B 90, 140403(R) (2014)
8. G. Q. Zhao *et al.* Sci. Rep. 7, 14473 (2017)

Resolving the VO_2 controversy: Mott mechanism dominates the insulator-to-metal transition

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Keywords: Mott-Pierls transitions

We consider a minimal model [1] to investigate the metal-insulator transition in VO_2. We adopt a Hubbard model with two orbital per unit cell, which captures the competition between Mott and singlet-dimer localization. We solve the model within Dynamical Mean Field Theory, characterizing in detail the metal-insulator transition and finding new features in the electronic states. We compare our results with available experimental data obtaining good agreement in the relevant model parameter range. Crucially, we can account for puzzling optical conductivity data obtained within the hysteresis region, which we associate to a novel metallic state characterized by a split heavy quasiparticle band. Our results show that the thermal-driven insulator-to-metal transition in VO_2 is compatible with a Mott electronic mechanism, providing fresh insight to a long standing "chicken-and-egg" debate and calling for further research of "Mottronics" applications of this system. Notably, we find Hubbard bands of a mix character with coherent and incoherent excitations. We argue [2] that this state is relevant for VO_2 and its signatures may be observed in spectroscopic studies, and possibly through pump-probe experiments.

References:

1. O. Nájera, M. Civelli, V. Dobrosavljević, and M. J. Rozenberg, Phys. Rev. B 95, 035113 (2017).
2. O. Nájera, M. Civelli, V. Dobrosavljević, and M. J. Rozenberg, Phys. Rev. B 97, 045108 (2018).

Charge-spin conversion at oxide interfaces

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Keywords: oxide interfaces, spintronics, Edelstein and spin-Hall effect

The manipulation of spin degrees of freedom in order to generate a charge current and the inverse process are at the heart of spintronics devices. One of the most prominent examples is the spin-Hall effect (SHE) where a charge current induced by an electric field along the x-direction produces a z-polarized spin current flowing along the y-direction. Another related phenomenon is the Edelstein effect where a charge current is converted into a non-equilibrium spin polarization. Both, SHE and Edelstein effect occur in systems with strong spin-orbit coupling, in particular two dimensional electron gases which lack inversion symmetry perpendicular to the gas plane and which are usually described with the so-called Rashba hamiltonian. The situation is more complex in $LaAlO_3$/$SrTiO_3$ interfaces where the interplay between inversion asymmetry and atomic spin orbit coupling is at the heart of strong Rashba interactions.
Recently, two experiments [1,2] have demonstrated a strong inverse Edelstein effect at such interfaces by generating a strong non-equilibrium spin-polarization at the interface and detecting the resulting charge current. The reported spin-to-charge efficiency is more than order of magnitude larger than in conventional metallic layers which suggests the LAO/STO interface as a promising system for spintronic devices.
Within linear response theory we investigate the inverse Edelstein effect in oxide interfaces by generalizing the approach of Raimondi *et al.* [3] to a multiband model which involves the 3d t_{2g} bands of the Ti ions. Consistently with experiment we find a gate-tunable inverse Edelstein effect which changes sign depending on the occupation of xy and xz/yz orbitals.

References:

1. E. Lesne *et al.*, Nature Materials 15, 1261 (2016).

2. Q. Song *et al.*, Nature Communications, 10.1038 (2016).
3. K. Shen, G. Vignale and R. Raimondi, Phys. Rev. Lett. 112, 096601 (2014).
4. G. Seibold *et al.*, Phys. Rev. Lett. 119, 1092 (2017)

FeSe superconductor from bulk to single unit-cell

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Keywords: FeSe, TRHEPD, inelastic neutron scattering

b-FeSe has one of the simplest crystal structure among many iron-based superconductors [1,2]. In addition, high-Tc above 60 K has been reported in a single unit-cell FeSe [3,4]. Because the pairing mechanism is still one of the central issues in Fe-based superconductors, FeSe is an idealistic compound to study the mechanism.
Bulk dynamical magnetic property of FeSe crystal has been studied by inelastic neutron scattering in order to obtain the dynamical spin susceptibility, which shows large enhancement at low energies below the structural phase transition [5]. At the same time, single unit-cell FeSe structure has been studied by Total-Reflection High-Energy Positron Diffraction [6]. The FeSe single unit-cell layer is asymmetrically compressed along the normal direction of Fe layer. The asymmetric structure will be discussed in comparison with the energy bands calculated by first-principles calculations.

References:

1. F. C. Hsu *et al.*, Proc. Natl. Acad. Sci. U.S.A. 105, 14262 (2008).
2. K. W. Yeh *et al.*, Euro. Phys. Lett. 84, 37002 (2008).
3. S. He *et al.*, Nature Materials 12 (2013) 605.
4. J.-F. Ge *et al.*, Nature Materials 14 (2015) 285.
5. S. Shamoto, K. Ikeuchi, M. Ishikado, R. Kajimoto, M. Nakamura, T. U. Ito, Y. Yamakawa, T. Watashige, S. Kasahara, H. Kontani, T. Shibauchi, and Y. Matsuda, in preparation.
6. Y. Fukaya, G. Zhou, F. Zheng, P. Zhang, L. Wang, Q-K. Xue, and S. Shamoto, to be submitted.

D2-2

Unveiling the phase diagram of a striped cuprate at high magnetic fields: Hidden order of Cooper pairs

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Keywords: cuprates, stripes, pseudogap, upper critical field, novel states

The interplay of charge orders with superconductivity in underdoped cuprates at high magnetic fields (H) is an open question, and even the value of the upper critical field (Hc2), a measure of the strength of superconductivity, has been the subject of a long-term debate. We combined three complementary transport techniques [1] on underdoped $La_{1.8-x}Eu_{0.2}Sr_xCuO_4$ with a "striped" charge order and a low H=0 transition temperature Tc0, to establish the T-H phase diagram and reveal the ground states in CuO_2 planes: a superconductor, a wide regime of superconducting phase fluctuations (i.e. a vortex liquid), and a high-field normal state. The relatively high Hc2 is consistent with the opening of a superconducting gap above Tc0, but only at T~ (2-3) Tc0, an order of magnitude below the pseudogap temperature. Within the vortex liquid, an unanticipated, insulatinglike region, but with strong superconducting correlations, begins to emerge already at T~ Tc0. The results suggest that the presence of stripes plays a crucial role in the freezing of Cooper pairs in this novel state. Our findings provide a fresh perspective on the pairing strength in underdoped cuprates, and introduce a new avenue for exploring the interplay of various orders.

References:

1. Z. Shi, P. G. Baity, T. Sasagawa, D. Popović, submitted; arXiv:1801.06903 (2018).

Previous related work to include in a broader lecture:

a) X. Shi, P. V. Lin, T. Sasagawa, V. Dobrosavljevic, and D. Popovic, Nat. Phys. 10, 437 (2014).
b) P. G. Baity, X. Shi, Z. Shi, L. Benfatto, and D. Popovic, Phys. Rev. B 93, 024519 (2016).
c) Z. Shi, X. Shi, and D. Popovic, Phys. Rev. B 94, 134503 (2016).

Orbital order in FeSe

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Keywords: orbital order, unconventional superconductivity

I will discuss the structure of the d-wave orbital order in FeSe in light of recent STM and ARPES data, which detect the shapes of hole and electron pockets in the nematic phase. The geometry of the pockets indicates that the sign of the orbital order is different between hole and electron pockets. I will argue that this sign change cannot be reproduced by solving for the orbital order within mean-field approximation, as the mean-field analysis yields either no orbital order, or sign-preserving order parameter. I will argue that another solution with sign-changing order parameter emerges if we include the renormalizations of the vertices in d-wave orbital channel. I will show that the ratio of the magnitudes of the orbital orders on hole and electron pockets is of order one, independent on the strength of the interaction. I will also discuss temperature variation of the energy of dxz and dyz orbitals at the centers of electron pockets and compare the results with ARPES data. Finally, I will discuss superconductivity emerging out of the orbitally ordered phase.

Giant diamagnetism in Ca2RuO4 induced by DC current

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Keywords: Mott insulator, Mott semimetal, diamagnetism, NESS, Ca_2RuO_4

DC current can be a powerful tuning parameter of the electronic states of strongly correlated electron systems in the vicinity of Mott transitions. In this presentation, we give a short review on the research progress on the novel phenomena in the layered perovskite Ca2RuO4 and related materials.
Under DC current, Ca_2RuO_4 with a small Mott gap (~ 0.4 eV) exhibits semimetallic tranport behavior with giant diamagnetism at low temperatures [1]. We ascribe this bevavior to emergent "Mott semimetal" state, in which the upper and lower Hubbard bands become tiny electron and hole pockets with light quasiparticle mass responsible for the large diamagnetism.
It demonstrate that in a non-equilibrium steady state (NESS) introduced by DC current, a Mott insulator with a small gap can be readily driven into novel electronic states.

This work is done mainly in collaboration with T. Oka, S. Kitamura, K. Kuroki, D. Shibata, T. Yoshida, and N. Kikugawa. This work was supported by JSPS KAKENHI Nos. JP26247060, JP15H05852, and JP15K21717.

References:

1. C. Sow, S. Yonezawa, S. Kitamura, T. Oka, K. Kuroki, F. Nakamura, Y. Maeno, Science 358, 1084 (2017).

Superconductor-insulator transition and topological nature of the Bose metal

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Keywords: Disordered BKT transition, gauge theories, superinsulators

It has long been believed that at absolute zero electrons can form only one quantum coherent state, a superconductor. Yet, several two dimensional superconducting systems were found to harbor the superinsulating state with infinite resistance, a mirror image of superconductivity, and a metallic state often referred to as Bose metal, characterized by finite longitudinal and vanishing Hall resistances. The nature of these novel and mysterious quantum coherent states is the subject of intense study.

Here, we propose a topological gauge description of the superconductor-insulator transition (SIT) that enables us to identify the underlying mechanism of superinsulation as Polyakov's linear confinement of Cooper pairs via instantons. We find a criterion defining conditions for either a direct SIT or for the SIT via the intermediate Bose metal and demonstrate that this Bose metal phase is a Mott topological insulator in which the Cooper pair-vortex liquid is frozen by Aharonov-Bohm interactions.

Disorder in competing superconducting and CDW or SDW systems

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Keywords: Superconductivity

Coexistence of superconductivity with other types of orders, charge density wave (CDW) or spin density wave (SDW) was found in several materials, such as NbSe2, where superconducting state arise on the background of CDW order and under doped compounds of 122 family of iron based pnictides where SDW state turns to superconducting on cooling. The question if those orders exclude each other or in contrary enhance is a key issue in understanding of the pairing mechanism. In my presentation I will discuss the effect of controlled point like disorder introduced by energetic particle irradiation on both SDW/CDW and superconducting transitions. Surprisingly strong depression of SDW transition temperature was observed in isovalently substituted Ba(FeAs1-xPx)2 system. Signatures of the transition jump in the Hall coefficient and departure from Mathiesen rule in conductivity are robust against disorder. This indicates the persistence of Lifshitz transition even in strongly disorder samples. In slightly under doped samples, normal state can be turned from antiferromagnetic to paramagnetic by disorder.

Observation of Vortex/Meron Pairs at Room Remperature in a planar α-Fe2O3/Co Heterostructure.

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Vortices are among the simplest topological structures, and occur whenever a flow field 'whirls' around a one- dimensional core. They are ubiquitous to many branches of physics. In the crystalline state, vortex formation is rare, since it is generally hampered by long-range interactions. Here, we present the discovery of a novel form of crystalline vortices in antiferromagnetic (AFM) hematite (α-Fe_2O_3) epitaxial films, in which the primary whirling parameter is the non-ferroics staggered magnetisation. Remarkably, ferromagnetic (FM) topological objects known as half-skyrmions or merons with the same vorticity and winding number of the α-Fe_2O_3 vortices are imprinted onto an ultra-thin Co ferromagnetic over-layer by exchange proximity. Our data suggest that the vortex/meron pairs are relatively robust well beyond the Co coercive field, but can be manipulated by the application of a larger ($H_\parallel \sim 100$mT) in-plane magnetic field $H_\parallel$, giving rise to large-scale vortex-antivortex annihilation.

Orbitals and Nematicity in La-1111 Single Crystals

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Keywords: nematic order, orbitals, FE-based superconductors

While there is broad consensus that superconductivity in Fe based superconductors is due to an unconventional, most likely electronic pairing, many important aspects of the normal and superconducting state are still unexplored. In particular, the role of orbital degrees of freedom for the normal state electronic properties, nematicity, and pairing is discussed very controversial. In my talk I will present results on a series of large high quality La-1111 single crystals which have been grown for the first time using a method based on anomalous solid state reaction. We have reexamined the phase diagram and studied magnetism and nematic order by means of NMR and strain dependent transport measurements. The possible formation of polaron-like structures will be discussed and evidence for an unusual state with suppressed long range order and soft nematic fluctuations will be presented.

New perspective of cuprate electronic properties from NMR

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Keywords: Cuprates; NMR

Nuclear magnetic resonance (NMR) shifts, if stripped off their uncertainties, must hold key information about the electronic fluid in the cuprates. The early shift interpretation that favored a single-fluid scenario will be reviewed, as well as recent experiments that reported its failure. Thereafter, based on literature shift data for planar Cu a contrasting shift phenomenology for cuprate superconductors is developed, which is very different from the early view while being in agreement with all published data. For example, it will be shown that the hitherto used hyperfine scenario is inadequate as a large isotropic shift component is discovered. Furthermore, the changes of the temperature dependences of the shifts above and below the superconducting transitions temperature proceed according to a few rules that were not discussed before. It appears that there can be substantial spin shift at the lowest temperature if the magnetic field lies in the CuO_2 plane, which points to a localization of spin in the $3d(x^2-y^2)$ orbital. A simple model is presented based on the most fundamental findings. The analysis must have new consequences for theory of the cuprates.

New Directions in Theoretical Studies of Iron-based Superconductors

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The discovery of high critical temperature superconductivity in iron-based pnictides and chalcogenides brought to the forefront the need to develop efficient theoretical procedures to treat multiorbital models of interacting electrons. Among the many challenges, we need to clarify the role that the orbital degree of freedom plays in pairing and how its interaction with magnetic and lattice degrees of freedom leads to the stabilization of exotic phases such as the nematic state. Theoretical studies in the strong and weak coupling limits cannot address the physically relevant intermediate regime, with a mixture of itinerant and localized degrees of freedom. Traditional numerical methods, such as Lanczos or quantum Monte Carlo, have either a too rapidly growing Hilbert space with increasing size or sign problems. For this reason, it is necessary to develop new models and techniques, and also better focus on systems where {\it both} experiments and accurate theory can be used in combination to reach a real understanding of iron pairing tendencies. Examples of recent advances along these directions that will be discussed in this talk include: i) The development of spin-fermion models [1] that allow studies in the difficult nematic regime with a finite short-range antiferromagnetic correlation length above the ordering critical temperatures. This type of studies also allow the inclusion of doping, quenched disorder, and the study of transport and real-frequency responses; ii) The application of the Density Matrix Renormalization Group (DMRG) approach to multi-orbital Hubbard models in chain and ladder structures [2] triggered by the discovery of superconductivity at high pressure in ladder iron-based compounds such as $BaFe_2S_3$ and $BaFe_2Se_3$. In this context, the recently reported [2] pairing tendencies unveiled at intermediate Hubbard U will be discussed.

References:

1. S.Liang *et al.*, Phys.Rev.Lett. **109**, 047001 (2012) and Phys. Rev. Lett. **111** 047004 (2013); Phys. Rev. B **92** 104512 (2015); C. Bishop *et al.*, Phys. Rev. Lett. **117** 117201 (2016); Phys. Rev. B **96** 035144 (2017).
2. N.D. Patel *et al.*, Phys. Rev. B **96**, 024520(2017). See also N.D. Patel *et al.*, Phys. Rev. B **94**, 075119(2016).

G-1

Competition between Mott and Hund metal states in $BaCoS_2$

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Keywords: Mott metal-insulator transition,Hund metal Non Fermi-liquid properties

Recent theoretical studies have unveiled the crucial role played by the Hund coupling in multiorbital systems to control the competition between Mott insulator and bad metals. I show that the quasi-twodimensional system $BaCoS_2$ displays the following ideal characteristics to study this competition: i) contrary to other multiorbital systems like Fe-based superconductors, in $BaCoS_2$, the coupling between electronic and lattice degrees of freedom is negligible; ii) an unusual linear behavior of the optical conductivity over a wide energy range suggests a borderline ground state separating a Mott phase from a non-Fermi liquid metal. Ab initio dynamical mean-field calculations provide a quantitative account of this results in terms of a Hund metal state which arises from an incipient Mott phase destabilized by strong low-energy charge fluctuations across the vanishing 3d-3p charge transfer gap.

Signatures of the topological s +− superconducting order parameter in the type-II Weyl semimetal T d-$MoTe_2$

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Keywords: Pressure effects, topological superconductivity, Weyl-Semimetal

In its orthorhombic Td polymorph, $MoTe_2$ is a type-II Weyl semimetal, where the Weyl fermions emerge at the boundary between electron and hole pockets. Non-saturating magnetoresistance and superconductivity were also observed in Td-$MoTe_2$. Understanding the superconductivity in Td-$MoTe_2$, which was proposed to be topologically non-trivial, is of eminent interest. We report the high-pressure muon-spin rotation experiments probing the temperature-dependent magnetic penetration depth in Td-$MoTe_2$ [1]. A substantial increase of the superfluid density and a linear scaling with the superconducting critical temperature Tc is observed under pressure. Moreover, the superconducting order parameter in Td-$MoTe_2$ is determined to have 2-gap s-wave symmetry. We also exclude time-reversal symmetry breaking in the superconducting state with zero-field μSR experiments. Considering the strong suppression of Tc in $MoTe_2$ by disorder, we suggest that topologically non-trivial s+− state is more likely to be realized in $MoTe_2$ than the topologically trivial s++ state.

