7th Swiss-Sino Workshop

8th – 9th May, 2018

5232 Villigen PSI

Switzerland

Organisers:
Paul Scherrer Institut: Aeppli Gabriel, Shi Ming, Fueglister Martina (Secretary)
Institute of Physics, CAS: Ding Hong, Yang Shulei (Secretary)

Table of Contents

Daily Programme Tuesday 8th May 2018

Villigen PSI 5232, Room WBGB/019

08:00 – 08:30	***Local Supports***	***Registration***
08:30 – 08:40	***Joël Mesot & Gabriel Aeppli***	***Welcome***
08:40 – 10:20	***Session 1***	***Chair: Frithjof Nolting***
08:40 – 09:05	*Enge Wang (CAS)*	Full Quantum Nature of Water on Surface
09:05 – 09:30	*Aharon Kapitulnik (Stanford Uni.)*	The Superconductor-Insulator Transition in two-dimensions: Phases and unique Symmetries
09:30 – 09:55	*Markus Müller (PSI)*	Coherent oscillators and spectral hole-burning in rare earth magnets
09:55 – 10:20	*Phil Willmott (PSI)*	SLS 2.0 The Science Case
10:20 – 10:50		Coffee Break
10:50 – 12:30	***Session 2***	***Chair: Yayu Wang***
10:50 – 11:15	*Guoqiang Yang (Institute of Chemistry, CAS)*	Molecular Glass Photoresists with High Resolution, Low LER and High Sensitivity for EUV Lithography
11:15 – 11:40	*Fuhua Yang (Institute of Semiconductor, CAS)*	Dopant atoms as quantum components in silicon nanoscale devices
11:40 – 12:05	*Yongzheng Wen (Tsinghua Uni.)*	Artificial optical nonlinearity generated by metamaterial
12:05 – 12:30	*Milan Radovic (PSI)*	Create and Control Properties of Transition Metal Oxides: Spectroscopy on hetero-structures
12:30 – 14:00		Lunch
14:00 – 15:40	***Session 3***	***Chair: Christopher Mudry***
14:00 – 14:25	*Jean-Marc Triscone (Uni. of Geneva)*	Magnetic properties of nickelate films and nickelate based heterostructures
14:25 – 14:50	*Jean-Philippe Brantut (EPFL)*	Quantum transport experiments with cold atoms
14:50 – 15:15	*Shancai Wang (Remin Uni. of China)*	The extremely large magnetoresistance and its electronic structure
15:15 – 15:40	*Urs Staub (PSI)*	Quantifying atomic motions with ultrashort x-ray pulses
15:40 – 16:10		Coffee Break
16:10 – 17:50	***Session 4***	***Chair: Huiqiu Yuan***
16:10 – 16:35	*T. Maurice Rice (ETHZ)*	Umklapp scattering as the origin of T-linear resistivity in the normal state of high-Tc cuprate superconductors
16:35 – 17:00	*Johan Chang (Uni. of Zurich)*	Direct Observation of Orbital Hybridisation in a Cuprate Superconductor
17:00 – 17:25	*Xingjiang Zhou (IOP)*	Laser ARPES on High Temperature Superconductors and Topological Materials
17:25 – 17:50	*Simon Gerber (PSI)*	Femtosecond electron-phonon lock-in in FeSe via ultrafast x-ray scattering and photoemission
18:30 *19:15*	*Speech:* *Gabriel Aeppli*	Aperitif start 18:30 Workshop Dinner start 19:15

Daily Programme Wednesday 9th May 2018

Villigen PSI 5232, Room WBGB/019

08:40 – 10:20	***Session 5***	***Chair: Hong Ding***
08:40 – 09:05	*Christian Rüegg (PSI)*	Spin-orbital Singlet, Spiral Spin-liquid and Novel Vortex States in Magnets with Spinel Structure
09:05 – 09:30	*Tao Xiang (IOP)*	Gapless Spin-Liquid Ground State in the S=1/2 Kagome Antiferromagnet
09:30 – 09:55	*Huiqiu Yuan (Zhejiang Uni.)*	Topological Kondo semimetals
09:55 – 10:20	*Qimiao Si (Rice Uni.)*	Magnetism and topology in strongly correlated metals
10:20 – 10:50		Coffee Break

10:50 – 12:30	***Session 6***	***Chair: Michel Kenzelmann***
10:50 – 11:15	*N. L. Wang (Peking Uni.)*	Light-induced new collective modes and metastable state in cuprate
11:15 – 11:40	*Philipp Werner (Uni. of Fribourg)*	Spin- and orbital-freezing in unconventional superconductors
11:40 – 12:05	*Alberto Morpurgo (Uni. of Geneva)*	Unconventional gate-induced superconductivity in transition metal dichalcogenides
12:05 – 12:30	*Xianhui Chen (Uni. of Science and Technology of China)*	Gating-controlled phase transitions in (Li,Fe)OHFeSe and MoS2 crystals
12:30 – 14:00		Lunch

14:00 – 15:40	***Session 7***	***Chair: Xingjiang Zhou***
14:00 – 14:25	*Dirk van der Marel (Uni. of Geneva)*	Measurements of the pair-distribution function in correlated matter
14:25 – 14:50	*Luc Patthey (PSI)*	SwissFEL: recent achievements and future plans
14:50 – 15:15	*Shuyun Zhou (Tsinghua Uni.)*	Two-dimensional materials and hetero-structures for new topological phases and tailored electronic
15:15 – 15:40	*Fu-Chun Zhang (Uni of CAS)*	Topological Larkin-Ovchinnikov phase and Majorana zero mode chain in bilayer superconducting topological insulator films
15:40 – 16 :10		Coffee Break

16:10 – 17:25	***Session 8***	***Chair: Ming Shi***
16 :10 – 16:35	*Oded Zilberberg (ETHZ)*	The 4D quantum Hall effect as a parent Hamiltonian for topological phenomena.
16:35 – 17:00	*Yayu Wang (Tsinghua Uni.)*	Quantum Phase Transitions in Magnetic Topological Insulators
17:00 – 17:25	*Hong Ding (IOP)*	Majorana bound state in iron-based superconductor Fe(Te, Se)
17:25 – 17:40		**Closing remarks**
Local Supports	*Milan Radovic, Junzhang Ma, Jasmin Jandke, Mengyu Yao, Alla Chikina, Tian Shang*	

Abstracts of talks:
Session 1

Full Quantum Nature of Water on Surface

Enge Wang

International Center for Quantum Materials and School of Physics, Peking University
and
Institute of Physics, Chinese Academy of Sciences

Despite water being a ubiquitous substance, it is surprising that some basic questions are still debated. Here using a combination of experimental (cryogenic STM) and theoretical (first-principle electronic structures and molecular dynamics) methods, we systematically studied the unusual structure and dynamics of ice surface at atomic scale, and the sub-molecular imagining, clustering and proton transfer mechanisms of water on salt. First, an order parameter, which defines the ice surface energy, is identified. We predict that the proton order-disorder transition, which occurs in the bulk at ~72 K, will not occur at the surface at any temperature below surface melting. In addition, we find that the surface of crystalline ice exhibits a higher than expected concentration of vacancies at the external layer that may contribute to the phenomenon of pre-melting and quasi-liquid layer formation. Second, a STM molecular imaging mechanism based on a subtle control over the tip-molecule coupling is proposed, which allows a sub-molecular level resolution for water. A concerted proton tunneling mechanism is studied within the water tetramer, which is the basic unit to form an extended 2D ice layer by bridging water molecules on NaCl (001). These results shed light on our understanding of water at atomic scale.

Notes:

The Superconductor-Insulator Transition in two-dimensions: Phases and unique Symmetries

Aharon Kapitulnik

Geballe Laboratory for Advanced Materials, Stanford University

The conventional picture of possible ground states in a two-dimensional electron gas (2DEG) system, at zero temperature and in the presence of disorder, allows only superconducting or insulating phases (and in magnetic field also quantum Hall liquid phases). Tuning the disorder and/or magnetic field between superconducting and insulating ground states -- the so called superconductor-insulator transition (SIT) -- has received acute attention because they led to exploration of new ground states and appear to be broadly relevant to other quantum phase transitions (QPTs) and unsolved puzzles such as unconventional superconductivity in the high-Tc cuprates. In particular, detailed experimental studies of disordered superconducting thin-films near the magnetic-field tuned superconductor-insulator transition (SIT) have revealed several unexpected new ground states for films that otherwise superconduct at zero magnetic field. For weakly disordered films (with normal state resistivity small compared to the quantum of resistance, the superconducting state gives way to an anomalous metallic phase with a resistivity that extrapolates to a non-zero value as the temperature tends to zero. For highly disordered superconducting films, a direct SIT occurs at at some critical field, giving way to a boson-dominated insulator. By supplementing the longitudinal resistance with Hall resistance data, we show that the resistivity tensor at criticality approaches the universal value expected at a point of vortex-particle self-duality, while the insulating phase proximate to the SIT appears to be a Hall insulator where in the limit of $T \rightarrow 0$, the longitudinal resistance tends to infinity while the Hall resistance is finite [PNAS 113, 280-285 (2016)]. These new results shade light on the nature of the SIT and bare important consequences to other QPTs in two-dimensional systems.

Notes:

Coherent oscillators and spectral hole-burning in rare earth magnets

Markus Müller

Paul Scherrer Institut

Experiments in rare earth compounds (such as $LiHoYF_4$ and GdGa garnet) have demonstrated very long lived coherent quantum degrees of freedom with sharply defined excitation energies many orders of magnitude below the scale of exchange or dipolar couplings between rare earth magnetic moments.