References:

1. Z. Guguchia *et al.*, Nature Communications 8, 1082 (2017).

G-3

Magnetism in the TMDC semiconductors

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The semiconducting transition metal dichalcogenides are of the form MX2 with M=Mo,W and X=S, Se and Te. The 2H (trigonal prismatic) polytype of these materials is expected to be semiconducting based on simple symmetry considerations, with fully filled metal orbitals in the valence band. I will discuss recent measurements by a variety of techniques that clearly show the surprising presence of magnetism in single crystals of these materials. I will discuss in particular scanning tunneling microscopy measurements of defects in these materials and consider their contribution to the observed magnetic properties at low temperature.

Correlation-enhanced spin-orbit coupling in ruthenates

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Keywords: ARPES, metal-insulator transitions, ruthenates, spin-orbit coupling

Spin-orbit coupling (SOC) plays a key role for topologically protected states and profoundly affects the phase diagram of correlated electron systems. While the effects of SOC are well studied for Mott insulators and in the limit of weakly interacting electrons, much less is known about SOC in correlated metals. Here, we combine angle resolved photoemission with dynamical mean field theory calculations to provide direct evidence for a correlation-induced enhancement of the effective spin-orbit coupling strength in Sr_2RuO_4. Even more pronounced effects are observed in the metallic phase of Ca_2RuO_4, where the effective SOC increases by more than a factor of two and becomes sufficiently strong to remove large sheets from the Fermi surface. Our results demonstrate that the concept of a correlation-enhanced effective SOC [1] is essential for a description of ruthenates and suggest that it is generally applicable to correlated multiband systems.

References:

1. M. Kim, J. Mravlje, M. Ferrero, O. Parcollet and A. Georges, arXiv:1707.02462 (2017)

Various topological spin structures and emergent transport phenomena in B20-type chiral magnets

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Keywords: skyrmion, hedgehog, chiral soliton lattice, Berry phase, thermoelectrics, SANS

We have realized various topological magnetic structures in a prototypical skyrmionic material, so-called B20-type compounds, by changing DM interaction, magnetic anisotropy and electronic structure, which are controlled by element substitution and device manufacturing. In this talk, we would like to present our recent results on topological magnetic structures and consequent unique transport properties in bulks and films of B20-type compounds [1-3].
This work is done in collaboration with K. Akiba, T. Arima, R. Arita, S. Awaji, C. D. Dewhurst, Y. Fujishiro, M. Ichikawa, K. Ishizaka, F. Kagawa, K. Kakurai, M. Kawasaki, A. Kikkawa, S. Kimura, T. Koretsune, Y. Kozuka, H. Mitamura, A. Miyake, D. Morikawa, T. Nakajima, A. Nakamura, K. Ohishi, H. M. Rønnow, K. Shibata, T. Shimojima, J. Shiogai, Y. Taguchi, M. Tokunaga, Y. Tokura, A. Tsukazaki, J. S. White, X. Z. Yu

References:

1. N. Kanazawa, J. S. White *et al.*, Phys. Rev. B 94, 184432 (2016).
2. N. Kanazawa, J. S. White *et al.*, Phys. Rev. B 96, 220414(R) (2017).
3. Y. Fujishiro, N. Kanazawa *et al.*, Nature Commun. 9, 408 (2018).

Effect of lattice distortion on the Lifshitz transition in cuprates

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Keywords: lattice distortion, Lifshitz transition, cuprates

We have calculated the density of states in cuprates at different doping and different lattice deformation. The first part with square deformed CuO_4 lattice is finished now.

References:

1. Vladimir A. Gavrichkov, Semen I. Polukeev and Sergey G. Ovchinnikov, Contribution from optically excited many-electron states to the superexchange interaction in Mott-Hubbard insulators, Phys. Rev. B 95, 144424 (2017); https://doi.org/10.1103/PhysRevB.95.144424
2. Gavrichkov V.A., Microscopic background in metal-insulator criterion for doped Mott-Hubbard materials, Proceedings of 9-th World Congress on Material Science and Engineering, p. 108, June 12-14, 2017, Rome, Italy; DOI: 10.4172/2169-0022-C1-067
3. Vladimir A. Gavrichkov,, Zlata V. Pchelkina, Igor A. Nekrasov and Sergey G. Ovchinnikov, Pressure effect on the energy structure and superexchange interaction in undoped orthorhombic La2CuO4, International Journal of Modern Physics B, 30, No. 25 (October 2016); DOI: 10.1142/S0217979216501800 (IF 0.79)
4. Gavrichkov V.A., A simple metal–insulator criterion for the doped Mott–Hubbard materials, Sol. St. Comm., 208, p.11-14 (2015); http://dx.doi.org/10.1016/j.ssc.2015.02.014 (IF 1.543)
5. K.A. Sidorov, V.A. Gavrichkov, S.N. Nikolaev, Z.V. Pchelkina, S.G. Ovchinnikov “Effect of external pressure on the normal and superconducting properties of high-Tc cuprates”, Phys.St.Solidi B, 253, 486 (2015); DOI: 10.1002/pssb.201552465 (IF 1.489)
6. E.I.Shneyder, J.Spitaler, E.E.Kokorina, I.A.Nekrasov, V.A.Gavrichkov, C.Draxl, S.G.Ovchinnikov. Coupling of Hubbard fermions with phonons in La2CuO4: A combined study using density-functional theory and the generalized tight-binding method. Journal of Allows and Compounds, 648, 258-264 (2015); http://dx.doi.org/10.1016/j.jallcom.2015.05.150 (IF 3.014)
7. S.G.Ovchinnikov, V.A.Gavrichkov, M.M.Korshunov, E.I.Shneyder, LDA+GTB method for band structure caculations in the strongly correlated materials.

In the «Theoretical Methods for strongly Correlated systems». Ed. A.Avella, F.Mancini,. Springer Series in Solid-State Science. V.171, 143-171. Springer-Verlag Berlin Heidelberg. 2012 . http://www.springer.com/gp/book/9783642218309

8. Gavrichkov V.A., Korshunov M.M, Ovchinnikov S.G., Shneyder E.I. , Orlov Yu.S, Nekrasov I.A. , Pchelkina Z.V., "Cuprates, manganites and cobaltites: multielectron approach to the band structure ", Modern Physics Letters B, Vol. 26, No. 24, 1230016, Сингапур, (2012). http://dx.doi.org/10.1142/S0217984912300165 (IF 0.56);

Spin-valley half-metallic states in doped density-wave insulators

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Half-metallicity (full spin polarization of the Fermi surface) usually occurs in strongly correlated electron systems. We demonstrate that doping a spin-density wave insulator in the weak-coupling regime may also stabilize half-metallic states. The undoped spin-density wave is formed by four nested bands [i.e., each band is characterized by charge (electron/hole) and spin (up/down) labels]. Of these four bands, only two accumulate the doped carriers, forming a half-metallic two-valley Fermi surface. Depending on parameters, the spin polarizations of the electron-like and hole-like valleys may be either (i) parallel or (ii) antiparallel. The Fermi surface of (i) is fully spin-polarized (similar to usual half-metals). Case (ii), referred to as "a spin-valley half-metal", corresponds to complete polarization with respect to the spin-valley operator. The properties of these states are discussed.

Fluctuation-induced magnetic skyrmions at topological insulator surfaces

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Ferromagnets in contact with a topological insulator have become appealing candidates for spintronics due to the Dirac surface states, which exhibit spin-momentum locking. Bilayer Bi_2Se_3-EuS structures, for instance, show a finite magnetization at the interface at temperatures well exceeding the Curie temperature of bulk EuS. Here we determine theoretically the effective magnetic interactions at a topological insulator-ferromagnet interface *above* the magnetic ordering temperature. We show that by integrating out the Dirac fermion fluctuations an effective Dzyaloshinskii-Moriya interaction and magnetic charging interaction emerge. As a result individual magnetic skyrmions and extended skyrmion lattices can form at interfaces of ferromagnets and topological insulators, the first indications of which have been very recently observed experimentally.

Quantum Interference Effects in Bi2Se3 and Bi nanowires

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Keywords: Aharonov-Bohm effect, topological states,

We report observation of the Aharonov-Bohm (AB) type quantum oscillation effects (i) in the array of Bi-nanowires (100nm in diameter and 60 mcm long), and (ii) in Bi_2Se_3 single nanowire (250x25 nm^2). By observing magnetoresistance at temperatures down to 0.3K and in magnetic field up to 14T applied parallel to the nanowire axis, we detected the magnetoresistance oscillations. In Bi-nanowires the oscillation period, as expected, corresponds to the flux quantum Φ0 = hc/e. In Bi2Se3 nanowire, beyond the anticipated Φ0-period we also observed oscillations with periods of 2Φ0 and 4Φ0.

References:

1. Yu.I.Latyshev, A.V.Frolov, b, V.A.Volkov, T.Wade, V.A.Prudkoglyad, A.P.Orlov, V.M.Pudalov, M.Konczykowski, JETP Lett., 107, 192 (2018).
2. A.V.Frolov, A.P.Orlov, A.A.Sinchenko, V.A.Volkov, Ya.A.Gerasimenko, A.Yu.Kuntsevich, V.M.Pudalov, J. of Physics: Conf. Ser. 941, 012063 (2017).

Negative energy antiferromagnetic instantons forming Cooper-pairing 'glue' and 'hidden order' in HTSC

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Keywords: negative energy antiferromagnetic instantons, Cooper-pairing 'glue', 'hidden order' in HTSC

An emergence of the magnetic boson of instantonic nature, that provides a Cooper-pairing glue, is considered in the repulsive 'nested' Hubbard model of superconducting cuprates. It is demonstrated, that antiferromagnetic instantons [1] of a spin density wave type may have negative energy due to coupling with Cooper pair condensate. A set of Eliashberg-like equations is derived and solved self-consistently, proving the above suggestion. An instantonic propagator plays the role of pairing boson Green's function. Simultaneously, the instantons defy condensation of the mean-field SDW order. We had previously demonstrated in analytical form [2-4] that periodic 'chain' of instantons along the axis of the Matsubara's time, a 'quantum crystal', has zero scattering cross section for weakly perturbing external probes, thus representing a 'hidden order'. Hence, the two competing orders, superconducting and antiferromagnetic, may coexist in the form of coupled mean-field and quantum 'hidden' order respectively. This new picture is discussed in relation with the mechanism of high temperature superconductivity.

References:

1. A.M. Polyakov, "Guage fields and strings", Harwood Academic Pub., 1987.
2. S. I. Mukhin, «Spontaneously broken Matsubara's time invariance in fermionic system: macroscopic quantum ordered state of matter», J. Supercond. Nov. Magn., vol. 24, 1165-1171 (2011).
3. S. I. Mukhin, «Euclidean action of fermi-system with "hidden order", Physica B: Physics of Condensed Matter, vol. 460, 264 (2015).
4. S. I. Mukhin, «Euclidian Crystals in Many-Body Systems: Breakdown of Goldstone's Theorem», J. Supercond. Nov. Magn., vol.27, 945-950 (2014).

Scaling of memories and crossovers in glassy magnets

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Aging and memory effects have been key features of glassy we have performed the thermo-remane .[1-4] Our TRM results show that scaling of magnetic memories with time can be used to classify magnetic glassy materials into two distinct classes. Most densely populated magnets exhibit similar memory behavior characterized by a relaxation exponent of ? − ? ≈ ?. ?(?). This exponent is different from ? − ? ≈ ?/? of dilute magnetic alloys that was ascribed to their hierarchical and fractal energy landscape, and is also different from ? − ? = ? of the conventional Debye relaxation expected for a spin solid, a state with long range order. Furthermore, our systematic study on dilute magnetic alloys with varying magnetic concentration exhibits crossovers among the two glassy states and spin solid.[1]

References:

1. Scaling of Memories and Crossover in Glassy Magnets, A. M. Samarakoon, M. Takahashi, D. Zhang, J. Yang, N. Katayama, R. Sinclair, H. D. Zhou, S. O. Diallo, G. Ehlers, D. A. Tennant, S. Wakimoto, K. Yamada, G-W. Chern, T. J. Sato, S.-H. Lee, Scientific Reports 7, 12053 (2017).
2. Aging, memory and nonhierarchical energy landscape of a spin jam, A. Samarakoon, T. J. Sato, T. Chen, G.-W. Chern, J. Yang, I. Klich, R. Sinclair, H. Zhou, S.-H. Lee, Proceedings of the National Academy of Sciences 113, 11806-11810 (2016).
3. Spin jam induced by quantum fluctuations in a frustrated magnet, J. Yang, A. Samarakoon, S. Dissanayake, H. Ueda, I. Klich, K. Iida, D. Pajerowski, N. P. Butch, Q. Huang, J. Copley, S.-H. Lee, Proceedings of the National Academy of Sciences 112, 11519-11523 (2015).
4. Glassiness and exotic entropy scaling induced by quantum fluctuations in a disorder-free frustrated magnet, I. Klich, S.-H. Lee, K. Iida5, Nature Comm. 5, 3497 (2014).

Charge-density wave dynamics in LaTe3

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Keywords: charge density waves, time-resolved probes

We report on our theoretical investigations of charge density wave (CDW) dynamics in the context of recent pump-probe experiments in $LaTe_3$ by A. Zong *et al.* The experiments obtain evidence of diverging timescales between the faster relaxation of the CDW amplitude and the slower recovery of the CDW phase coherence. We treat amplitude dynamics in terms of coupled equations for electronic and lattice order parameters. As far as the phase recovery is concerned, we attempt to interpret it in terms of creation, motion and annihilation of topological defects in the CDW texture.

Competing Strong Correlations and Fermiology Drive Cuprate Quantum Phase Transition

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The strong electronic interactions within the cuprates give rise to an array of exotic phases. Multiple broken symmetries are observed, but the organization of the ground state remains unknown. This complex phase diagram is proposed to be controlled by a quantum phase transition (QPT) beneath the superconducting dome. Empirical evidence for such a transition is the abrupt change in Fermi surface topology, and identifying the interactions that transform states across the QPT is key to decoding the structure of the entire phase diagram.

We use STM to image the electronic structure of $(Bi,Pb)_2(Sr,La)_2CuO_{6+\delta}$ (Bi-2201). Using the density-wave (DW) states as a probe of interactions, we track their evolution across the critical doping. The DW changes at the Fermi surface transition, from near commensurate to incommensurate with a wave-vector tracking the Fermi surface. These observations indicate a reorganization of the electronic structure in which the DW mechanism shifts abruptly, and suggests a new view of the cuprate QPT.

Critical temperature enhancement from quantum confinement in niobium-doped strontium titanate thin films

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A precise solution of the quasi-2D problem for the mean-field critical temperature T_c at any electron density in a finite rectangular potential well reveals shape resonances induced by quantum confinement [1]: T_c oscillates as a function of well thickness and is enhanced compared to the bulk above a threshold confinement strength [2]. Such threshold is lower for low-density superconductors like doped strontium titanate (STO) thus favoring Tc enhancements in quasi-2D [3]. We fabricated niobium-doped STO thin films of different thickness at 1% doping, sandwiched between undoped STO, and performed transport experiments to measure the thin-film Tc and Hall carrier density. Tc is enhanced with decreasing thickness at constant 3D carrier density. We analyze the system utilizing a two-band model for Nb-doped STO with pairing interaction reproducing the density-dependent bulk Tc [4]. We apply confinement in the square-well quasi-2D geometry and find a Tc enhancement in the thin-film limit consistent with experiments. We discuss the effect of 3D density inhomogeneities on the calculations.

References:

1. D. Valentinis, D. van der Marel and C. Berthod, Phys. Rev B 94, 024511 (2016)
2. A. Bianconi, D. Innocenti, A. Valletta and A. Perali, J. Phys. Conf. Ser. 529, 012007 (2014)
3. D. Valentinis, D. van der Marel and C. Berthod, Phys. Rev. B 94, 054515 (2016)
4. M. Kim, Y. Kozuka, C. Bell, Y. Hikita and H. Y. Hwang, Phys. Rev. B 86, 085121 (2012)
5. D. Valentinis, S. Gariglio, A. Fête, J.-M. Triscone, C. Berthod, and D. van der Marel, Phys. Rev. B 514, 189 (2017)

Orbital selectivity and Hund's physics in Iron-based superconductors

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The description of electronic correlation in iron-based superconductors is complicated by their multi-orbital character. For long time the nature and degree of local correlations, as well as the relation between the so call Hund's coupling and the Mott physics has been highly debated. I will show that in iron-based superconductors correlations are orbital selective and I will clarify the connection between Hund metal physics and half-filled Mott physics [1, 2]. I will also explain that contrary to what happens in Mott systems, the atomic spin polarization promoted by Hund's coupling induces strong correlations, without necessary leading to an increase in the localization of total charge. Indeed, in some cases the polarization may even promote itineracy [2].
I will then discuss the interplay between local correlations and ordered phases of iron based systems. As a matter of fact, although a number of experiments calls for a prominent role of local correlations and place iron superconductors at the entrance of a Hund metal state, the effect of the local correlations on the nematic, superconducting and magnetic states of iron materials has been theoretically poorly investigated. I will discuss the nematicity at the Hund's metal crossover [3]. I will show how correlations severely constrain the precise nature of the feasible orbital-ordered state and induces a differentiation in the effective masses of the zx/yz orbitals in the nematic phase. The latter effect leads to distinctive signatures in different probes, so far overlooked in the interpretation of experiments. I will then discuss the consequences of the orbital selectivity on the superconducting phase, in particular concerning the symmetry of the pairing [4].

References:

1. L. De Medici, G. Giovannetti and M. Capone, Phys. Rev. Lett., 112, 177001 (2014).
2. L. Fanfarillo and E. Bascones, Phys. Rev. B, 92, 075136 (2015).
3. L. Fanfarillo, G. Giovannetti, M. Capone and E. Bascones, Phys Rev. B 95 144511 (2017).
4. L. Fanfarillo, M. Capone in preparation (2017).