The nature of these coherent entities has remained a mystery for a long time. I will discuss their possible origin, and argue that they most likely arise from an intricate interplay between nuclear and electronic spins in such systems. These may be promising candidates for magnetic qubits.

The search for these coherent objects has inspired new ideas of how to realise quantum memories, and potentially quantum computation, in the solid state.

Notes:

SLS 2.0 The Science Case

Phil Willmott

Paul Scherrer Institut

The SLS has been a premier third-generation facility since its inception in 2001. With the advent of diffraction-limited storage-rings baed on multi bend achromats, it is now imperative to upgrade the SLS in order for it to remain competitive in the next generation of synchrotrons beginning to come online. SLS 2.0 promises a horizontal electron-beam emittance of 120 pm.rad and up to a fortyfold improvement in the coherent fraction.

In this talk I will present an overview of the core activities at the SLS that will profit from the upgrade, in particular in the fields of imaging, macromolecular crystallography, and soft x-ray electron spectroscopy of operando systems.

Notes:

Abstracts of talks:
Session 2

Molecular Glass Photoresists with High Resolution, Low LER and High Sensitivity for EUV Lithography

Guoqiang Yang

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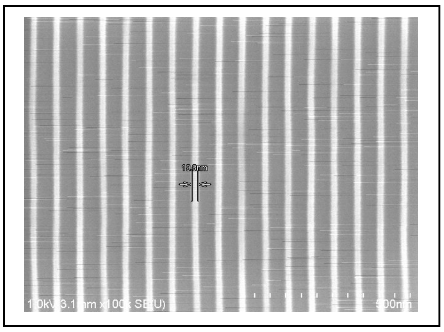
Novel positive-tone molecular glass molecules (BPA-6 and BPA-10) were designed and synthesised. The molecules show good thermal stability and well film forming properties for patterning application as EUV photoresists. The films were exposed at various doses by using the soft X-ray with 12.5nm wavelength interference photolithography beamlines located in Shanghai Synchrotron Radiation Facility and the XIL-II beamline on Swiss Light Source, respectively. The patterns with high resolution feature sizes, low line edge roughness and high sensitivity were obtained using BPA-10, enabling the satisfaction of the threefold requirements on resolution, sensitivity and LER for EUV lithography.



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Notes:

Dopant atoms as quantum components in silicon nanoscale devices*

Xiaosong Zhao[1], Weihua Han[1], Hao Wang[1], Liuhong Ma[1,2] and **Fuhua Yang**[1,2]

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[2]*State Key Laboratory for Superlattices and Microstructures, Institute of Semiconductors, Chinese Academy of Sciences, Beijing 100083, P. R. China*

Abstract: Recent progresses in nanoscale fabrication allow many fundamental studies of the few dopant atoms in various semiconductor nanostructures. Since the size of nanoscale devices has touched the limit of the nature, a single dopant atom may dominate the performance of the device. Besides, the quantum computing considered as a future choice beyond Moore's law also utilizes dopant atoms as functional units. Therefore, the dopant atoms will play significant role in the future novel nanoscale devices. In this work, we report the electron transport behaviors through the arrays of phosphorus atoms in a heavily n-doped silicon junctionless nanowire transistor. The multiple-split current peak features are observed due to the interdot coupling in the initial stage of conduction at the low temperatures. With the gate voltage increasing, one-dimensional transport behavior is occurred with the appearance of a series of regular current plateaus. The gate-dependent transport evolution is determined by the modulation of the tunnel barrier potentials of ionized dopant atoms. It can be predicted that the development of nanoelectronics based on dopant atoms will pave the way for new possibilities in quantum electronics.

Key words: Silicon nanoscale devices; Dopant atoms; Ionization energy; Dopant-induced quantum dots; Quantum transport

Notes:

Artificial optical nonlinearity generated by metamaterial

Yongzheng Wen

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Abstract: Over the past two decades, metamaterial has drawn great attention as a type of artificial material, allowing unprecedented control of light and exhibiting intriguing optical properties not found in nature, such as negative refractive index, invisible cloaking, and perfect lens. With the fruitful achievements in linear optics, the research of metamaterial has extended to the area of nonlinear optics, and rapid progress has been reported, including phase mismatch free and giant nonlinear susceptibility. In this talk, I will introduce our recent work on artificial generation of optical nonlinearity with a metamaterial route. With a fundamental magneto-electric interaction in a metamolecule, an intensive magnetic force drives an anharmonic oscillation of free electrons, generating an intrinsically nonlinear electromagnetic response. Unlike almost all the reported nonlinear metamaterials, whose nonlinear responses are actually derived from the external nonlinear materials, this novel mechanism of optical nonlinearity is artificially dominated by the metamolecule geometry and possesses unprecedented design freedom. I will focus on how to achieve the conventional second- order and high-order harmonic generation and the novel giant dynamic Hall effect by elaborately designing the metamolecule structure.

Notes:

Create and Control Properties of Transition Metal Oxides: Spectroscopy on hetero-structures

Milan Radovic

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email: milan.radovic@psi.ch;

Transition Metal Oxides (TMOs) exhibit unique and multifunctional physical phenomena (such as high-temperature superconductivity, colossal magnetoresistance, metal-insulator transitions, etc.) directly related to the spin and orbital degrees of freedom of the transition metal d-states and their interplay with the lattice. Importantly, the iso-structure of TMOs permits realization of hetero-structures generating at their surfaces and interfaces new physical matters that radically differ from those of the constituent bulk materials. Therefore, to fully explore the potential of modern quantum and hybrid materials based on TMO the first worldwide experimental setup combining Pulse Laser Deposition and Angle Resolved Photoemission (ARPES) has been designed at the SIS beamline (Swiss Light Source, Paul Scherrer Institut). Presently, this set up is being extended with Molecular Beam Epitaxy (MBE) chamber and Scanning Tunnelling Microscope (STM). With this capability, the control of structure and morphology of ultrathin films down to one unit cell thickness prior to the spectroscopy experiments will be secured.

Thanks to the unique combination of growth and spectroscopy at SIS beam line two methods to manipulate properties of TMO based hetero-structures have been established:

1. Altering orbital ordering and band filling of the 2DEG at titanates surfaces.

Employing ARPES diverse ways have been established to manipulate the 2DEG and, consequently, electronic properties of titanates surfaces ($SrTiO_3$ in bulk and film forms [1, 2, 3], TiO_2-anatase [3] and $CaTiO_3$ [4] films).

2. Tuning electronic phases in ultra-thin $NdNiO_3$ films via the proximity to the magnetic layer.

The electronic structure of NNO films grown solely and in proximity to magnetically ordered manganite layers has been studied. Combining the ARPES experimental data with the theoretical calculations, we found that the insulator phase in ultra-thin NNO films is destabilized probably due to quenching of anti-ferromagnetic (AF) order via proximity to the ferromagnetic manganite layer [4, 5].

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[6] Z. Ristic, R. S. Dhaka, T. Das, Z. Wang, C. E. Matt, N. C. Plumb, M. Naamneh, M. Shi, L. Patthey, M. Radovic, and J. Mesot, ***Quenching Insulator phase in ultra-thin NdNiO3 films via the proximity to the magnetic layer,*** under review 2018.

Notes:

Abstracts of talks:
Session 3

Magnetic properties of nickelate films and nickelate based heterostructures

Sara Catalano, Marta Gibert, Jennifer Fowlie, Claribel Dominguez,
and Jean-Marc Triscone

*DQMP, University of Geneva, 24 Quai Ernest-Ansermet,
1211 Geneva 4, Switzerland*

Perovskite nickelates ($RENiO_3$, RE = Rare Earth) are fascinating materials, well-known for their metal to insulator transition (MIT) and unique antiferromagnetic (AFM) ground state [1-3]. $LaNiO_3$ is the only member of the family that is metallic and paramagnetic down to low temperatures [1-3]. Recent results, however, suggest that $LaNiO_3$ single crystals may be antiferromagnetic below 150K [4]. In this talk, I will review what is known on the MIT and Néel transitions in thin films and heterostructures. I will in particular discuss for thin films the effect of strain [5] and growth orientation [6]. I will also discuss the unusual magnetic properties of some nickelate based superlattices. Exchange bias and antiferromagnetic interlayer coupling are for instance observed in [111]-oriented ($LaNiO_3$)/($LaMnO_3$) superlattices [7,8].

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[8] M. Gibert *et al.*, Nature Comm. **7**, 11227 (2016)

Notes:

Quantum transport experiments with cold atoms

Jean-Philippe Brantut

Fondation Sandoz Chair in Physics of Quantum Gases, EPFL, Switzerland

Over the last decade, the level of control over cold atomic gases has improved to the point that atoms can now be used to simulate the behavior of electrons in realistic materials. I will present the progresses that we accomplished in the last years in measuring the transport properties of cold atomic gases using the Landauer two- terminals setup, in particular the emergence and disappearance of quantized conductance in the regimes of weak and strong interactions. I will then describe some of the most recent technical and theoretical developments, in particular the use of optical manipulation and observation of transport at the scale of the Fermi wavelength and novel concepts for quantum limited atomic current detectors.