Gate-controlled 2D superconductivity

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Ionic gating is a powerful tool for inducing and controlling superconductivity. Gate-controlled electrostatic charge accumulation in electric double layer transistors (EDLTs) has produced truly two-dimensional (2D) superconductivity with a thickness of several nm or less, which exhibits a variety of new phenomena including quantum metallic states (Bose metal), quantum Griffiths phases, dramatically enhanced Pauli-limit due to the spin-orbit interactions, and nonreciprocal superconducting transport [1].
Here we report gate-controlled electrochemical reaction also offers new opportunities to approach 2D superconductivity with a couple of examples: One is the gate-controlled interaction in single-crystalline lithium-intercalated layered nitrides (HfNCl and ZrNCl), and the other is the electrochemical etching in FeSe monolayer. In the former subject, we will discuss an approach toward the 2D BCS-BES crossover with reducing the carrier density. In the second subject, we report thermopower measurements on FeSe monolayer superconductors which was produced by gate-controlled electrochemical etching.

References:

1. Y. Saito, T. Nojima, and Y. Iwasa, *Nat. Rev. Mater.* **2**, 16094 (2016).

Magic Angle Graphene: a New Platform for Strongly Correlated Physics

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The understanding of strongly-correlated quantum matter has challenged physicists for decades. Such difficulties have stimulated new research paradigms, such as ultra-cold atom lattices for simulating quantum materials. In this talk I will present a new platform to investigate strongly correlated physics, based on graphene moiré superlattices. In particular, I will show that when two graphene sheets are twisted by an angle close to the theoretically predicted 'magic angle', the resulting flat band structure near the Dirac point gives rise to a strongly-correlated electronic system. These flat bands exhibit half-filling insulating phases at zero magnetic field, which we show to be a Mott-like insulator arising from electrons localized in the moiré superlattice. Moreover, upon doping, we find electrically tunable superconductivity in this system, with many characteristics similar to high-temperature cuprates superconductivity. These unique properties of magic-angle twisted bilayer graphene open up a new playground for exotic many-body quantum phases in a 2D platform made of pure carbon and without magnetic field. The easy accessibility of the flat bands, the electrical tunability, and the bandwidth tunability though twist angle may pave the way towards more exotic correlated systems, such as quantum spin liquids.

References:

1. Nature 556, 80 (2018)
2. Nature 556, 43 (2018)

Pair formation, local phase coherence, BEC-BCS crossover and magnetic resonance mode as key elements of unconventional superconductivity

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In 1989 we presented a nearly linear relationship between the superfluid density and Tc in underdoped cuprates, and pointed out a fundamental similarity to BEC condensation and incompatibility with BCS condensation [1]. In 1991, we initiated an energy-scale phenomenology to discuss unconventional superconductors based on a plot of the effective Fermi temperature TF and Tc [2]. Since then, common behavior has been found in many systems including cuprates, Fe-based, organic BEDT, alkali-doped C60, heavy fermion systems [3], and most recently in twisted bi-layer graphene [4]. In 2004, we proposed possible role of magnetic resonance mode as pair-non-breaking excitations analogous to rotons in superfluid He [5,6].

In this talk, based on the energy scale phenomenology and a special case of BEC-BCS crossover concept, we dis-entangle several key concepts of unconventional superconductors by arguing:

(a) Pair formation and build-up of local phase coherence (LPC) are completely separate phenomena in the underdoped (BEC-like) pseudogap region.

(b) Onset of LPC at TLPC is determined solely by the number density and mass of bosonic (preformed) pairs in the normal state

(c) The onset of photo-excited transient superconductivity and Nernst effect in the underdoped region occurs at TLPC

(d) The actual bulk Tc is significantly reduced from TLPC due to the existence of competing magnetic order

(e) The reduction from TLPC to bulk Tc is caused by thermal excitation of the superconducting condensate to the magnetic resonance mode, which can be viewed as a hybrid of pair-non-breaking and pair-breaking excitations

(f) Inelastic excitation similar to the magnetic resonance mode has been observed in the paramagnetic-metal side of the Mott transition of non-superconducting system BaCoS2. This implies that the resonance mode has a character of dynamic

spin correlations of imminent antiferromagnetic order, which does not require existence of pair-breaking excitation of superconducting condensate.
(g) The relationship between Tc and the 2-dimensional superfluid density can be different from the system-independent scaling of Kosterlitz-Thouless transitions, favoring 3-d BEC concept.
(h) The optimal Tc region occurs where the charge energy TF becomes comparable to the spin fluctuation energy J, suggesting possible resonating phenomena of the two energy scales [3,5].

References:

1. Y.J. Uemura *et al.*, Phys. Rev. Lett. 62 (1989) 2317.
2. Y.J. Uemura *et al.*, Phys. Rev. Lett. 66 (1991) 2665.
3. Y.J. Uemura, Physica B 404 (2009) 3195.
4. Pablo Jarillo-Herrero, Presentation at APS March Meeting 2018; Yuan Cao, Nature (accelerated article preview) doi:10.1038/nature26160 (2018).
5. Y.J. Uemura, J. Phys. Condens. Matter 16 (2004) S4515.
6. Y.J. Uemura, Nature Materials 8 (2009) 253.

BEC-to-BCS crossover in a doped spin liquid

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I will report on the transport properties of a hole-doped organic material with a triangular lattice. At low pressures, static susceptibility behaves nearly exactly like a spin-liquid Mott insulator, whereas resistivity is metallic (a non-Fermi liquid); thus, this system hosts a doped spin liquid. By applying pressure, the non-FL crosses over to a conventional FL. This system shows superconductivity, whose properties vary with pressure; the coherence length dramatically increases when the non-FL crosses over to the FL by pressure. The pressure-induced BEC to BCS crossover is associates with the non-FL to FL crossover in the normal state.

References:

1. Nature Communications 9 307 (2018).
2. Nature Communications 8, 756 (2017).
3. Rev. Mod. Phys.89 025003 (2017).

Mixtures of BCS and BCS-BEC crossover condensates and Lifshitz transitions in multigap superconductors: a mechanism for very high-Tc superconductivity

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The superconductivity in iron-based, magnesium diborides, and other novel high-Tc superconducting materials, possibly including the recently discovered superconducting hydrogen disulfide and the indications of high-Tc superconductivity in potassium doped paraterphenyl, has a strong multi-band and multi-gap character. Recent experiments support the possibility for a BCS-BEC crossover induced by strong-coupling and proximity of the chemical potential to the band edge of one of the bands, with evidences for Lifshitz transitions associated with changes in the Fermi surface topology [1,2]. Here we study the simplest theoretical model which accounts for the BCS-BEC crossover in a two-band / two-gap superconductor, considering tunable interactions. When the gap is of the order of the local chemical potential, superconductivity is in the crossover regime of the BCS-BEC crossover and the Fermi surface of the small band is completely smeared by the gap opening. In this situation, small and large Cooper pairs coexist in the total condensate, which is the optimal condition for high-Tc or even for room temperature superconductivity, thanks also to the screening of the superconducting fluctuations generated by the deep band. Using available experimental data, our analysis shows that iron-based superconductors have the partial condensate of the small Fermi surface which is in the crossover regime of the BCS-BEC crossover [2], supporting in this way the ARPES findings. We discuss different physical systems in which the multigap and multiband BCS-BEC crossover can be realized, pointing toward very high-Tc superconductivity. As an example we consider superconducting stripes in which shape resonances and multigap physics at the band edge play a cooperative role in enhancing superconductivity in the crossover regime of pairing [3]. We focus on a key prediction of the above discussed physics: the isotope effect of the superconducting critical temperature in the vicinity of a Lifshitz transition, which has a unique dependence on the energy distance between the chemical potential and the Lifshitz transition point. Comparisons with available experimental data for superconducting cuprates and hydrogen disulfide will be discussed [4]. The recent experimental indications of high-Tc superconductivity in potassium-doped para-terphenyl will be finally reviewed and discussed in this context [5], provinding a possible theoretical framework for high-Tc superconductivity in quasi-1D quantum organic materials.

References:

1. D. Innocenti, N. Poccia, A. Ricci, A. Valletta, S. Caprara, A. Perali, and A. Bianconi, Phys. Rev. B **82**, 184528 (2010).
2. A. Guidini and A. Perali, Supercond. Sci. Technol. **27**, 124002 (2014).
3. A. Perali, A. Bianconi, A. Lanzara, N.L. Saini, Solid State Comm. **100**, 181, (1996).
4. A. Perali, D. Innocenti, A. Valletta, A. Bianconi, Supercond. Sci. Technol. **25**, 124002 (2012).
5. M.V. Mazziotti, A. Valletta, G. Campi, D. Innocenti, A. Perali, A. Bianconi, Europhysics Letters **118**, 37003 (2017).

Superconductivity in single- and multi-band Hubbard models: can we optimise them?

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We can capture various high-Tc superconductors basically either with single-band models or multi-band ones. Since the two classes have distinct control parameters, we can theoretically explore how we can optimise them for higher Tc's with various pairing glues and pairing symmetries. There, "multibands" should not be confused with "multiorbital" systems. I shall thus discuss and compare merits and demerits of the two classes from both quantum many-body algorithms and materials-science points of view. For the former, I shall introduce DΓA (dynamical vertex approximation) and DMFT (dynamical mean-field theory) + FLEX (fluctuation exchange approximation) to fathom the correlation between the electronic structure and the superconductivity and to search for enhanced Tc's. For the latter, I shall present various ideas that include "hidden ladder" compounds and "flat-band" superconductivity.

Electronic phase separation in the systems with imperfect nesting

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Keywords: electronic phase separation, imperfect nesting, chromium alloys, iron-based pnictides, bilayer graphene

An overview of the theoretical studies on the electronic phase separation in the systems with the imperfect nesting of Fermi surface sheets is presented. Among these systems, there are chromium and its alloys, superconducting iron-based pnictides, bilayer graphene, and some other materials.

References:

1. A.L. Rakhmanov, A.V. Rozhkov, A.O. Sboychakov, F. Nori, Phys. Rev. Lett. 109, 206801 (2012).
2. A.L. Rakhmanov, A.V. Rozhkov, A.O. Sboychakov, F. Nori, Phys. Rev. B 87, 075128 (2013).
3. A.O. Sboychakov, A.V. Rozhkov, K.I. Kugel, A.L. Rakhmanov, F. Nori, Phys. Rev. B 88, 195142 (2013).
4. A.O. Sboychakov, A.L. Rakhmanov, K.I. Kugel, A.V. Rozhkov, F. Nori, Phys. Rev. B 95, 014203 (2017).
5. A.L. Rakhmanov, K.I. Kugel, M.Yu. Kagan, A.V. Rozhkov, A.O. Sboychakov, JETP Lett. 105, 806 (2017).

Electronic band structure of optimal superconductors: from cuprates to ferropnictides and back again

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Keywords: Lifshitz transition, superconductivity, HTSC, iron based superconductors

Based on the detailed comparison of the electronic band structures of different families of cuprates and iron based superconductors I argue that a general mechanism of the Tc enhancement in all known high-Tc superconductors is likely related with the proximity of certain Van Hove singularities to the Fermi level. While this mechanism remains to be fully understood, one may conclude that it is not related with the electron density of states but likely with some kind of resonances caused by a proximity of the Fermi surface to topological Lifshitz transition. One may also notice that the electronic correlations often shifts the electronic bands to optimal for superconductivity positions.

References:

1. A. A. Kordyuk, Low. Temp. Phys. (2018); arXiv:1803.01487.
2. A. A. Kordyuk, Low Temp. Phys. 38, 888 (2012).
3. A. A. Kordyuk, Low Temp. Phys. 41, 319 (2015).
4. Y. V. Pustovit, A. A. Kordyuk, Low Temp. Phys. 42, 995 (2016).

Topological Crystalline Insulators: Role of Superconductivity and Magnetism

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The current status of research on cubic IV-VI semiconductor compounds will be reviewed in the context of topological properties of these systems [1-4]. We will address the question why bulk superconductivity is observed in p-type SnTe but not in p-type PbTe with similar magnitudes of hole concentrations. Hole mediated ferromagnetism of (Pb,Sn,Mn)Te will be reviewed in the light of present knowledge on dilute ferromagnetic semiconductors and topological materials [5]. Finally, we will discuss recent results of point-contact spectroscopy in topological (Pb,Sn)Te and (Pb,Sn,Mn)Te. The data reveal the presence of zero-mode excitations superimposed onto an energy gap that shows a BCS-type critical behavior as a function of the magnetic field and temperature [6]. The origin of these Majorana-like excitations will be discussed taking into account the presence of 1D topological states at atomic steps.

References:

1. T. H. Hsieh, Hsin Lin, Junwei Liu, Wenhui Duan, A. Bansil, and Liang Fu, Nat. Commun. 3, 982 (2012).
2. K. A. Kolwas, G. Grabecki, S. Trushkin, J. Wróbel, M. Aleszkiewicz, Ł. Cywiński, T. Dietl, G. Springholz, and G. Bauer, phys. stat. sol. (b) 250, 37 (2013), arXiv:1111.2433.
3. P. Dziawa, B.J. Kowalski, K. Dybko, R. Buczko, A. Szczerbakow, M. Szot, E. Łusakowska, T. Balasubramanian, B.M. Wojek, M.H. Berntsen, O. Tjernberg, and T. Story, Nat. Mater. 11, 1023 (2012).
4. P. Sessi, D. Di Sante, A. Szczerbakow, F. Glott, S. Wilfert, H. Schmidt, T. Bathon, P. Dziawa, M. Greiter, T. Neupert, G. Sangiovanni, T. Story, R. Thomale, M. Bode, Science 354, 1269 (2016).
5. T. Dietl and H. Ohno, Rev. Mod. Phys. 86, 187 (2014).
6. G.P. Mazur, K. Dybko, A. Szczerbakow, M. Zgirski, E. Łusakowska, S. Kret, J. Korczak, T. Story, M. Sawicki, and T. Dietl, arXiv:1709.04000.

Novel MBE Materials for Spintronics

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Keywords: molecular beam epitaxy, spintronics ,

Molecular beam epitaxy (MBE) is a versatile method for developing new materials with interesting properties for spintronics and other topics of interest in the study of quantum complex matter. In our laboratory at Ohio State, we have recently developed a variety of new magnetic and topological materials and heterostructures. These include atomically thin magnets that exhibit room temperature ferromagnetism likely to originate from van der Waals monolayers, thin films and heterostructures of B20 skyrmion materials with interfacial spin texture, and topological Dirac semimetal Na3Bi thin films that can be interfaced with ferrimagnetic insulators. In this talk, I will focus on one or two of these materials for detailed discussion ranging from materials synthesis to their magnetic and electrical properties.

Driving Mechanism for the Electronic Nematic Phase in FeSe Revealed by its Anisotropic Optical Response

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Keywords: optical properties, iron-pnictide superconductors

The origin of the anisotropy in physical quantities within the electronic nematic phase of high-temperature superconductors is still very much debated. Here, we offer a thorough investigation of the excitation spectrum in detwinned FeSe, which at ambient pressure ideally undergoes a structural, tetragonal-to-orthorhombic phase transition at T_s = 90 K without any magnetic ordering on further cooling. Our unprecedented results provide evidence for an important interplay of the anisotropic Drude weight and scattering rate in the nematic phase, when shaping the anisotropy of the excitation spectrum. In the frequency to zero limit though, the temperature dependence of the anisotropic scattering rate plays the dominant role and, combined with the order parameter of the nematic phase as evinced from the high energy anisotropic optical response, accounts for the anisotropic dc resistivity. This favours the scattering by anisotropic spin fluctuations as driving mechanism for nematicity.

References:

1. M. Chinotti *et al.*, Phys. Rev. B, 96, 121112(R) (2017) references therein.

Decoupling between critical temperature and energy gaps in irradiated P-doped Ba-122 films

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Keywords: Iron-based superconductors, irradiation, energy gaps, point-contact spectroscopy

We report on direct measurements of the energy gaps (carried out by means of point-contact Andreev reflection spectroscopy, PCARS) and of the critical temperature in thin, optimally doped, epitaxial films of $BaFe_2(As,P)_2$ irradiated with 250 MeV Au ions [1]. The low-temperature PCARS spectra (taken with the current flowing along the c axis) can be fitted by a modified Blonder–Tinkham–Klapwijk model [2] with two nodeless gaps; this is not in contrast with the possible presence of node lines suggested by some experiments in literature [3]. Up to a fluence Phi=7.3 × $10^{(11)}$ $cm^{(-2)}$, we observe a monotonic suppression of the critical temperature and of the gap amplitudes Δ1 and Δ2. Interestingly, while Tc decreases by about 3%, the gap amplitudes decrease much more (by about 37% and 25% respectively), so that both the relevant gap ratios strongly decrease. This indicates an unusual decoupling between high-temperature and low-temperature superconducting properties that could be explained by quasiparticle confinement by defects [4], which makes the effective density of states available for pairing be higher near Tc than at low temperatures, where the gaps are measured [5].

References:

1. D. Daghero *et al.*, Appl. Surf. Sci. 395 9–15 (2017)
2. S. Kashiwaya, Y. Tanaka, M. Koyanagi and K. Kajimura, Phys. Rev. B 53 2667 (1996)

3. K. Hashimoto *et al.*, Phys. Rev. B 81 220501(R) (2010); M. Yamashita *et al.*, Phys. Rev. B 84 060507(R) (2011); Y. Zhang *et al.*, Nat. Phys. 8 371 (2012); T. Yoshida *et al.* Sci. Rep. 4 7292 (2014).
4. Z. Long, M. D. Stewart and J.M. Valles Phys. Rev. B 73 140507 (2006)
5. D. Daghero *et al.* Supercond. Sci. Technol. 31, 034005 (2018)

M-5

Pairing fluctuations in high temperature superconductors out of equilibrium

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The recent developments of femtosecond photon sources from the Thz to ultraviolet spectral range have largely enriched the methods to probe condensed matter on ultrafast timescales. Among the possible approaches, time resolved photoemission spectroscopy is acquiring an increasing recognition because of the unique capability of visualizing the temporal evolution of electronic excitations. I review the basic principles of this experimental method and discuss the results that we have obtained in the cuprate family of high temperature superconductors. Relevant examples are the estimate of average electron-phonon coupling and the photoinduced melting of superconducting phase. Both the physics of the non-equilibrium and critical condensate is ruled by fluctuations of the pairing field. These ones are responsible for the softening the superfluid stiffness and the partial filling of the superconducting gap. In the second part of the seminar I introduce the principles of time resolved THz spectroscopy. The THz data trade the lack of wavevector information by a considerable gain in signal to noise ratio. In particular, the high sensitivity of to superconducting correlations enables an inspection of the critical regime and reveals that fluctuating condensate obeys a scaling law casting information on the universality class.

N-1

Strain Engineering of a Topological Semi-metal

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The structural transition in the transition metal dichalcogenide (TMD) semimetal of $MoTe_2$, from the metastable 1T’ monoclinic to the non-centrosymmetric orthorhombic Td phase is the key to the emergence of four Weyl nodes with the breaking of the inversion symmetry. Here, we report on single crystal neutron diffraction experiments probing a discontinuous transition from the 1T’ to the Td phase, giving rise to substantial thermal diffuse scattering upon cooling due to Mo-Te bilayer shifting. Moreover, in the 1T’ phase, the mirror symmetry operation is absent, lowering the symmetry even further to P21 but the absence of inversion symmetry does not lead to Weyl nodes, making this a trivial semimetal.

Antiferromagnetic correlations in high oxidation state nickel oxides

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The material class of rare earth nickelates with high Ni^{3+} oxidation state is generating continued interest due to the occurrence of a metalinsulator transition with charge order and the appearance of noncollinear magnetic phases within this insulating regime. The recent theoretical prediction for superconductivity in $LaNiO_3$ thin films has also triggered intensive research efforts. $LaNiO_3$ seems to be the only rare earth nickelate that stays metallic and paramagnetic down to lowest temperatures. So far, centimetre-sized impurity-free single crystal growth has not been reported for the rare earth nickelates material class since elevated oxygen pressures are required for their synthesis.
Here, we report on the successful growth of centimetre-sized $LaNiO_3$ single crystals by the floating zone technique at oxygen pressures of up to 150 bar. Our crystals are essentially free from Ni^{2+} impurities and exhibit metallic properties together with an unexpected but clear antiferromagnetic transition.

Anomalous Aharonov-Bohm in the Strange Metal

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Keywords: Quantum Criticality

For the past 30 years, the strange metallic phase seen in the cuprate superconductors and many other quantum critical metals, have defied an explanation in terms of the standard building blocks in quantum field theory —- particles with local interactions and conservation laws. A recent proposal suggests that all of the properties of such `strange metals' can be understood if the current has an anomalous dimension not determined simply by dimensional analysis. My talk will focus on trying to understand this claim. To demystify this claim, I will first show that even in the standard formulation of electricity and magnetism, Noether's Second Theorem actually allows for the current and the associated gauge field to have any allowable dimension. However, I will show that the only quantum theories to date which exhibit such odd behaviour are holographic models that are derived from a gravity theory that lives in higher dimensions. I will focus on various experimental probes to detect such anomalous dimensions and construct the Virasoro algebra for such fractional currents and discuss the general implications for the bulk-boundary construction in holography.

References:
1. G. la Nave and P. Phillips, "Geodesically incomplete metrics Induce Boundary Non-locality in Holography: Consequences for the Entanglement Entropy", Phys. Rev. D 94, 126018 (2016).
2. G. La Nave and P. Phillips, "Anomalous Dimensions for Boundary Conserved Currents in Holography via the Caffarelli-Silvestri Mechanism for p-forms", To appear in Comm. Math. Physics, 2018.
3. Kridsanaphong Limtragool, Philip W. Phillips, "Anomalous Dimension of the Electrical Current in the Normal State of the Cuprates from the Fractional Aharonov-Bohm Effect", to appear in Euro. Phys. Lett.

O-1

Interacting Dirac bosons and fermions

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There is a growing family of honeycomb materials and systems which host fermionic and bosonic quasiparticles. The archetype of the former is graphene, while it has been recently rediscovered that the ferromagnetic transition metal trihalides are realizations of the former. The quasiparticles are electrons and magnons respectively. While the dispersion surfaces are the same for the fermions and bosons, there are clear consequences of the multiple site occupancies allowed for bosons but not for fermions. In particular, edge and surface states acquire dispersions for bosons and not fermions. Furthermore, there are very different many-body corrections for the Dirac magnons in the tri-halides than the electrons in graphene. Remarkably, the Dirac magnon self-energy corrections were observed in experiments reported almost half a century ago. More general results on the effects of statistics and interaction range are also presented.

Quantum Simulation with Ultracold Atoms

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Keywords: superfluidity, strongly correlated fermions

We will show how dilute samples of ultracold atoms can be used as quantum simulators of more complex quantum matter.
We will report on the measurement of the equation of state of a spin ½ Fermi gas with tunable interaction. In the strongly correlated regime the theoretical description of this phase is particularly challenging. Yet it applies to a variety of systems including the outer part of ultra-dense neutron stars [1]. Next, we will describe the first production and study of a novel quantum system, a mixture of Bose and Fermi superfluids. Such a mixture had long been sought in liquid helium where superfluidity was only achieved separately in bosonic 4He and fermionic 3He. Using dilute quantum gases where interactions can be tuned, we have produced a Bose-Fermi mixture where both species are superfluid [2]. By exciting center of mass oscillations of the mixture we probe the superfluid counterflow which exhibits very small damping below a certain critical velocity. We compare this critical velocity to a recent theoretical prediction [3,4]. Finally the lifetime of the Bose-Fermi mixture is governed by a very simple formula involving the fermionic two-body contact [5].

References:

1. N. Navon, S. Nascimbène, F. Chevy, C. Salomon, Science 328, 729-732 (2010)
2. Igor Ferrier-Barbut, Marion Delehaye, Sebastien Laurent, Andrew T. Grier, Matthieu Pierce, Benno S. Rem, Frédéric Chevy, Christophe Salomon, A Mixture of Bose and Fermi Superfluids, Science 345, 1035, (2014).
3. Y. Castin, I. Ferrier-Barbut, and C. Salomon, The Landau critical velocity for a particle in a Fermi superfluid, Comptes Rendus Physique, 16, 241 (2015).
4. M. Delehaye, S. Laurent, I. Ferrier-Barbut, S. Jin, F. Chevy, and C. Salomon, Critical Velocity and Dissipation of an ultracold Bose-Fermi Counterflow, Phys. Rev. Lett., 115, 265303 (2015).
5. S. Laurent, M. Pierce, M. Delehaye, T. Yefsah, F. Chevy, C. Salomon, Connecting few-body inelastic decay to quantum correlations in a many-body system : a weakly coupled impurity in a resonant Fermi gas, Phys. Rev. Lett., 118, 103403 (2017)

Magneto exciton condensation in double layer graphene

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Keywords: graphene, Columb drag, quantum Hall, magnetoexciton, BEC, BCS, crossover

We will discuss a superfluid condensation of magnetic-field-induced excitons by observing quantized Hall drag effect in graphene double layers spaced by atomically thin hexagonal-boron nitride (hBN). In our experiment, capitalizing strong Coulomb interaction across the atomically thin hBN separation layer, we realize the magneto-exciton BEC BCS in graphene double layers. We observed exciton condensation in dual-graphite-gated graphene double-layer devices for a wide range of the ratio between the layer separation (d) and the magnetic length (l) as the controlling parameter. For small (d/l) (the BEC limit), the counter-flow resistance shows an activation behavior. On the contrary, for large (d/l) (the BCS limit), the counter-flow resistance exhibits sharp transitions in temperature exhibiting characters of Berezinskii-Kosterlitz-Thouless (BKT) transition. Our experimental observations thus suggest the exciton condensate in graphene undergoes a BCS-BEC crossover around (d/l) ~ 0.5.

O-4

Spin-lattice coupling and nematic phase in iron pnictides

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We use inelastic neutron scattering to study acoustic phonons and spin excitations in single crystals of NaFeAs, a parent compound of iron pnictide superconductors. NaFeAs exhibits a tetragonalto-orthorhombic structural transition at Ts 58 K and a collinear antiferromagnetic (AF) order at TN 45 K. While longitudinal and out-of-plane transverse acoustic phonons behave as expected, the in-plane transverse acoustic phonons reveal considerable softening on cooling to Ts, and then harden on approaching TN before saturating below TN. In addition, we find that spin-spin correlation lengths of low-energy magnetic excitations within the FeAs layer and along the c-axis increase dramatically below Ts, and show weak anomaly across TN. These results suggest that the electronic nematic phase present in the paramagnetic tetragonal phase is closely associated with dynamic spin-lattice coupling, possibly arising from the one-phonon-two-magnon mechanism.

Room Temperature Topological Superconductors (RTTS) by controlling Lifshitz transitions in valleytronics by anisotropic strain

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The quantum mechanism to push the critical temperature toward room temperature topological superconductivity (RTTS) was proposed on Dec 7, 1993 [1-3]. This theory provides indications for the design of quantum material made of heterostructures at atomic limit. made of stacks of quantum wells or. Practical realizations of this theory are the arrays of *quantum stripes* in cuprates [4,5] *quantum wires* in pressurized H_3S [6-8] and 1D organic conductors [9] stacks of *quantum wells* in diborides [10] and iron based superconductors [11,12], and today stacks of flakes or ribbons. The electronic structure if this quantum topological materials shows multi-valley scenarios in the k-space with coexisting multiple different Fermi surfaces. The critical temperature is driven to high temperature by fine tuning the topology of both the real space and the k-space. The typical spacing between the quantum units are of the order of the electron Fermi wavelength and the superconductivity coherence length. The particular Fermi surface topologies for a given lattice topology are controlled by the charge density and strain. Anisotropic strain is used to tune the chemical potential near a topological Lifshitz transition [13] to change the electronic hopping energy between quantum units at the level of the energy cut-off of the pairing interaction. A major step in the field has been the development of the BPV multigap theory of superconductivity for steep and flat bands in the BCS-BEC crossover near Lifshitz transitions beyond all BCS approximations [4,5,9-14]. RTTS show the complex nanoscale phase separation in multi-band-Hubbard systems near topological Lifshitz transitions [13] observed by using scanning micro x-ray diffraction [15-17]. Here we discuss the emerging role of Fano resonances in sulfur hydrides, in organics and related matter with flat and steep bands mediated by high energy modes at the topological Lifshitz transition [13]. We show that the physics of systems showing high temperature superconductivity coexists with fluctuations of short range Periodic Lattice Modulations controlled by charge density or pressure. or anisotropic strain.

References:

1. A. Bianconi, US Patent **6,265,019** (2001)
2. A. Bianconi, *Solid State Communications* **91,** 1 (1994)
3. A. Bianconi, M. Missori Sol. State Commun. 91, 287 (1994) doi:10.1016/0038-1098(94)90304-2,
4. A. Bianconi, et al. S*olid State Communications* **102**, 369 (1997)
5. A. P9,erali, et al. *Supercond. Sci. Technol.* **25**, 124002 (2012)
6. A. Bianconi, T. Jarlborg, *EPL (Europhysics Letters)* **112**, 37001 (2015). doi:10.1209/0295-5075/112/37001.
7. A. Bianconi, T. Jarlborg, *Nov. Supercond. Mater.* **1**, 37 (2015) doi:10.1515/nsm-2015-0006.
8. T. Jarlborg, A. Bianconi, *Scientific Reports* **6**, 24816 (2016). doi:10.1038/srep24816
9. M.V. Mazziotti, et al. **118,** 37003 (2017). doi:10.1209/0295-5075/118/37003
10. A. Bianconi, *Journal of Superconductivity* **18,** 625 (2005) doi:10.1007/s10948-005-0047-5
11. M. Fratini, et al., *Supercond. Sci. Technol.* **21**, 092002 (2008)
12. R. Caivano, et al., *Supercond. Sci. Technol.* **22,** 014004 (2009). doi:10.1088/0953-2048/22/1/014004
13. A. Bianconi, *Nature Physics* **9,** 536-537 (2013). doi:10.1038/nphys2738.
14. Bussmann-Holder, A., Köhler, J., Simon, A., Whangbo, M.-H., Bianconi, A., and Perali, A. Bussmann-Holder, A. *et al.*. *Condensed Matter* **2**, 24 (2017). doi:10.3390/condmat2030024.
15. G. Campi et al., *Nature* **525**, 359 (2015). doi:10.1038/nature14987
16. G. Campi, et al. Phys. Rev. B **87**, 014517 (2013) doi:10.1103/physrevb.87.014517
17. G. Campi, A. Bianconi, *J. of Superconduct. and Novel Magnetism* **29**, 627 (2016). doi:10.1007/s10948-015-3326-9

Intertwined order and the hair of the black hole

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Keywords: Quantum matter, High Tc superconductivity, Holographic duality.

Holographic duality is a mathematical machine discovered in string theory that translates the physics of densely many body entangled quantum matter into the gravitational physics of black holes. This describes strange metals that may become unstable at low temperatures to ordered forms of matter in terms of the black holes developing "hair". Using numerical GR it is becoming possible to compute this and very recently it has become clear that the black hole acquires a highly fanciful haircut that appears to reproduce the most salient features of the intertwined order observed in underdoped cuprates.

References:

1. J. Zaanen, Y.-W. Sun, Y. Liu and K. Schalm, "holographic duality in condensed matter physics" (Cambridge Univ. Press, 2015).
2. B. Keimer *et al.*, Nature 518, 179 (2015).
3. T. Andrade *et al.*, arXiv:1710.05791
4. R.-G. Cai et al, Phys. Rev. Lett. 119, 181601 (2017)

P-3

Vestigial order in unconventional superconductors

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Low-density superconductors are affected by collective fluctuations of the order parameter. In systems like the doped topological insulator $Cu_xBi_2Se_3$ or half-Heusler superconductors such as YPtBi, strong spin-orbit coupling tends to promote unconventional superconducting states with multi-component order parameters.

We show that fluctuations fundamentally change the nature of the superconducting transition in these systems. New symmetry-broken phases emerge above Tc with an order parameter that is made of the Cooper pair bound states, so called composite order parameters. We find that for $Cu_xBi_2Se_3$ this gives rise to a nematic phase above Tc. In YPtBi we obtain time-reversal symmetry breaking. We also propose a phase with charge 4e superconductivity that occurs above the usual charge 2e a.k.a. Cooper-pair phase that should be easily identifiable through its half-integer flux-quanta.

P-4

Unconventional multi-band superconductivity in bulk $SrTiO_3$ and $LaAlO_3/SrTiO_3$ interfaces

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Although discovered many decades ago, the origin of superconductivity in $SrTiO_3$ remains a widely debated subject, with implications for our understanding of superconducting heterostructures and superconductivity in the very dilute limit. In this talk, I will discuss theoretical models for the normal and superconducting states of doped $SrTiO_3$ and gated $LaAlO_3/SrTiO_3$. I will argue that, in its normal state, this system is a weakly-correlated Fermi liquid with unusual transport properties. I will also show that the double-dome structure of the superconducting Tc, which peaks at two Lifshitz transitions, is only compatible with an unconventional multi-band superconducting state with strong intra-band attraction and weaker inter-band repulsion. Finally, I will discuss the possible origin of the intra-band attraction and its relationship with the longitudinal and transverse phonon modes associated with the nearby ferro-electric transition.

Magnetism in artificial Ruddlesden-Popper iridates leveraged by structural distortions, interlayer coupling and ultra-fast optical excitation

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Many appealing structural and electronic analogies between iridates and traditional 3d-electron based cuprates have been identified. One crucial difference, however, is that iridates host spin-orbit coupled Jeff=1/2 magnetic moments rather than pure spin S = 1/2 moments. This coupling means that subtle structural modulations driven by heterostructuring in iridates can be leveraged to drive large changes in the magnetic interactions. This talk focuses on resonant x-ray scattering studies of this phenomenology in (SrIrO3)n-(SrTiO3)m and Sr2IrO4 based heterostructures. This includes a demonstration of how twisting of the Ir-O octahedra drive the magnetic interactions in n=1 and 2 (SrIrO3)n-(SrTiO3)m heterostructures and how these systems mimic the bulk Ruddelston-Popper iridates Srn+1IrnO3n+1 [1]. It will further cover how the magnetic state of SrIrO3 changes as a function of the number of intervening SrTiO3 layers m [2]. It was found that both interlayer coupling and local anisotropy act in concert to stabilize Mott insulating antiferromagnetic states and that the relative importance of these effects change with m. An emergent new field focuses on further modifying magnetic interactions with ultra-fast laser excitation. It has recently been shown that x-ray free electron lasers can be used to probe the nature of the magnetic correlations in transient states of iridates and that the magnetic dynamics is strongly dependent on the dimensionality of the magnetic interactions [3].