Notes:

The extremely large magnetoresistance and its electronic structure

Shancai Wang

Department of Physics and Beijing Key Laboratory of Opto-electronic Functional Materials & Micro-nano Devices, Renmin University of China, Beijing 100872, China

Abstract: The extremely large magnetoresistance attracts interest for its potential application. The origin of the XMR remains controversial. Here we present angle-resolved photoemission study of the XMR materials. We show that the the XMR could be caused by electron-hole compensation, such as in LaBi family. Besides the conventional electron-hole compensation caused XMR, we did ARPES measurement of the TaAs2 and found that the unambiguously observed Fermi surfaces (FSs) are dominated by an open-orbit topology extending along both the [100] and [001] directions in the three-dimensional Brillouin zone. We further reveal the trivial topological nature of MoAs2 by bulk parity analysis. Based on these results, we examine the proposed XMR mechanisms in other semimetals, and ascribe the origin of quadratic XMR in MoAs2 to the carriers motion on the FSs with dominant open-orbit topology, innovating in the understanding of quadratic XMR in semimetals.

Notes:

Quantifying atomic motions with ultrashort x-ray pulses

Urs Staub

Swiss Light Source, Paul Scherrer Institut, Villigen, Schweiz

Different cases are presented how ultrafast x-ray pulses can be used to study ultrafast dynamics in correlated electron systems. It is shown how an optical excitation can drive an electronic ordering transition and how it can be driven by direct phonon excitation in doped manganites. In addition, it is shown how we can increase a structural order parameter with an electronic excitation in a simple perovskite and that we can upconvert phonons in $SrTiO_3$ by driving its soft mode resonantly.

Notes:

Abstracts of talks: Session 4

Umklapp scattering as the origin of T-linear resistivity in the normal state of high-T_c cuprate superconductors

T. Maurice Rice

Theor. Physik, ETH Zurich & Brookhaven Natl. Lab. NY USA

The high-temperature normal state of the unconventional cuprate superconductors has resistivity linear in temperature T, which persists to values well beyond the Mott-Ioffe-Regel upper bound. At low-temperature, within the pseudogap phase, the resistivity is instead quadratic in T, as would be expected from Fermi liquid theory. Developing an understanding of the pseudogap phases of the cuprates is crucial to explain the unconventional superconductivity. Umklapp scattering of electrons gives a simple explanation for the anomalous linear T resistivity. This fits within the general picture emerging from functional renormalization group calculations that spurred the Yang-Rice-Zhang ansatz.

Ref. T.M.Rice, N.J.Robinson and A.M.Tsvelik, PRB **96** 220502(R), 2017

Notes:

Direct Observation of Orbital Hybridisation in a Cuprate Superconductor

Johan Chang

Physik-Institut, Universität Zürich, Switzerland

Recent synchrotron experiments [1,2,3] on cuprate and related oxide materials will be presented. The talk will focus on the electronic band structure of La2-xSrxCuO4. Topological symmetry protecting aspects will be discussed along with implications on superconductivity and the pseudogap phase.

[1] Nature Communications 9, 972 (2018)
[2] Physical Review X 8, 11048 (2018)
[3] https://arxiv.org/abs/1802.01376

Notes:

Laser ARPES on High Temperature Superconductors and Topological Materials

Xingjiang Zhou

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Email: XJZhou@iphy.ac.cn

In this talk, I will first introduce our progress in developing vacuum ultra-violet laser-based angle-resolved photoemission systems. Then I will report our recent results on studying high temperature superconductors and topological materials including: (1). Distinct electronic structure and superconducting gap in single-layer $FeSe/SrTiO_3$ films, (Li,Fe)OHFeSe and bulk FeSe superconductors[1-6]; (2). Quantitative determination of pairing interactions in high-Tc cuprate superconductors[7] and (3). Electronic structure of topological materials including monolayer silicene[8], $ZrTe_5$ and HfTe [9,10] and WTe_2[11].

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Notes:

Femtosecond electron-phonon lock-in in FeSe via ultrafast x-ray scattering and photoemission

Simon Gerber

Laboratory for Micro and Nanotechnology, Paul Scherrer Institut, Switzerland

Identifying the degrees of freedom that lead to the emergence of superconductivity in iron-based materials remains the subject of active research. Amongst spin-driven scenarios, it has also been suggested that electron-electron correlations enhance the electron-phonon coupling in iron chalcogenides and related pnictides, but direct experimental verification has been lacking. Measurements of ultrafast lattice dynamics benefit immensely from the advent of x-ray free-electron lasers, providing coherent femtosecond x-ray pulses with unprecedented brilliance. Using the Linac Coherent Light Source in Stanford, California, we have tracked the light-induced femtosecond coherent lattice motion in FeSe, which originates from a single optical phonon mode. At same time, photoemission spectroscopy allowed us to monitor the corresponding orbital-resolved, coherent change in the electronic band structure. Combining these two time-domain experiments into a “coherent lock-in” measurement in the terahertz regime, permits quantifying the electron-phonon coupling strength in FeSe purely from experiments and with high precision. Notably, comparison of the experimentally derived electron-phonon deformation potential with theory reveals a strong enhancement of the coupling strength in FeSe owing to correlation effects. More generally, the coherent lock-in approach establishes an experimental paradigm for precision measurements of fundamental physical quantities by only relying on a linear, coherent response. Thereby, it provides a purely experimental and model-free technique for unbiased tests of emergent phenomena in correlated materials.