References:

1. D. Meyers, Yue Cao, G. Fabbris, Neil J. Robinson, Lin Hao, C. Frederick, N. Traynor, J. Yang, Jiaqi Lin, M. H. Upton, D. Casa, Jong-Woo Kim, T. Gog, E. Karapetrova, Yongseong Choi, D. Haskel, P. J. Ryan, Lukas Horak, X. Liu, Jian Liu, and M. P. M. Dean, arXiv:1707.08910 (2017)
2. L. Hao, D. Meyers, C. Frederick, G. Fabbris, J. Y. Yang, N. Traynor, L. Horak, D. Kriegner, Y. S. Choi, J. W. Kim, D. Haskel, P. J. Ryan, M. P. M. Dean, J. Liu, Phys. Rev. Lett. 119, 027204 (2017)

3. M. P. M. Dean, Y. Cao, X. Liu, S. Wall, D. Zhu, R. Mankowsky, V. Thampy, X. M. Chen, J. Vale, D. Casa, Jungho Kim, A. H. Said, P. Juhas, R. Alonso-Mori, M. Glownia, A. Robert, J. Robinson, M. Sikorski, S. Song, M. Kozina, H. Lemke, L. Patthey, S. Owada, T. Katayama, M. Yabashi, Yoshikazu Tanaka, T. Togashi, J. Liu, C. Rayan Serrao, B. J. Kim, L. Huber, C.-L. Chang, D. F. McMorrow, M. Först, and J. P. Hill , Nature Materials, 15 601-605 (2016)

Intrinsic nanoscale phase separation in the stripes phase of cuprates and nickelates at low temperature

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To probe the proposed superstripes scenario [1-3] generated by a nanoscale phase separation in doped strongly correlated quantum matter made of nanoscale striped puddles, have developed the scanning micro x.-ray diffraction with highly focused x-ray synchrotron radiation beams [4-12]. While incommensurate spin stripes order in $La_{2-x}Sr_xNiO_4$ is the archetypal case of spin striped phases in doped strongly correlated insulators, no information is available on their spatial distribution. A unexplained anomalous drop of the stripe order and a shift of the stripe modulation wave-vector appears decreasing temperature below 70K in Cu L_3-edge resonant elastic X-ray scattering. Here we report direct evidence for mesoscopic spatial phase separation using scanning Cu K-edge resonant micro X-ray diffraction with a coherent beam. The inhomogeneous stripes order shows coexistence of linear micro-domains of high (and low) density of striped puddles in different locations. The temperature dependent complex distribution of point-to-point fluctuations of stripes size, wave-vector, and intensity is determined. Decreasing temperature a phase transition from a commensurate (C) stripes phase at a devil'staircase at 70K to a 30 K incommensurate (IC) phase has been discovered with a critical power-law distribution of the stripe puddles aspect ratio indicating an emerging intrinsic functional correlated disorder in the mesoscale at low temperature.

1. Bianconi, A. Quantum materials: Shape resonances in superstripes. *Nature Physics* **9**, 536-537 (2013).
2. Kusmartsev, F. V., Di Castro, D., Bianconi, G. & Bianconi, A. Transformation of strings into an inhomogeneous phase of stripes and itinerant carriers. *Physics Letters A* **275**, 118-123 (2000).
3. Kugel, K. I., Rakhmanov, A. L., Sboychakov, A. O., Poccia, N. & Bianconi, A. Model for phase separation controlled by doping and the internal chemical pressure

in different cuprate superconductors. *Phys. Rev. B* **78**, 165124 (2008).
4. Fratini, M. *et al.* Scale-free structural organization of oxygen interstitials in La_2CuO_{4+y}. *Nature* **466**, 841-844 (2010).
5. Poccia, N. *et al.* Spatial inhomogeneity and planar symmetry breaking of the lattice incommensurate supermodulation in the high-temperature superconductor $Bi_2Sr_2CaCu_2O_{8+y}$. *Phys. Rev. B* **84**, 100504 (2011).
6. Poccia, N. *et al.* Optimum inhomogeneity of local lattice distortions in La_2CuO_{4+y}. *Proc. Natl. Acad. Sci. U.S.A.* **109**, 15685-15690 (2012).
7. Campi, G. *et al.* Scanning micro-x-ray diffraction unveils the distribution of oxygen chain nanoscale puddles in $YBa_2Cu_3O_{6.33}$. *Phys. Rev. B* **87**, 014517 (2013). [61] Ricci, A. *et al.* Multiscale distribution of oxygen puddles in 1/8 doped $YBa_2Cu_3O_{6.67}$. *Scientific Reports* **3**, 2383 (2013).
8. Ricci, A. *et al.* Networks of superconducting nano-puddles in 1/8 doped $YBa_2Cu_3O_{6.5+y}$ controlled by thermal manipulation. *New J. Phys.* **16**, 053030 (2014).
9. Ricci, A. *et al.* Direct observation of nanoscale interface phase in the superconducting chalcogenide $K_xFe_{2-y}Se_2$ with intrinsic phase separation. *Phys. Rev. B* **91**, 020503 (2015).
10. Campi, G. *et al.* Inhomogeneity of charge-density-wave order and quenched disorder in a high-T_c superconductor. *Nature* **525**, 359-362 (2015).
11. Campi, G., Ricci, A., Poccia, N., Fratini, M., and Bianconi, A. X-Rays Writing/Reading of charge density waves in the CuO2 plane of a simple cuprate superconductor. *Condensed Matter* 2:26 (2017).
12. Campi, G., Di Gioacchino, M., Poccia, N., Ricci, A., Burghammer, M., Ciasca, G., and Bianconi, A. Nanoscale correlated disorder in out-of-Equilibrium myelin ultrastructure. *ACS Nano* **12**, 729-739 (2018).

Universality of Complex Electronic Pattern Formation in Correlated Oxides

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Keywords: strongly correlated electronic systems pattern formation fractal scale-free

Inside the metals, semiconductors, and magnets of our everyday experience, electrons are uniformly distributed throughout the material. By contrast, electrons often form clumpy patterns inside of strongly correlated electronic systems (SCES) such as colossal magnetoresistance materials and high temperature superconductors. In copper-oxide based high temperature superconductors, scanning tunneling microscopy (STM) has detected an electron nematic on the surface of the material, in which the electrons form nanoscale structures which break the rotational symmetry of the host crystal. These structures may hold the key to unlocking the mystery of high temperature superconductivity in these materials, but only if the nematic also exists throughout the entire bulk of the material.
Using new methods we have developed for decoding these surface structures, we find that the nematic indeed persists throughout the bulk of the material. We furthermore find that the intricate pattern formation is set by a delicate balance between disorder, interactions, and material anisotropy, leading to a fractal nature of the cluster pattern. The methods we have developed can be extended to many other surface probes and materials, enabling surface probes to determine whether surface structures are confined only to the surface, or whether they extend throughout the material.

Pairing and phase coherence in superconducting oxide interfaces

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In $LaAlO_3/SrTiO_3$ heterostructures, a gate tunable superconducting electron gas is confined in a quantum well at the interface between two insulating oxides. Remarkably, the gas coexists with both magnetism and strong Rashba spin-orbit coupling. The band structure based on titanium d-orbitals is rich and complex. Therefore, charge, spin and orbital degrees of freedom are at play in these systems, which can be controlled by a gate voltage, and may lead to exotic phases such as topological superconductivity for instance. However, both the origin of superconductivity and the nature of the thermal or quantum phase transition to the normal state over the whole doping range remain elusive.

Through DC transport measurements, we have explored the phase diagram and showed that phase fluctuations, disorder and possibly spontaneous electronic phase separation play a crucial role in these transitions [1,2]. Through AC measurements, namely resonant microwave experiments, we recently measured the superfluid stiffness and inferred the superconducting gap energy as a function of carrier density. We showed that the superconducting phase diagram of $LaAlO_3/SrTiO_3$ is controlled by the competition between electron pairing and phase coherence [3]. Whereas a good agreement with the BCS theory is observed at high carrier doping, we found that the suppression of Tc at low doping is controlled by the loss of macroscopic phase coherence instead of electron pairing as in standard BCS theory, and that a very small fraction of the electrons condenses into the superconducting state, corresponding to the weak filling of a high-energy dxz/yz band.

From this, a coherent view of the phase diagram of $LaAlO_3/SrTiO_3$ heterostructures is proposed.

References:

1. J. Biscaras *et al.*, Nature Materials 12, 542 (2013)
2. N. Scopigno *et al.*, Physical Review Letters 116, 026804 (2016)
3. G. Singh *et al.*, Nature Communications 9, 407 (2018)

Charge density waves rule the phase diagram of cuprates

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Keywords: Dynamical charge density waves, cuprate superconductors

In the last few years, charge density waves (CDWs) have been ubiquitously observed in superconducting cuprates and are now the most investigated among the competing orders. A wealth of recent experimental data raises several questions that challenge the various theoretical proposals. We relate our mean-field instability line T^0 CDW of a strongly correlated Fermi liquid to the pseudogap line T*(p), which marks the onset of CDW-fluctuations. These fluctuations suppress the extension of the ordered region. Controlling this reduction via an infrared frequency cutoff related to the characteristic time of the probes, we account for the complex experimental temperature versus doping phase diagram. We provide a coherent scenario explaining why different CDW onset curves are observed by different experimental probes and seem to extrapolate at zero temperature into seemingly different quantum critical points (QCPs) in the intermediate and overdoped region. We also show that phase fluctuations of the CDWs, which are enhanced in the presence of strong correlations near the Mott insulating phase, naturally account for the disappearance of the CDWs at low doping with yet another QCP as seen by the experiments.

References:

1. S. Caprara. *et al.*, Phys. Rev. B 95, 224511 (2017).
2. S. Andergassen, *et al.*, Phys. Rev. Lett. 87, 056401 (2001).
3. G. Ghiringhelli, *et al.*, Science 337, 821 (2012).
4. J. Chang, *et al.*, Nat. Phys. 8, 871 (2012).
5. S. Blanco-Canosa, *et al.*, Phys. Rev. B 90, 054513 (2014).

Intrinsic magnetic moments in topological insulators and their role in spin-charge conversion

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Keywords: topological insulators; magnetic moments.

We report the comprehensive studies of the magnetic state of 3D topological insulators (TI) which emerges due to intrinsic magnetic moments, originating from the nonmagnetic structural defects of these compounds [1]. Using ESR spectroscopy together with the SQUID magnetometry and transport measurements we argue that the experimental data evidence in favor of superparamagnetic state formed by nanoscale single-domain ferromagnets dissolved in the TI. Such a state resembles a frustrated phase separation giving rise to tiny ferromagnetic droplets in the bulk of TI. Due to stochastic polarization of these nanoscale ferromagnets their net magnetic polarization in the absence of the external magnetic field is completely averaged out. Therefore, contrary to the situation typical for the TI with extrinsic (doped) local magnetic moments, in the absence of external field the time reversal symmetry of TI is not violated.

In conclusion we discuss also the possibility of spin-charge conversion via the pumping of the spin resonance of the intrinsic local moments.

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References:

1. A. B V. Sakhin et al., Journal of Magnetism and Magnetic Materials, Volume 459, 290 (2018) https://doi.org/10.1016/j.jmmm.2017.10.047

Crossover-induced spin fluctuation and electron pairing in strongly correlated electrons

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Keywords: strong correlation; mechanism of superconductivity; kinetic driven superconductivity; spin fluctuation; Hubbard model; d-p model

The mechanism of high-temperature superconductivity has been studied intensively since the discovery of cuprate high-temperature superconductors. It is certain that the electron correlation plays an important role in cuprate superconductors since parent materials without doped carriers are insulators. It is important to clarify the phase diagram of electronic states in the CuO_2 plane. We investigate the ground state of the strongly correlated electronic models by employing the optimization variational Monte Carlo method [1, 2]. We consider the two-dimensional Hubbard model and also the three-band d-p model. We use the improved wave function that takes into account inter-site electron correlation beyond the Gutzwiller wave function. The ground-state energy is lowered considerably, which now gives the best estimate of the ground-state energy for the two-dimensional Hubbard model. We argue that there is a crossover from weakly to strongly correlated regions as the on-site Coulomb repulsion U increases when holes are doped. The antiferromagnetic (AF) correlation function increases as U increases in weakly correlated region, and has a peak at the intermediate value of U being of the order of the bandwidth. The large U, greater than the bandwidth, suppresses the AF correlation to lower the ground-state energy by obtaining the kinetic energy gain. The large spin and charge fluctuations are induced in the strongly correlated region. This results in electron pairing and would lead to high-temperature superconductivity. The conventional spin fluctuation in weakly correlated region should be distinguished from that in strongly correlated region. We think that it is just the spin fluctuation in strongly correlated region that would induce high-temperature superconductivity.

References:

1. T. Yanagisawa, J. Phys. Soc. Jpn. 85, 114707 (2016).
2. T. Yanagisawa, S. Koike and K. Yamaji, J. Phys. Soc. Jpn. 67, 3867 (1998).
3. T. Yanagisawa and M. Miyazaki, EPL 107, 27004 (2014).

4. T. Yanagisawa, Phys. Rev. B 75, 224503 (2007).
5. T. Yanagisawa, M. Miyazaki, K. Yamaji, J. Phys. Soc. Jpn. 78, 013706 (2009).
6. T. Yanagisawa, S. Koike and K. Yamajji, Phys. Rev. B64, 184509 (2001).

Electronic compressibility in FeSe and its correlation with Tc

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Keywords: Fe-based superconductors, strongly-correlated materials, unconventional superconductivity

We compute the compressibility of the conduction electrons in both bulk orthorhombic FeSe and monolayer FeSe on $SrTiO_3$ substrate, including dynamical electronic correlations within slave-spin mean-field + density-functional theory.
Results show a zone of enhancement of the electronic compressibility crossing the interaction-doping phase diagram of these compounds in accord with previous simulations on iron pnictides and in general with the phenomenology of Hund's metals.
Interestingly at ambient pressure FeSe is found slightly away from the zone with enhanced compressibility but moved right into it with hydrostatic pressure, while in monolayer FeSe the stronger enhancement region is realized on the electron-doped side. These findings correlate positively with the enhancement of superconductivity seen in experiments, and support the possibility that Hund's induced many-body correlations boost superconductive pairing when the system is at the frontier of the normal- to Hund's-metal crossover.

References:

1. L. de' Medici, Phys. Rev. Lett. 118, 167003 (2017).
2. P. Villar-Arribi and L. de' Medici, unpublished (2017).

Fermi Surface Topology in Striped HTSC

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Keywords: HTSC, Fermi Surface Topology

In this work, the impact of a striped phase on the Fermi surface topology will be analyzed. The superconducting properties such as energy gap and critical temperature will be computed adopting of the "standard" BCS approach.

Phase separation and proximity effects in itinerant ferromagnet – superconducting heterostructures

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Keywords: Proximity effect, phase separation, itinerant ferromagnetism, Josephson effect, hybrid systems, correlated band model, Bogoliubov - de Gennes

We analyze pair correlations and the magnetic structure of itinerant magnetic – superconducting heterostructures in the clean limit. In contrast to most models used for hybrid systems, ferromagnetism is not enforced as an external Zeeman field but induced in correlated single-band models (CSBM) that display itinerant ferromagnetism as a mean-field ground state. This allows us to consider magnetic and superconducting orders on equal footing, using the self-consistent Bogoliubov-de Gennes approach. In particular, we investigate the influence of adjacent superconducting layers on the properties of the ferromagnet. The CSBM displays a variety of features close to the interface that are absent in the Zeeman exchange model, as for example, phase separation, or the inverse proximity effect.

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Ultracold atom quantum simulations: Exploring low temperature Fermi-Hubbard phases

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Keywords: Fermi Hubbard, Quantum Simulation, Antiferromagnetism, doping, Ultracold Atoms, Optical Lattices

Exotic phenomena in systems with strongly-correlated electrons emerge from the interplay between spin and motional degrees of freedom. Quantum simulation using ultracold fermions in an optical lattice can shed light on the Hubbard Hamiltonian, a paradigmatic strongly-correlated system. We report on the realization of a Hubbard antiferromagnet and explore the interaction between spin and charge as we dope the system. Single-site resolution provides access to quantities such as the site-resolved spin correlation function, spin structure factor, and full counting statistics of the staggered magnetization. We hole-dope the system and study the interplay between hole motion and antiferromagnetic order. As the hole tunnels in the antiferromagnet, it leaves signatures by distorting the surrounding magnetic order. We explore these signatures and examine the dynamics of the holes themselves.

The evolution from BCS to BEC superfluidity in multiband systems: Applications to two-band superconductors and ultra-cold Fermi gases

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Keywords: Two band superconductors, FeSe, BCS to BEC

In the first part of the talk, I review some early work about the evolution from Bardeen-Cooper-Schrieffer (BCS) to Bose-Einstein Condensate (BEC) superfluids in the context of multiband systems. I focus primarily on three-dimensional s-wave two-band superfluids with a possible Josephson coupling between bands and discuss how collective modes evolve during the crossover from BCS to BEC superfluidity [1]. I also review the case where the Josephson interaction is tuned from negative to positive values leading to a quantum phase transition. In addition, I show that population imbalances between the two bands can be created by tuning intraband or interband interactions. Furthermore, I discuss the critical temperature of two-band superfluids, obtain the resulting coupled Ginzburg-Landau equations and show that they reduce to coupled Gross-Pitaevskii equations for two types of bosons in the BEC limit [2, 3]. In the second part of the talk, I present unpublished results on the evolution from BCS to Bose superfluidity for two-band fermions in two dimensions, including the cases of two particle (two hole) bands or of one particle and one hole bands. In these cases, I discuss also the critical temperature, the superfluid density tensor of the system and the resulting vortex-antivortex structures in connection to the Berezinskii-Kosterlitz-Thouless (BKT) transition [4]. For the twodimensional case, possible connections are made to experimental systems consisting of two-band ultra-cold fermions such as 6Li or 40K, as well as, of two-band superconductors such as FeSe.

References:

1. M. Iskin and C. A. R. Sá de Melo, "BCS-BEC crossover of collective excitations in two-band superfluids", Phys. Rev. B 72, 024512 (2005).
2. M. Iskin and C. A. R. Sá de Melo, "Two-band superfluidity from the BCS to BEC limit", Phys. Rev. 74, 144517 (2006).
3. M. Iskin and C. A. R. Sá de Melo, "Evolution of two-band superfluidity from weak

to strong coupling”, J. Low Temp. Phys. 149, 29 (2007).
4. A. J. Buser and C. A. R. Sá de Melo, “Two-band superfluids in two-dimensions: evolution from weak to strong coupling”, unpublished (2018).

Dynamical Properties of Skyrmions in Chiral Magnets

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Skyrmions in chiral magnets and related topological spin textures attract great interest as a possible route towards novel spintronics devices. We report a series of studies exploring the topological stability of skyrmions in chiral magnets, considering different decay routes and the effects of entropy compensation under changes of temperature and field. We address further the response of skyrmions and topological spin textures to electric currents and associated spin currents across the entire magnetic phase diagram of selected materials. Based on the combination of electrical resistivity, Hall effect, planar Hall effect, ac susceptibility and kinetic small angle neutron scattering we explore the interplay of spin transfer torques with defects for the different magnetic phases and phase boundaries.

Interplay of superconductivity and magnetism in Fe-based superconductors under high pressure

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Keywords: pairing mechanism, iron-based superconductors, Mössbauer effect, pressure

The family of iron-based superconductors is being intensively studied but the mechanism of superconductivity in these materials still remains enigmatic disputed. The currently available experimental data reveals that the structure, magnetism, and superconductivity strongly correlate in the iron-based superconductors. One of the main aspects is the widely acknowledged scenario that magnetic fluctuations are responsible for the superconducting pairing. The application of pressure is a versatile and elegant tool to induce structural changes and consequently to investigate the interplay between magnetic and superconducting properties. Our study is focused on the simplest systems based mainly on FeSe, where magnetism, or nematic order, could be „switched off“ by doping or intercalation. The studies were conducted on Li/NH_3 intercalated FeSe with Tc up to 44 K, and FeSe-related compounds, namely the $A_{1-x}Fe_{2-y}Se_2$ (A = K, Rb, Cs, Tl) series of compounds belonging to the $ThCr_2Si_2$ type of structure with Tc values up to 33 K. The emergence of the superconducting state under pressure was investigated in conjunction with the magnetic properties of the respective material in the normal state.

Anharmonicity of lattice dynamics in the Im-3m structures, H3S, ScF3, ReO3, SrTiO3 by EXAFS and XANES

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Anharmonicity of lattice dynamics in the Im-3m structures, ScF_3, ReO_3, $SrTiO_3$ and H_3S, detected by EXAFS and XANES controlling negative thermal expansion, structural phase transitions, ferroelectricity and high Tc superconductivity

Free surfaces recast superconductivity in few-monolayer MgB_2: Combined first-principles and ARPES demonstration

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Keywords: Superconductivity, ultrathin films, surface states, MgB2, ARPES

Two-dimensional materials are known to harbour properties very different from those of their bulk counterparts. Recent years have seen the rise of atomically thin superconductors, with a caveat that superconductivity is strongly depleted unless enhanced by specific substrates, intercalants or adatoms. Surprisingly, the role in superconductivity of electronic states originating from simple free surfaces of two-dimensional materials has remained elusive to date. Here, based on first-principles calculations, anisotropic Eliashberg theory, and angle-resolved photoemission spectroscopy (ARPES), we show that surface states in few-monolayer MgB_2 make a major contribution to the superconducting gap spectrum and density of states, clearly distinct from the widely known, bulk-like σ- and π-gaps. As a proof of principle, we predict and measure the gap opening on the magnesium-based surface band up to a critical temperature as high as ~30 K for merely six monolayers thick MgB_2. These findings establish free surfaces as an unavoidable ingredient in understanding and further tailoring of superconductivity in atomically thin materials.

References:

1. Sci Rep. 2017; 7: 14458. doi: 10.1038/s41598-017-13913-z

Tunable properties of molybdenum oxides thin films: conductivity vs. work function

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The interplay of nano- and micrometer-scale factors is typically at the origin of the properties and the macroscopic behavior of many transition metal (TM) oxides. [1-4] Molybdenum oxide films are multiphase systems characterized by transparent and insulating phases such as MoO_3 or metallic phases such as MoO_2, both of high-interest for fundamental issues and technological applications. Different chemical and structural factors may affect the properties of Mo-based films and, in particular, the work function. In many transition metal oxides the work function decreases near a metal/metal-oxide interface, a behavior useful to tune properties such as the field emission when the metallic substrate is properly selected. I will present and discuss experimental data of metallic TM oxides thin films grown on a metallic substrate like copper of great interest for many technological applications. [5,6]

References:

1. N. Poccia, A. Ricci, G. Campi, M. Fratini, A. Puri, D. Di Gioacchino, A. Marcelli, M. Reynolds, M. Burghammer, N.L. Saini, G. Aeppli and A. Biancon, Optimum inhomogeneity of local lattice distortions in La2CuO4+y, Proc. Nat. Acad. Sci. 109, 15685-15690 (2012).
2. A. Marcelli, B. Spataro, S. Sarti, V.A. Dolgashev, S. Tantawi, D.A. Yeremian, Y. Higashi, R. Parodi, A. Notargiacomo, Junqing Xu, G. Cappuccio, G. Gatti, G. Cibin, Characterization of thick conducting molybdenum films: enhanced conductivity via thermal annealing, Surf. Coat. Tech. 261, 391-397 (2015).
3. A. Marcelli, Phase separations in highly correlated materials, Acta Phisica Polon. A 129, 264-269 (2016).

4. A. Marcelli, M. Coreno, M. Stredansky, W. Xu, C. Zou, L. Fan, W, Chu, S. Wei, A. Cossaro, A. Ricci, A. Bianconi, A. D'Elia, Nanoscale phase separation and lattice complexity in VO2: the metal-insulator transition investigated by XANES via Auger electron yield at the vanadium L23-edge and Resonant Photoemission, Condens. Matter 2, 38 (2017); doi:10.3390/condmat2040038.
5. A. Marcelli, B. Spataro, G. Castorina, W. Xu, S. Sarti, F. Monforte and G. Cibin, Materials and breakdown phenomena: heterogeneous molybdenum metallic films, Condensed Matter 2, 18 (2017).
6. V.A. Dolgashev, G. Gatti, Y. Higashi, O. Leonardi, J.R. Lewandowski, A. Marcelli, J. Rosenzweig, B. Spataro, S.G. Tantawi, D.A. Yeremian, High power tests of an electroforming cavity operating at 11.424 GH, J. Instr. 11, P03010 (2016).

Resonant Inelastic X-ray scattering from correlated electron systems and unconventional High-Tc superconductors

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Resonant inelastic X-ray scattering (RIXS) is a powerful bulk-sensitive photon-in / photon-out spectroscopic and scattering probe. It has following key advantages: (1) Working at the resonance of an absorption threshold, it provides elementary sensitivity for the study of quantum complex matter especially with mixed-valence states; (2) The direct RIXS obeys the x-ray dipole selection rule and is sensitive to (entangled) electronic, magnetic and lattice dynamics of samples particularly those with magnetic and electronic interactions.
The dedicated I21-RIXS beamline at Diamond Light Source covers an energy range from 250 to 3000 eV with a combined energy resolution of 35 meV at 1 keV as a design target. To achieve such demanding goal, we constructed a 81 meter long beamline with a 15 meter long RIXS spectrometer which can pivot around the sample continuously by 150 degrees. Through the x-ray commissioning, we have obtained the energy resolution of about 35 meV at Cu L-edge (930 eV) and about 15 meV at Oxygen K-edge (532 eV). In this talk, I will give a brief introduction of RIXS technique, the achieved performance at the I21 beamline, and the science applications in one-dimensional quantum spin chain system and unconventional high-Tc superconductors.

BCS-BEC crossover in Fe(Se,S) superconductors

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Among iron-based superconductors, FeSe has the simplest crystal structure but it exhibits arguably the richest physics. Unlike other iron-based materials, the bulk FeSe samples do not show magnetic order below the structural (nematic) transition at 90 K. The electronic structure is quite unusual, having very small and anisotropic hole and electron pockets with the very low Fermi energies [1]. This put the system deep inside the BCS-BEC crossover regime, and we find giant superconducting fluctuations above Tc consistent with the preformed pairs [2]. By substituting Se with isoelectric S, the structural transition temperature can be completely suppressed, which allows us to tune into a nonmagnetic nematic quantum critical point [3]. In the non-nematic (tetragonal) phase, the temperature dependence of specific heat shows quite unusual behaviors, suggesting an unexpected evolution of superconducting fluctuations with S substitutions.

References:

1. S. Kasahara *et al.*, PNAS 111, 16309 (2014).
2. S. Kasahara *et al.*, Nat. Commun. 7, 12843 (2016).
3. S. Hosoi *et al.*, PNAS 113, 8139 (2016).

Neutron scattering data challenges and opportunities for quantum condensed matter

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Understanding atomic and magnetic structures and identifying the interplay between lattice and magnetic excitations is at the forefront of quantum condensed matter research. Neutron diffraction and spectroscopy is one of major tools that is used in this area. New facilities with high neutron fluxes, and time of flight instruments with many detectors, offer unprecedented opportunities for novel experiments. However, the large amount of data produced by these measurements provides challenges for processing, visualization, and analysis.
This presentation will provide an overview of computational advances made at the Oak Ridge National Laboratory. I will focus on recent diffuse neutron diffraction and polarized spectroscopy experiments.

Non-Fermi-Liquid Behavior in Quantum Magnets

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We discuss the commonly observed non-Fermi-liquid transport properties of metallic quantum magnets, which manifest themselves in a low-temperature electrical resistivity proportional to $T^{3/2}$, or a power law close to that. We present three scattering mechanisms that lead to a $T^{3/2}$ behavior of the resistivity, due to the coupling of the conduction electrons to ferromagnetic magnons, helimagnons, or columnar fluctuations realized by, e.g., skyrmionic spin textures. We discuss these theoretical results in the context of experiments on ferromagnets such as ZrZn2, Ni_3Al, and others, and on the helical magnet MnSi.

Achieving electric field influence on thin films of antiferromagetic CuMnAs

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Antiferromagnets attract a lot of attention due to potential applications in spintronics. It was shown that it is possible to influence the magnetic order in antiferromagnetic CuMnAs using electrical current, which exerts relativistic Néel order spin-orbit torque on spins of Mn ions [1-2]. The current pulses modify the domain structure of the material [3]. It is also possible to move the domain walls [4]. It is also known that there are many ferromagnetic systems that can couple the electric field and magnetic order [5]. Here, we report initial attempts to address the question what can be the influence of a static electric field on thin films of antiferromagnetic CuMnAs. The work comprises studying transport properties of gated devices and the gate voltage dependence of the resistivity. The investigation aims at studying anisotropic magnetoresistance, which can be a suitable tool to measure the magnetic order and its changes in the antiferromagnetic systems [2-4].

References:

1. J. Železný, H. Gao, K. Výborný *et al.*, Phys. Rev. Lett. 113, 157201 (2014).
2. P. Wadley, B. Howells, J. Železný *et al.*, Science 351, 6273 (2016).
3. M. J. Grzybowski, P. Wadley, K. W. Edmonds *et al.*, Phys. Rev. Lett. 118, 057701 (2017).
4. P. Wadley, S. Reimers, M. J. Grzybowski *et al.*, Nat. Nanotech., in press (2018).
5. D. Chiba, S. Fukami, K. Shimamura *et al.*, Nat. Mater. 10, 853 (2011)

209Bi NMR Study of Topological Insulator Bi2Se3 Single Crystals

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Keywords: Topological Insulator, Quadrupole NMR, single crystal

Three-dimensional topological insulators are still under intense investigation in laboratories all over the world. Due to its simple surface states described by a single Dirac-cone, Bi_2Se_3 fertilizes theoretical considerations and the desire for their experimental confirmation. 77Se nuclear magnetic resonance (NMR) of Bi_2Se_3 has taught us that a unique electronic spin susceptibility yields an unusual strong indirect internuclear coupling among Selenium and Bismuth nuclei, producing significant field independent linewidths [1]. For 209Bi NMR in Bi_2Se_3, we see a rapid transversal decay (T2) that is in good agreement with a strong indirect coupling among 209Bi nuclei that have a high natural abundance of 100%. Careful investigation of the orientation dependent 209Bi resonances in various single crystals revealed a second, highly anisotropic 209Bi NMR signal beneath the well-defined first order quadrupole pattern that proves a surprisingly big number of highly disordered Bismuth sites. This 'second' signal has not been mentioned so far in the literature [2] while chemical disorder is neither seen by 77Se NMR nor by X-Ray diffraction. Possible effects leading to this extraordinary observation will be discussed.

References:

1. N. M. Georgieva, D. Rybicki, R. Guehne, G. V. M. Williams, S. V. Chong, K. Kadowaki, I. Garate, and J. Haase, Phys. Rev. B 93, 195120 (2016).
2. D. M. Nisson, A. P. Dioguardi, X. Peng, D. Yu, and N. J. Curro, Phys. Rev. B 90,125121 (2014).

Time-resolved APRES measurements on monolayer MoS_2

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The band structures across the whole Brillouin zone for monolayer MoS_2 samples are characterized using angle-resolved photoelectron spectra (ARPES) with femtosecond extreme UV from high harmonic generation of a Ti:Sapphire laser. In the experiment, mm-sized macroscopic polycrystalline and single crystal MoS_2 monolayer samples have been prepared with CVD and gold-assisted exfoliation respectively. The fs EUV source are further combined with a femtosecond visible pump laser pulse to conduct time-resolved measurements, which reveals the injection and decay dynamics of the photoexcited charge carriers at the K point of the MoS_2 monolayer samples.

Long Range Intrinsic Magnetic Order in Bulk Semiconducting $MoTe_2$ and $MoSe_2$

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The search for semiconducting materials with intrinsic dilute magnetism has been an ongoing challenge for many years. The semiconducting transition metal dichalcogenides have drawn great interest due to a wide array of applications such as spintronics, however intrinsic magnetism has not been observed in them or any other 2D material. In this work, we report the direct observation of long-range magnetic order below TM=40K and TM=100K in bulk 2H-$MoTe_2$ and 2H-$MoSe_2$ respectively by muon spin relaxation/rotation (μSR). To investigate the origin of the long-range magnetic order, we perform scanning tunneling microscopy (STM) which reveals a uniform density of intrinsic defects in the materials. Atomic-resolution STM reveals that the primary defects are substitutions of chalcogen atoms, likely by molybdenum. Hubbard density functional theory (DFT) simulations predict that these molybdenum substitutional defects induce magnetic moments at defect sites with long range interaction. Scanning tunneling spectroscopy taken at defect sites is also in confirmation with the L-DOS calculated via the DFT simulations . Thus, we conclude that the long range magnetic order observed via μSR is native to the materials, due to self-ordered intrinsic defects. This is the first experimental observation of dilute magnetism in transition metal dichalcogenides.

Emergence of Dirac fermions in a correlated antiferromagnet $EuCd_2As_2$ with broken parity-time symmetry

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Topological Dirac semimetals (DSMs) are the materials that host massless Dirac fermions in the bulk, arising as low-energy excitations (quasiparticles) near Dirac nodal points formed by the crossing of two doubly degenerate bands in the three-dimensional (3D) reciprocal space. So far, all the identified DSMs possess the parity-time (PT) symmetry, where P and T are the inversion and time-reversal operators, respectively, which protects the band degeneracy. Here, combining density functional theory (DFT) calculations and angle-resolved photoemission spectroscopy (ARPES) experiments, we demonstrate that Dirac fermions can emerge in a correlated antiferromagnet, $EuCd_2As_2$, in which (PT) symmetry is broken. In this system the Dirac nodal points are protected by the combination of (PT) symmetry with an additional translational operation (L), which makes the system invariant under the (PTL) symmetry operation. Our results reveal that the (PT) symmetry is not an essential requirement for realizing a topological Dirac semimetal phase in condensed matter, and that Dirac fermions can emerge from a wider range of materials, thus providing an enlarged platform for the quest of Dirac fermions in a magnetic system.

Majorana-like excitations in a ferromagnetic topological crystalline insulator

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Keywords: Topological insulators, superconductivity, ferromagnetism, Majorana fermions

As qubits resistant to local decoherence, Majorana bound states (MBSs) open prospects for fault-tolerant quantum computation. These zero-energy excitations are predicted to emerge at one-dimensional (1D) junctions of nonconventional superconductors and topologically trivial systems, i.e., at the terminations of relevant 1D quantum wires[1] or at boundaries, such as vortices, of 2D counterparts[2]. Here we show, by using soft point-contact spectroscopy, that an electron-hole gap with a broad zero-bias conductance maximum develops at the topological surfaces of diamagnetic, paramagnetic, and ferromagnetic Pb1-y-xSnyMnxTe, where y > 0.67 and 0 x 0.10. The temperature dependence of the gap shows a critical behaviour with Tc up to 4.5 K, which however is not accompanied by a global superconductivity. We assign these findings to the presence of 1D topological states adjacent to surface atomic steps in topological crystalline insulators of IV-VI compounds[3]. Within this scenario, the interplay of carrier-carrier interactions, spin exchange with Mn ions, and pairing coupling within the at 1D channels results in MBSs with lifted Kramers degeneracy, which are immune to the ferromagnetic ordering in the sample interior.

References:

1. Kitaev, A. Y. Phys.-Usp. 44, 131 – 136 (2001).
2. Fu, L. & Kane, C. L. Phys. Rev. Lett. 100, 096407 (2008).
3. Sessi, P. *et al.* Science 354 1269–1273 (2016).

Electronic Raman scattering in $SrIrO_3$ thin films

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Keywords: Confocal Raman spectroscopy, SrIrO3, Electronic Raman scattering

$SrIrO_3$ has been proposed as a candidate to realize the so-called 'topological insulator' phase due to its strong spin-orbit coupling (0.4 eV) and electron-electron correlations (0.5 eV) [1,2]. The narrow bands and their extreme sensitivity to the rotations of IrO6-octahedra place the compound close to a metal-insulator transition [3]. This has motivated us to investigate the lattice dynamics of these systems, which potentially plays an important role in conductivity.
For the first time, we report lattice and electron dynamics in 50 nm thick SrIrO3 films using Raman scattering experiments as a function of temperature and light polarizations.
In bulk, SrIrO3 has a monoclinic crystal structure. However, under the influence of effective compressive strain of 0.25%, a stable perovskite structure is obtained in pulsed-laser-deposition grown SrIrO3 films on (101)-oriented DyScO3 substrates. Using confocal Raman spectroscopy, we measured the temperature dependence of phonons modes with Ag and B2g symmetries. Corresponding atomic displacements are assigned with the help of first-principle lattice dynamics calculations. Finally, an electronic continuum could directly be evident. Moreover, such an electron continuum gives rise to a strong Fano-like asymmetry to a particular phonon line shape of Ag symmetry. Furthermore, the symmetry dependent electron scattering continuums agree well with the results of an angle resolved photoemission spectroscopy (ARPES) study of $SrIrO_3$ thin films [3].