Notes:

Abstracts of talks:
Session 5

Spin-orbital Singlet, Spiral Spin-liquid and Novel Vortex States in Magnets with Spinel Structure

Christian Rüegg

Division Research with Neutrons and Muons, Paul Scherrer Institut, Switzerland

Magnets with spinel structure AB_2S_4 and magnetic ions on their A-sites have been proposed theoretically to realize exotic magnetic states like spin-orbital singlets (SOS) and spiral spin-liquids. Application of magnetic field or pressure to control spin-orbit coupling may further lead to emergent new phases near quantum critical points. $FeSc_2S_4$ is a candidate material to realize a nearly quantum critical spin-orbital singlet state, where entangled spin and orbital moments fluctuate in a global singlet state at the boarder of spin and orbital order. We observe the magnetic excitations in this material by inelastic neutron scattering and find that spin-orbital triplon excitations of an SOS state can capture well key aspects of the spectrum in both zero and applied magnetic fields up to 8.5 T [1]. Using neutron scattering techniques, we experimentally prove the existence of a spiral spin-liquid in $MnSc_2S_4$ by directly observing a continuous 'spiral surface' of spiral propagation vectors in reciprocal space [2]. In the same material we discover a vortex-like triple-q phase on application of a magnetic field and hence demonstrate a new mechanism to realize a magnetic vortex lattice through frustrated interactions.

References:

[1] A. Biffin et al., Physical Review Letters, 118, 067205 (2017).
[2] S. Gao et al., Nature Physics, 13, 157 (2017).

Notes:

Gapless Spin-Liquid Ground State in the S=1/2 Kagome Antiferromagnet

T. Xiang

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Collaborative Innovation Center of Quantum Matter, Beijing 100190, China

The defining problem in frustrated quantum magnetism, the ground state of the nearest-neighbor spin 1/2 antiferromagnetic Heisenberg model on the kagome lattice, has defied all theoretical and numerical methods employed to date. We apply the formalism of tensor-network states, specifically the method of projected entangled simplex states, which combines infinite system size with a correct accounting for multipartite entanglement. By studying the ground-state energy, the finite magnetic order appearing at finite tensor bond dimensions, and the effects of a next-nearest-neighbor coupling, we demonstrate that the ground state is a gapless spin liquid. We discuss the comparison with other numerical studies and the physical interpretation of this result.

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Notes:

Topological Kondo semimetals

Huiqiu Yuan

Center for correlated Matter and Department of Physics, Zhejiang University

In this presentation, we will report our recent progress studying the topological properties of the correlated semimetals *R*X (*R* = Ce, Pr, Sm; X=Sb, Bi) and YbPtBi.

Evidence for Weyl fermions has also been found in the heavy fermion semimetal YbPtBi. At higher temperatures where the Kondo interaction is weaker, the presence of Weyl fermions is inferred from the chiral anomaly in magnetotransport measurements, as well as the ARPES measurements and DFT calculations [1]. Upon lowering temperature, the Kondo interactions between the 4f electrons and conduction electrons are strengthened and therefore the electronic bands are renormalized. As a result, the contributions of chiral anomaly to the magnetotransport become negligible in the heavy fermion state. Instead, we obtained evidence for Weyl fermions at low temperatures from the measurements of specific heat and topological Hall effect. [1]. These results show clear evidence for the influence of strong electronic correlations on the Weyl fermion state, opening up the opportunity for studying the interplay between Weyl fermions, electron-electron correlations and quantum criticality.

The *RX* family of materials display a very large magnetoresistance and non-trivial band topologies. Angular dependent magnetoresistance measurements and band structure calculations provide evidence for Weyl fermions in the field-induced ferromagnetic state of CeSb [2]. In PrSb a trivial topology is revealed [3], whereas a non-trivial topology is found in SmSb, where quantum oscillations show anomalous behavior. Meanwhile in *R*Bi, band inversions and topological surface states are revealed by ARPES measurements and band structure calculations [4].

[1] C. Y. Guo et al., arXiv: 1710.05522.

[2] C. Y. Guo et. al., npj Quantum Materials **2**, 39 (2017).

[3] F. Wu et al., Phys. Rev. B **96**, 125122 (2017).

[4] P. Li et al., arXiv:1802.03111 (2018); X. Duan et al., arXiv: 1802.04554

Notes:

Magnetism and topology in strongly correlated metals

Qimiao Si

Rice University

This talk will cover two topics. First, I will discuss some new frontiers in the area of quantum criticality in heavy fermion metals. Particularly, I will emphasize how the complex entwining of spins with other degrees of freedom can end up with unusual simplicity in the low-energy physics. Second, I'll demonstrate how this prototypical subject of correlated electron physics has recently been connected to the seemingly unrelated area of topological metals. This route has led to a correlation-driven Weyl semimetal state. I'll discuss the expected properties of this Weyl-Kondo semimetal and the experiments that have provided evidence for its existence in heavy fermion systems.

Notes:

Abstracts of talks:
Session 6

Light-induced new collective modes and metastable state in cuprate superconductors

S. J. Zhang, Z. X. Wang, D. Wu, Tao Dong, N. L. Wang

International Center for Quantum Materials, School of Physics, Peking University, Beijing 100871, China

We present near and mid-infrared pump c-axis terahertz probe measurement on hole and electron doped 214 superconducting single crystals. The measurement reveals that the pump-induced change occurs predominantly at the Josephson plasma edge position below Tc. Upon excitation by the intense near- or mid-infrared pulses, the superconducting state is severely disturbed and incoherent quasiparticle excitations develop in frequency regime above the static plasma edge. However, within very short time delay (~1.5 ps) we observe the reappearance of a very sharp Josephson plasma edge at frequency lower than the static Josephson plasma edge and the emergence of a new light-induced edge at higher energy. Then the effect keeps almost unchanged up to the longest measurement time delay 250 ps. The results suggest that the intense pump drives the system from a superconducting state with a uniform Josephson coupling to a new metastable superconducting phase with modulated Josephson coupling strengths.

Notes:

Spin- and orbital-freezing in unconventional superconductors

Philipp Werner

Department of Physics, University of Fribourg, Switzerland

The phase diagrams of unconventional superconductors exhibit a superconducting dome below a non-Fermi liquid metal phase and next to a magnetically ordered insulator. In multi-orbital systems with Hund coupling, these generic properties can be naturally explained by the phenomenon of spin-freezing [1], i.e. the appearance of disordered local moments in a certain filling and interaction regime. The fluctuating local moments at the border of the spin-frozen region produce the non-Fermi liquid behavior at elevated temperatures, and provide the glue for an unconventional spin-triplet pairing at low temperature [2]. Using appropriate mappings, one can connect this phenomenon to the d-wave spin-singlet superconductivity in the two-dimensional Hubbard model [3]. In multi-orbital models with negative Hund coupling, which are relevant for fulleride superconductors, the role of spin and orbital is exchanged, and the unconventional spin-singlet pairing is induced by an orbital-freezing phenomenon [4].

[1] P. Werner, E. Gull, M. Troyer and A. J. Millis, PRL 101, 166405 (2008)
[2] S. Hoshino and P. Werner, PRL 115, 247001 (2015)
[3] P. Werner, S. Hoshino and H. Shinaoka, PRB 94, 245134 (2016)
[4] K. Steiner, Y. Nomura, S. Hoshino, and P. Werner, PRB 94, 075107 (2016)

Notes:

Unconventional gate-induced superconductivity in transition metal dichalcogenides

Alberto Morpurgo

University of Geneva

The possibility to induce and control superconductivity at the surface of insulating materials by means of electrostatic gating is a breakthrough development that has taken place during the last decade. Probing the nature of the gate-induced superconducting state is however extremely difficult, because the superconducting surface –buried between the gate electrode and the insulating material itself– is difficult to access with most experimental probes. This is why, until now, the superconducting properties of these systems have been studied almost exclusively by means of transport measurements. Here, I will discuss our work on gate induced superconductivity on exfoliated MoS_2 crystals. I will first show that superconductivity survives down to the ultimate level of an individual monolayer. I will then discuss tunneling spectroscopy measurements in the gate-induced superconducting state that we succeeded in doing using suitably nano-fabricated devices. The measurements allow us to determine the density of states in the superconducting regime as a function of carrier density, and demonstrate that the superconducting state is not fully gapped. We find that throughout the carrier density range investigated, a finite sub-gap density of states vanishing linearly at low energy is present, indicative of unconventional superconductivity. I will point to different aspects of the measurements and discuss which indications they provide as to the nature of the superconducting state.