References:

1. D. Xiao *et al.* Nat. Commun., 2, 596 (2011).
2. L. Zhang *et al.* Critical Reviews in Solid State and Materials Sciences, 0, 1-25 (2017).
3. Y.F. Nie *et al.* Phys. Rev. Lett. 114, 016401 (2015)

Optical Signatures of Dirac Nodal-line semimetal in $NbAs_2$

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Keywords: Diracl Nodal-line semimetal, Optical conductivity, Landau level transitions

Using optical and magneto-optical spectroscopy, we have demonstrated universal aspects of electrodynamics associated with massive Dirac nodal-lines. We investigated anisotropic electrodynamics of $NbAs_2$ where the spin-orbit interaction triggers energy gaps along the nodal-lines, which manifest as sharp steps in the optical conductivity spectra. We show experimentally and theoretically that dispersive 2D Dirac nodal-lines feature linear scaling $\sigma 1(E) \sim E$, similar to 3D nodal-points. Massive Dirac nature of the nodal-lines are confrmed by magneto-optical data, which may also be indicative of theoretically predicted surface states. Optical data also offer a natural explanation for the giant magneto-resistance in $NbAs_2$

Low-energy quasiparticle excitations in superconducting doped topological insulator $Sr_xBi_2Se_3$ studied by penetration depth measurements

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Keywords: Nematic superconductivity, Topological insulator, Penetration Depth

Superconducting doped bismuth selenide is a promising candidate of topological superconductor. Recent studies reveal that these materials show spontaneous rotational symmetry breaking inside the superconducting state. This phenomenon may associate with "unconventional" anisotropy in the gap function, called as nematic superconductivity. According to D3d point group of Bi2Se3, four possible pairing states are predicted. Among them, only the odd-parity pairing with Eu representation can generate nematic superconductivity. Multi-dimensional Eu pairing states allow two types of states, Δ4x and Δ4y state.
We measure magnetic penetration depth λ in $Sr_xBi_2Se_3$ down to 40 mK. At lowest temperature region, Δλ deviates from power-law behavior and it tends to saturate. Our experimental result suggests that tiny but finite gap minima exist on the Fermi surfaces, which is consistent with Δ4y state.

Superfluid density and carrier concentration across a superconducting dome: The case of strontium titanate

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In many superconductors with an insulating parent, the critical temperature T_c is a nonmonotonic function of carrier concentration. The very existence of such a superconducting dome raises a fundamental question: does the superfluid density, n_s, remain equal to the concentration of electrons in the normal state? Or does it follow the nonmonotonic variation of T_c?

In the case of high-Tc cuprates, the correlation between n_s and T_c has been the subject of intense discussions [1,2].

However, a comparison between the magnitude of ns with the normal-state carrier concentration n_H was absent in this debate.

My poster will present a study of the supefluid density of $SrTi_{\{1-x\}}Nb_xO_3$ as a function of carrier concentration. Because of its well apprehended Fermi surface [3,4] and its classical s-wave gap [4,5], this compound will serve as a drosophila to better understand the link between T_c and n_s.

References:

1. Božovic, X. He, J. Wu, and A. T. Bollinger, Nature (London) 536, 309 (2016).
2. N. R. Lee-Hone, J. S. Dodge, and D. M. Broun, Phys. Rev. B 96, 024501 (2017).
3. X. Lin, G. Bridoux, A. Gourgout, G. Seyfarth, S. Krämer, M. Nardone, B. Fauqué, and K. Behnia, Phys. Rev. Lett. 112, 207002 (2014).
4. X. Lin, A. Gourgout, G. Bridoux, F. Jomard, A. Pourret, B. Fauqué, D. Aoki, and K. Behnia, Phys. Rev. B 90, 140508 (2014).
5. X. Lin, C. W. Rischau, C. J. van der Beek, B. Fauqué, and K. Behnia, Phys. Rev. B 92, 174504 (2015).

X-2

Metal-Insulator transition in VO_2: structure and electron dynamics at the nanoscale, from multi domain systems toward single domain limit

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Because of the interplay between electrons and lattice, VO_2 undergoes a hysteretic metal insulator transition (MIT) around room temperature (~340 K) with a change in resistivity of different orders of magnitude [1], paired to a complex structural phase transition (SPT) starting from an insulating monoclinic phase at low temperature to a final stable metallic phase at high temperature with the rutile symmetry.
The VO_2 is also extremely sensitive to chemical and physical perturbations such as stress and strain [2] that slightly tune the MIT temperature. Moreover, as other TMOs, it is characterized by a phase separation, intermediate phases at the nanoscale with different micro- and nano-domains having different electrical, structural and optical properties [3-5]. All these phenomena make VO_2 an extremely interesting case-study with a wide range of potential applications in optics, sensors and novel memory devices [6].

References:

1. J. Cao, J. Wu,Mat. Sci. Eng. R71 (2011).
2. E. Dagotto, Science 309, (2005).
3. N. Poccia *et al.*, Proc. Natl. Acad. Sci. U.S.A.109 (2012).
4. G. Campi, *et al.*,Nature 525 (2015).
5. A. Marcelli, Acta Phys. Pol. A 129 (2016).
6. M. A. Kats, *et al.*, Appl.Phys. Lett. 101 (2012).

Time-Resolved Near-Field investigation of the Insulator to Metal transition in Vanadium Dioxide

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We have preformed femtosecond time-resolved and nanometer spatially resolved measurements of the insulator-to-metal transition in Vanadium Dioxide (VO_2). In order to make this work possible, we have devised and implemented a method for artifact-free nano-imaging with pulsed laser sources [1]. We observe that the transient metallic state is highly inhomogeneous. Following an ultrafast pumping event an increase in near-field signal occurs, where no significant inhomogeneity is observed for approximately fifteen picoseconds. This is followed by a second stage where significant growth of the photo-induced insulator-to-metal transition is observed to evolve inhomogeniously in real space over hundreds of picoseconds. Finally, the growth saturates after several hundred picoseconds when the photo-induced metallic phase occupies the bulk of the material. Our advances pave a pathway to study a wide range of systems with nanoscopic spatial, and ultrafast temporal resolution.

References:

1. A. J. Sternbach *et al.*, Optics Express 25 (23), 28589-28611 (2017)

X-4

Deposition and characterization of MoO_3 films on copper to improve accelerating technologies

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Thin films deposited on a substrate modify or improve the surface properties of the underlying substrate. Particularly important is the case of transition metals oxides thin films. Taking into account the complex molybdenum oxide phase diagram, the most interesting composition is represented by MoO_3, which is a hard transparent insulator, on copper. Indeed, due to its properties a thin "insulating" layer of MoO_3 a thick copper substrate tends to become conductive, while its work function should remain high and constant (~7 eV).
The combination of copper coated by MoO_3 can be used in accelerating devices, e.g., RF cavities and photo-guns where the dark current, (i.e. the emission of electrons from the surface) is reduced because of the high work function, without degrade the surface conductivity. To understand the proprieties of these films we developed and built a dedicated evaporation setup and characterized the prepared samples with multiple techniques.

Quantum Tribology and Motors

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Keywords: quantum, tribology, friction, Casimir effect

In recent years, the Casimir effect, arising from quantum vacuum fluctuations of electromagnetic field between two plates separated by vacuum, has given rise to considerable interest among the scientific community, e.g. see [1]. This effect has been verified with many experiments using different geometries of the plates: in fact, geometry has an important role in both normal and tangential Casimir forces [2,3,4]. The existence of the tangential component and its ratio with the normal one thus lead to what we could define as “Quantum Tribology” and quantum friction coefficient. It is strongly influenced by the geometry of the plates and such a geometry could be considered regular/patterned or disordered/rough as well as without or with hierarchy. Accordingly, we here present calculation of quantum tribology for different plate geometries.
An interesting application of these results is the possibility to realize Quantum Motors filling the gap between Molecular Motors and Nano Electro Mechanical Systems.

References:

1. A. W. Rodriguez *et al.*, Phys. Rev. A 80, 2009.
2. K. A. Milton *et al.*, Symmetry, 8, x, 2016.

3. Yu . S. Voronina and P. K. Silaev, Physics of Particles and Nuclei Letters, 2013, Vol. 10, No. 6, pp. 535–538, 2013.
4. J. B. Pendry, J. Phys. Condens. Matter, 9, 10301–10320, 1997.

Muon Spin Relaxation Studies of Mott Transition in (La,Sr)VO_3

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$La_xSr_{1-x}VO_3$ (LSVO) exhibits a Mott transition from an Antiferromagnetic Insulator (AFI) to a Paramagnetic Metal (PMM) tuned by charge doping. At low temperatures with x 0.3. We performed MuSR measurements using single crystal specimens. In the AFI state in zero field, clear precession signal was observed from full volume fraction with almost no x-dependence of the frequency, indicating long-range magnetic order. This evolves into a damped relaxation signal in the AFM state, corresponding to highly random spin configurations, associated with a gradual build-up of ordered volume fraction with decreasing temperature. This behavior is generally consistent with first-order quantum evolution seen between the AFI and PMM states in $RENiO_3$ and V_2O_3. The highly random and weak static magnetism in the AFM phase is similar to the behavior seen in the AFM state in Ba(Co,Ni)S_2 with Ni doping.

Role of local structural distortions on frustrated $Ho_2Ti_2O_7$ and $Ho_2Ir_2O_7$ pyrochlores with joint x-ray and neutron pair distribution function analysis

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The pyrochlore lattice forms a vertex-sharing tetrahedral network, which is promising for studying novel properties in frustrated spin ice systems. The pair distribution function (PDF) technique is becoming prominent for studying nanoscale disorder in frustrated materials, since the structural features can be resolved within the short-range length-scales required, below 100 Å. The presence of significant short-range-ordered magnetic correlations within such geometrically frustrated magnetic systems also provides an appropriate candidate for magnetic PDF (mPDF) analysis. We use x-ray and neutron total scattering based PDF measurements to study the local atomic and magnetic structural distortions on holmium titanate and iridate pyrochlores, of formula $Ho_2Ti_2O_7$ and $Ho_2Ir_2O_7$. The combination of high real-space resolution X-ray PDF and the neutron magnetic signals will enable the study of local magnetic frustration in spin ice systems.

References:

1. M. J. Harris, S. T. Bramwell, D. F. McMorrow, T. Zeiske, and K. W. Godfrey, Phys. Rev. Lett. 79, 2554 (1997).
2. B. A. Frandsen, K. A. Ross, J. W. Krizan, G. J. Nilsen, A. R. Wildes, R. J. Cava, R. J. Birgeneau, and S. J. L. Billinge, Phys. Rev. Materials 1, 074412 (2017).
3. J. Shamblin, M. Feygenson, J. Neuefeind, C. L. Tracy, F. Zhang, S. Finkeldei, D. Bosbach, H. Zhou, R. C. Ewing, and M. Lang, Nat. Mater. 15, 507 (2016).
4. E. Lefrançois, V. Cathelin, E. Lhotel, J. Robert, P. Lejay, C. V. Colin, B. Canals, F. Damay, J. Ollivier, B. Fåk, L. C. Chapon, R. Ballou, and V. Simonet, Nat. Commun. 8, 209 (2017).

Single Crystal Growth and Propertis Study of Diluted Magnetic Semicondutor (Ba,K)(Zn,Mn) 2As2 & (Ba,Na)(Zn,Mn)2 As 2

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Diluted magnetic semiconductors (DMS) have received much attention due to their fantastic physical properties and applications for spintronic devices since the discovery of (Ga,Mn)As film by H. Ohno in 1990s. In this talk, we report a new kind of DMS materials with decoupled spin and charge doping. We use flus method to grow the single crystal DMS (Ba,K)(Zn,Mn) 2As2 and (Ba,Na)(Zn,Mn)2As2 (BZA) for the first time[1]. We also did a very systematic study, including the magnetic susceptibility testing, transport measurements,Xray Magnetic CIRcular Dichroism research, Andreev Reflection experiments and angle-resolved photoemission spectroscopy (ARPES)[2-5], etc.

References:

1. G. Q. Zhao, C. J. Lin, Z. Deng, G. X. Gu, S. Yu, X. C. Wang, Z. Z. Gong, Y. J. Uemera, Y. Q. Li, and C. Q. Jin, Sci Rep 7 (1), 14473 (2017).
2. Gangxu Gu, Guoqiang Zhao, Chaojing Lin, Yongqing Li, Changqing Jin, and Gang Xiang, Applied Physics Letters 112 (3), 032402 (2018).
3. G. Q. Zhao *et al.*, in preparetion. (2018).
4. F. Sun, G. Q. Zhao, C. A. Escanhoela, B. J. Chen, R. H. Kou, Y. G. Wang, Y. M. Xiao, P. Chow, H. K. Mao, D. Haskel, W. G. Yang, and C. Q. Jin, Physical Review B 95 (094412) (2017).
5. H. Suzuki, G. Q. Zhao, K. Zhao, B. J. Chen, M. Horio, K. Koshiishi, J. Xu, M. Kobayashi, M. Minohara, E. Sakai, K. Horiba, H. Kumigashira, Bo Gu, S. Maekawa, Y. J. Uemura, C. Q. Jin, and A. Fujimori, Physical Review B 92 (23), 235120 (2015).

Current Induced Metal-Insulator Transition in 1D Charge Density Wave

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Nakamura, Maeno and co-workers (Scientific Reports, 2013) reported that a modest electric field (~40 V/cm) suppresses the metal insulator transition in Ca_2RuO_4, so that the metal phase persists down to temperatures well below the equilibrium transition temperature. They further argued that this effect is an intrinsic nonequilibrium correlation effect, due neither to Joule heating nor filamentary conduction. We investigate theoretically this issue by studying a 1D charge density wave model, using a Hartree-Fock/Boltzmann equation formalism which includes intraband and interband (up to quadratic order) relaxation processes. We find that even modest fields for which Zener tunnelling is negligible can have a strong effect on the distribution function, increasing the number of carriers in conduction band, reducing the gap and ultimately driving a transition from insulating to metal phase.

Structural Determination of Alkali Metal-Doped p-Terphenyl Using the Pair Distribution Function (PDF) Method

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Alkali metal-doped p-terphenyl (ptp) is an exciting new candidate material for high-Tc superconductivity at ambient pressure. While the crystal structure of pristine ptp is well-known, the structure of the doped material is not, and the nanocrystallinity of the material makes it difficult to analyze this structure by conventional diffraction methods. Here, we utilize total x-ray scattering methods with pair distribution function (PDF) analysis to determine local and crystal structure of alkali-doped ptp for many different dopants, dopant concentrations, and doping methods. Structural determination combined with density functional theory will help to elucidate the possible mechanisms for superconductivity in this material.

References:

1. Wang, R.-S., Gao, Y., Huang, Z.-B., Chen, X.-J., 2017. arXiv:1703.06641 [cond-mat].
2. Zhong, G.-H., Wang, X.-H., Wang, R.-S., Han, J.-X., Zhang, C., Chen, X.-J., Lin, H.-Q., 2018. J. Phys. Chem. C 122, 3801–3808.
3. Baskaran, G., 2017. arXiv:1704.08153 [cond-mat].
4. Liu, W., Lin, H., Kang, R., Zhu, X., Zhang, Y., Zheng, S., Wen, H.-H., 2017. Phys. Rev. B 96, 224501.

Superconductivity in the BCS-BEC crossover near a topological Lifshitz transition in organic superconductors

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Recently interest is growing on high-temperature superconductivity in 2D anisotropic organic superconductors made of weakly interacting quantum wires [1–7]. In a recent work [8], we have proposed a driving mechanism for high Tc based on the control of the quantum shape resonance between a first superconducting gap in a first condensate where the Fermi energy is near a topological Lifshitz transition and the superconducting gaps in other bands with high Fermi energy. In this scenario the maximum critical temperature occurs where the hot condensate in the appearing new small Fermi surface pocket is in the BCS-BEC crossover. Here we have studied the tuning of the strength of the pairing interaction in the new appearing band to drive the hot condensate in the BCS-BEC crossover regime. To this end we have studied the multi-gaps superconductivity by increasing the pairing coupling term in the hot band near the Lifshitz transition. We have found that the BCS-BEC regime occurs where the ratio between the superconducting gap and the Fermi energy is close to 0.5. The compelling evidence for the BCS-BEC crossover is indicated by the fact that the maximum of the Tc occurs in the range where the ratio of the Fermi energy on the pairing energy cut off is in the range between 0.5 and 1 and the value of the chemical potential, where the maximum of the critical temperature appears, moves with the pairing strength and it does not coincide with the point where the DOS exhibits a maximum.

References:

1. A Bianconi, M Missori Solid state communications 91, 287 (1994)
2. A. Bianconi, A. Valletta, A. Perali, N. L. Saini, Solid State Communications **102**, 369 (1997)
3. A. Valletta, A. Bianconi, A. Perali, N. L. Saini, Zeitschrift fur Physik B **104**, 707 (1997)
4. R. Caivano et al. *Supercond. Sci. Technol.,* **22**, 014004 (2009).
5. D. Innocenti et al. *Supercond. Nov. Magn.,* **24**, 1137 (2011).
6. A. Perali et al. *Supercond. Sci. Technol.,* **25**, 124002 (2012).
7. A. Bianconi, *Nature Physics,* **9**, 536 (2013).
8. M. V. Mazziotti, A. Valletta, G. Campi, D. Innocenti, A. Perali, A. Bianconi. *EPL (Europhysics Letters)* **118**, 37003 (2017).

Substrate-induced topological mini-bands in graphene

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We investigate band arrangements and topological properties of mini-bands in graphene superstructures with hexagonal symmetry. We find that the effective Hamiltonian describing the low-energy band structure is governed by a 7-dimensional parameter space and divide it into different phases according to gap closures and reopenings. This parameter space classification provides a map to engineer non-trivial (valley) topology in graphene and graphene-like superstructures.

Designer bandstructures in bilayer graphene by superlattice patterning

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With a locally tunable band gap on the order of 100meV, bilayer graphene is a simple yet promising 2D material with various potential applications in nanoelectronics. The electronic structure of bilayer graphene can be engineered by a superlattice, producing novel effects including Brilliouin zone folding, additional Dirac fermions and Hofstader's butterfly. Here we present our magneto-transport data from bilayer graphene devices with electrostatically-defined superlattices whose wavelength can be as small as 35nm. In addition, we compare these data with our previous data on monolayer graphene superlattices and predictions from various theoretical models.

References:

1. D. R. Hofstadter, Phys. Rev. B 14, 2239 (1976).
2. C. R. Dean, L. Wang, P. Maher, C. Forsythe, F. Ghahari, Y. Gao, J. Katoch, M. Ishigami, P. Moon, M. Koshino, T. Taniguchi, K. Watanabe, K.L. Shepard, J. Hone, and P. Kim, Nature (London) 497, 598 (2013).

One-dimensional potential in graphene

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One-dimensional Coulomb problem has attracted attention for long [1, 2]. It has generated further interest in the case of Dirac materials [3]. It has been shown that carbon-nanotubes are excellent to be used at a ~ 1 nm gate length limit for various materials [4, 5]. In this work, we fabricate encapsulated graphene devices and use carbon nanotubes to engineer a 1D potential landscape. Furthermore, electrical transport measurements in this geometry will enable us to observe interactions between different edge-states in the quantum Hall regime.

References:

1. Loudon, Rodney, American Journal of Physics, 27, 649-655 (1959).
2. G. Abramovici, and Yshai Avishai, Journal of Physics A: Mathematical and Theoretical, 42.28, 285302 (2009).
3. C.A. Downing, and M. E. Portnoi, Physical Review A, 90.5, 052116 (2014).
4. Svensson, Johannes, *et al.*, Nanotechnology, 19.32, 325201 (2008).
5. Sujay B. Desai, *et al.*, Science, 354.6308, 99-102 (2016)

Properties of pair density waves in SC/CDW systems

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Pair density wave (PDW) is a state of matter with a spatially oscillating amplitude of the superconducting pairing. One of the cases where PDW is expected to arise is in a system where uniform superconductivity coexists with a charge density wave. This situation is realized in underdoped cuprates, where PDW has been recently discovered in a scanning Josephson tunneling microscopy (SJTM) experiment [1]. In this regard, we consider a mean-eld model with the Gorkov formalism, which allows us to study the structure of the PDW also at low temperatures. We find that the PDW amplitude has an intricate momentum dependence that bears information about the order parameters as well as the underlying Fermi surface. We also consider the implications of our results for the SJTM experiments and discuss applications to other materials where coexistence of superconductivity and charge density waves has been reported.

References:

1. M. H. Hamidian *et al.*, Nature 532, 343 (2016).

Finite size effect on the spin dynamics of the quasi-one dimensional spin chains system $SrCuO_2$

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Keywords: spinon, pseudogap, one-dimensional, spin liquid, cuprates

We investigate the impact of substitution, with fractional amounts of S=0 impurities, on the low energy region of magnetic excitations spectrum of the quasi-1D spin ½ chains cuprate $SrCuO_2$. Due to low-dimensionality and confinement, the finite size effect is reported to give rise to exotic behaviors [1-3] in this compound. $SrCuO_2$ crystallizes in the orthorhombic space group Cmcm; it carries two parallel spin chains distanced by one Cu-O bond length, along the c-crystallographic axis, resulting in zigzag chains of copper ions. This quantum magnet is among the best experimental realizations of the XXZ Heisenberg model and satisfies the Tomonaga Luttinger spin liquid theory so that its magnetic excitations spectrum is found to be a gapless des Cloizeaux-Pearson two-spinon continuum [4].

We present the magnetic excitations spectra of the pristine and 1% Mg, Zn or La-doped $SrCuO_2$, measured by Inelastic Neutron Scattering. We show that chains fractionalization by S=0 impurities systematically results in a gapped two-spinon continuum [1-2].

References:

1. D.Bounoua, R.Saint-Martin, S.Petit, P.Bethet, F.Damay, Y.Sidis, F.Bourdarot, L.Pinsard-Gaudart, Phys. Rev. B. 95, 224429 (2017).
2. Y.utz, F.Hammerath, R.Kraus, T.Ritschel, J.Geck, L.Hozoi, J.van den.Brink, A.Mohan, C.Hess, K.Karmakar, S.Singh, D.Bounoua, R.Saint-Martin, L.Pinsard-Gaudart, A.Revcolevschi, B. Büchner, H-J. Grafe, Phys. Rev. B, 96, 115135 (2017).
3. G. Simutis, S. Gvasaliya, M. Mansson, A.L. Chernyshev, A. Mohan, S. Singh, C. Hess, A.T. Savici, A.I. Kolesnikov, A. Piovano, T. Perring, I. Zaliznyak, B. Büuchner, and A. Zheludev, Phys. Rev. Lett. 111, 067204 (2013).
4. I. A. Zaliznyak, H. Woo, T. G. Perring, C. L. Broholm, C. D. Frost, and H. Takagi, Phys. Rev. Lett. 93 (2004).

Properties of the electronic fluid of superconducting cuprates from NMR relaxation and shift

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Very recently, some of us showed that the early NMR shift interpretation of the superconducting cuprates, based on the common hyperfine scenario, is inappropriate [1]. Motivated by these findings, we turned to the analysis of nuclear relaxation data and present results here. We show that there is a rather simple relaxation phenomenology that can explain all findings, except for very few compound, including LaSrCuO that has an additional temperature independent relaxation channel (this material is also is an outlier for the shift analysis). We show that a few, strongly overdoped systems show indeed Fermi liquid behavior, including shift and relaxation. However, at slightly lower doping levels where the shifts still show temperature independent Fermi liquid like behavior, nuclear relaxation rates deviate already at higher temperatures. More details, also in comparison with the shift data will be discussed.

References:

1. Jürgen Haase, Michael Jurkutat, Jonas Kohlrautz, Condensed Matter 2, 16 (2017).

Phase diagram of the underdoped cuprates at high magnetic field

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Keywords: Superconductivity, Charge Order, Cuprates, Phase diagram, Competition

The experimentally measured phase diagram of cuprate superconductors in the temperature-applied magnetic field plane illuminates key issues in understanding the physics of these materials. At low temperature, the superconducting state gives way to a long-range charge order with increasing magnetic field; both the orders coexist in a small intermediate region. The charge order transition is strikingly insensitive to temperature, and quickly reaches a transition temperature close to the zero-field superconducting T c . We argue that such a transition along with the presence of the coexisting phase cannot be described simply by a competing orders formalism. We demonstrate that for some range of parameters there is an enlarged symmetry of the strongly coupled charge and superconducting orders in the system depending on their relative masses and the coupling strength of the two orders. We establish that this sharp switch from the superconducting phase to the charge order phase can be understood in the framework of a composite SU(2) order parameter comprising the charge and superconducting orders. Finally, we illustrate that there is a possibility of the coexisting phase of the competing charge and superconducting orders only when the SU(2) symmetry between them is weakly broken due to biquadratic terms in the free energy. The relation of this sharp transition to the proximity to the pseudogap quantum critical doping is also discussed.

References:

1. D. Le Boeuf *et al.*, Nat. Phys. 9, 79 (2013).
2. K. B. Efetov, H. Meier and C. Pepin, Nat. Phys. 9, 442 (2013).
3. F. Laliberté *et al.*, npj Quantum Materials 3, 11 (2018).
4. Debmalya Chakraborty, Corentin Morice, Catherine Pépin, arXiv:1802.10122.

Properties of the electronic fluid of superconducting cuprates from NMR relaxation and shift

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Very recently, some of us showed that the early NMR shift interpretation of the superconducting cuprates, based on the common hyperfine scenario, is inappropriate (1). Motivated by these findings, we turned to the analysis of nuclear relaxation data and present results here. We show that there is a rather simple relaxation phenomenology that can explain all findings, except for very few compound, including LaSrCuO that has an additional temperature independent relaxation channel (this material is also an outlier for the shift analysis). We show that a few, strongly overdoped systems show indeed Fermi liquid behavior, including shift and relaxation. However, at slightly lower doping levels where the shifts still show temperature independent Fermi liquid like behavior, nuclear relaxation rates deviate already at higher temperatures. More details, also in comparison with the shift data will be discussed.

References:
1. Jürgen Haase, Michael Jurkutat, Jonas Kohlrautz, Condensed Matter 2, 16 (2017)

Imaging local strain spatial fluctuations in superconducting $BaPb_{1-x}Bi_xO_3$ by scanning micro-XANES

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It has been proposed that in complex quantum matter the correlated lattice disorder favors the emergence both of quantum coherence in high temperature superconductors [1-2] and of life in biological matter [3,4]. The bismuthate superconductors $BaPb_{1-X}Bi_XO_3$ are archetypal systems for the relation between the emergence of quantum coherence and lattice disorder. The dimorphic composition of bismuthates was first identified by EXAFS and XANES [5], and recently its spatial distribution unveiled by electron microscopy [6,7]. XANES spectroscopy of complex matter [8] has been used to probe nanoscale phase separation in cuprates [9-12] near a topological Lifshitz transition driven by strain and doping [13-15]. Here we report the imaging of spatial fluctuations of local

lattice strain at the Pb site by scanning micro of Pb L_3-edges. XANES. We used energy dispersive XANES spectrometer at the ID24 beamline of ESRF. The key result of this work is the evidence of a correlated disorder with a power law distribution in the low temperature superconducting phase which supports the emergence of the superconducting phase in a filamentary hyperbolic space [1,2].
We thank M. Di Gioacchino, A. P. V. Ivanov and the staff of the ID24 beamline at ESRF for the experimental support.

References:

1. G. Campi et al., *Nature* **525**, 359 (2015)
2. G. Campi, A. Bianconi, *J Supercond. Nov. Magn.* **29**, 627 (2016)
3. G. Campi et al., ACS Nano **12**, 729 (2018)
4. M. Di Gioacchino, et al., *Condensed Matter* **2**, 29 (2017)
5. A. Balzarotti, A.P. Menushenkov, N. Motta, J. Purans, *Sol. State Commun.* **49**, 887 (1984)
6. P. Giraldo-Gallo et al., *J Supercond. Nov. Magn.* **26**, 2675 (2013)
7. P. Giraldo-Gallo et al., *Nature Communications* **6**, 8231 (2015)
8. A. Bianconi, et al. *Chemical Physics Letters* **59**, 121 (1978)
9. A. Bianconi, et al. *Physica C: Superconductivity* **153-155**, 1760 (1988)
10. A. Bianconi, M. Missori, *Solid State Communications* **91**, 287 (1994)
11. S. Agrestini, et al. *Journal of Physics A: Mathematical and General* **36**, 9133 (2003)
12. N. Poccia et al., *Applied Physics Letters* **104**, 221903 (2014)
13. A. Bianconi, et al. *Solid State Communications* **102**, 369 (1997)
14. K. I. Kugel, et al., *Physical Review* B **78**, 165124 (2008)
15. A. Bianconi, *Nature Physics* **9**, 536 (2013)

Z-1

EDL gating in optimally doped BaFe2(As1-xPx)2 ultrathin films

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In this work we performed Electrical-Double-Layer gating experiments on thin (10 nm) epitaxial films of optimally P-doped $BaFe_2As_2$ ($BaFe_2(As_{1-x}P_x)_2$) on single crystal MgO substrate.

A lattice mismatch between film and substrate is present and increases with P content. The resulting in-plane tensile strain shifts the superconducting dome to lower P contents with respect to single crystals (maximum TCon≈24.0K at x=0.2). We induced surface carrier densities up to ±3.5x1014 e-cm-2 and obtained an asymmetric TC suppression (up to ≈200mK) for both positive and negative induced charge densities. This suggests that the films that are optimized for the highest Tc with respect to the P content, are also intrinsically optimized with respect to the charge doping. This unexpected result may act as a guide for further fundamental studies and help to better understand this class of superconductors.

Three-dimensional electronic phase diagram of FeSeS

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The roles of electronic nematicity and magnetism in realizing high temperature superconductivity are not clear in iron-based superconductors. To approach this issue, FeSe is important material because it shows unique phase diagrams. It shows a non-magnetic nematic order under ambient pressure[1]. This order is suppressed under pressure and concurrently dome-shaped magnetic order appears, which competes with high-T c superconducting phase[2,3]. On the other hand, in isovalent S-substitution system $FeSe_{1-x}S_x$, a non-magnetic nematic quantum critical point was discovered[4]. From these facts, we thought pressurization and S-substitution are different control parameters and we have tried to establish the three-dimensional electronic phase diagram , temperature(T)-pressure(P)-S-substitution (x), in $FeSe_{1-x}S_x$. We report our recent high-pressure studies in high-quality single-crystalline FeSe1-xSx up to 8 GPa[5].

References:

1. S-H. Baek *et al.*, Nat. Mat. 14, 210 (2015).
2. J. P. Sun *et al.*, Nat. Commun. 7, 12146 (2016).
3. K. Kothapalli *et al.*, Nat. Commun. 8, 12728 (2016).
4. S. Hosoi *et al.*, Proc. Natl. Acad. Sci. USA 113, 8139 (2016).
5. K. Matsuura *et al.*, Nat. Commun. 8, 1143 (2017).

Ultrafast spin density wave dynamics in iron-based pnictides at intense optical pulse excitation

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Keywords: spin density wave, dynamics, iron-based superconductors

Ultrafast time-resolved spectroscopy has become an important tool for studying rapidly evolving phase transitions [1-4] because it offers an insight into microscopic process happening during the transition which cannot be observed in equilibrium experiments. Here we present the ultrafast all-optical time-resolved spectroscopy measurements of the system trajectory through a spin density wave (SDW) phase transition in $SrFe_2As_2$ and $EuFe_2As_2$.

Using the standard pump-probe technique we estimated the threshold fluence for a nonthermal destruction of the SDW order (Fth ≈ 0.3 mJ/cm2) at two different pump-photon energies (1.55 eV and 3.1 eV). Using the multi-pulse pump-probe technique the SDW order destruction timescale of ~150 fs was found to be fluence independent.

By comparing the temperature dependences of the standard and multi-pulse transient reflectivity long after the arrival of the destruction pulse we determined the transient lattice heating in $SrFe_2As_2$. At high excitation densities (~ mJ/cm2) the destruction pulse penetration depth significantly exceeds the equilibrium penetration depth suggesting absorption saturation.

Using the multipulse pump-probe technique we also measured the recovery of the SDW order at different destruction fluences. The fluence of the destruction pulse was used as an adjustable parameter to control the quench conditions [5]. In the case of the fast quench (F ~1 mJ/cm2), when the final lattice temperature does not exceed the SDW transition temperature, the ordered state recovers on a sub picosecond timescale.

The SDW state recovery can be sufficiently well described within the framework of a three temperature model (3TM). The 3TM simulation results suggest that: (i) the SDW destruction timescale is set by the thermalization of the initially excited electronic distribution; (ii) the recovery rate depends on the destruction pulse fluence and is governed by cooling of the optical phonons to the lattice bath. The fluence dependent recovery timescale can be attributed to the opening of additional electronic relaxation channels upon suppression of the pseudogap related to the nematic fluctuations.

References:

1. S. Iwai, S. Tanaka, K. Fujinuma, H. Kishida, H. Okamoto, and Y. Tokura, Phys. Rev. Lett. 88, 57402 (2002).
2. A. Cavalleri, Th. Dekorsy, H. H. W. Chong, J. C. Kieffer, and R. W. Schoenlein. Phys. Rev. B 70, 161102 (2004).
3. M. Matsubara, Y. Okimoto, T. Ogasawara, Y. Tomioka, H. Okamoto, and Y. Tokura, Phys. Rev. Lett. 99, 207401 (2007).
4. P. Kusar, V.V. Kabanov, S. Suagi, J. Demsar, T. Mertelj and D. Mihailovic, Phys.Rev. Lett. 101, 227001 (2008).
5. I. Madan, P. Kusar, V.V. Baranov, M. Lu-Dac, V.V. Kabanov, T. Mertelj and D. Mihailovic, Physical Review B 93, 224520 (2016).

Z-4

Tunable strain of monolayer TMD: effects on excitons

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Keywords: TMDs, strain, WSe_2, WS_2, $MoSe_2$, excitons, photoluminescence

We present photoluminescence data on uniaxial strain of up to 6% on monolayer WSe_2, WS_2 and $MoSe_2$.

Z-5

Electronic and photonic quantum engineered systems

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I am working on turbulent motion in fluids with the goal of connecting it to Hall physics.

Polymeric zone plates for terahertz radiation focusing

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Three diffractive lenses are experimentally investigated at a frequency of 1 THz. Their characterization is performed by means of THz time-domain spectroscopy. The samples are fabricated by milling slabs of an ultralow-loss polymer. Three zone plate configurations are studied: a binary zone plate, a four-level zone plate, and a novel double-sided zone plate consisting of the stack of two binary zone plate. Experimental results demonstrate that the double-sided configuration shows a 25% higher power focusing efficiency and 7λ longer depth of field compared to its conventional counterpart. Even if the double-sided zone plate does not reach the multilevel zone plate performance, the proposed zone plate is simpler to fabricate and less sensitive to mechanical damage than multilevel zone plate and it constitutes a promising diffractive lens configuration for terahertz focusing.

Two-component model of superconductivity in a checkerboard background

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We consider a two-component model of superconductivity in the presence of a checkerboard background possibly existing in high-temperature cuprate superconductors. The model involves preformed pairs of fermions residing in nonmagnetic regions and unpaired fermions residing in magnetic regions. For this model, we calculate low-energy excitations and the critical temperature.

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