Notes:

Gating-controlled phase transitions in (Li,Fe)OHFeSe and MoS_2 crystals

Xianhui Chen

Hefei National Laboratory for Physical Sciences at Microscale and Department of Physics, and CAS Key Laboratory of Strongly-coupled Quantum Matter Physics, University of Science and Technology of China, Hefei, Anhui 230026, People's Republic of China

In this talk, we report on the recent progresses of gate-controlled phase transitions in (Li,Fe)OHFeSe and MoS_2 crystals. Through driving lithium ions into the (Li,Fe)OHFeSe thin flakes with the solid ionic gating technique by using lithium glass as a gate dielectric, the superconductivity was enhanced to the optimal superconductivity with T_c=43 K and then suppressed, and a dome-like phase diagram was mapped out. With further inserting lithium ions, we observed a phase transition from superconductor to ferromagnetic insulator. It should be addressed that the process is reversible. Using the same method, we studied the structure and transport on MoS_2 crystals. It is striking that the metastable insulating 1T'''phase can be transformed to semiconducting 1T' phase: LixMoS_2, and the semiconducting 1T' phase of LixMoS_2 is transferred to superconducting 1T' phase of MoS_2 when Li is de-intercalated. Our works pave a way to obtain the metastable phase and control structural phase transition as well as physical properties by the electric field, and greatly enrich material functionality in the future.

Notes:

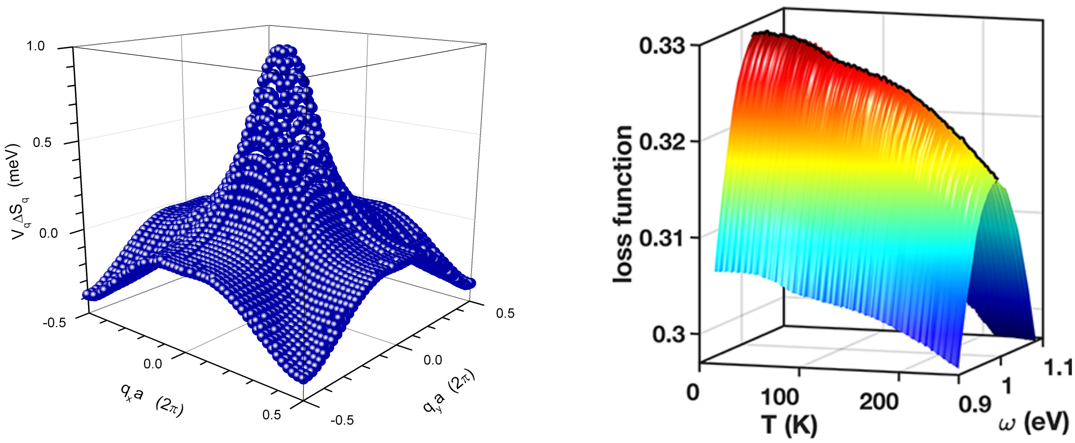
Abstracts of talks:
Session 7

Measurements of the pair-distribution function in correlated matter

Dirk van der Marel

Université de Genève

Many properties of materials are the result of correlated behavior of the electrons in partially filled bands around the Fermi energy. Magnetic order, metallic conductivity, and superconductivity are just a few examples of different states of matter, each characterized by different types of correlation between the charge and spin of the electrons in a solid. The most important type of correlation in a solid or liquid is the one related to the pair distribution, g(r). It is defined as the probability that another particle is at coordinate r, if there is already one at r=0. The Fourier transform of the pair distribution function is called the (static) structure factor, S_q, and can be calculated from the charge susceptibility with the help of the fluctuation-dissipation theorem as applied to the susceptibility $\chi(q,\omega)$, related to the energy-loss function by $L(q,\omega)=V_q$ Im $\chi(q,\omega)$ where V_q is the bare electron-electron Coulomb potential. $L(q,\omega)$ is a purely experimental quantity, and can for example be measured with the help of electron energy loss spectroscopy or optical spectroscopy. The Coulomb interaction energy E_c is obtained by simply integrating the energy loss-function over all energies. It was pointed out by Leggett that E_c should become smaller in the superconducting phase, and that this saving of Coulomb energy comes predominantly from the regime of small q and the energy range around the plasmon. Recently we have demonstrated that it is indeed possible to determine experimentally the difference between $L(q,\omega)$ in the superconducting state and the normal state, and to determine the corresponding change of E_c . This result, using optical spectroscopy, was however limited to the q-->0 region of momentum space. Using inelastic scattering with large momentum transfer it should be possible to extend this this to high momentum, which ultimately should allow determining the progression of the pair-correlations in correlated matter as a function of tuning parameters. Such big facility developments would allow answering important questions such as the issue of the nature of the correlations responsible for the pseudo-gap in high T_c superconductors and the mechanism of superconductivity itself.



Left: Prediction for the change from d-wave superconducting to normal state of the correlation function in momentum space, ΔS_q , multiplied with the bare Coulomb potential, V_q for 16 % hole doping with interaction tuned to give T_c = 100 K. Data shown are for q_z = 0, corresponding to electric field polarized along the planes. Right: Spectrum of the energy loss function for q~0 measured. The data exhibit an increased intensity below T_c

1. A.J. Leggett, Proc. Natl. Acad. Sci. U.S.A. 96, 8365 (1999).
2. J. Levallois, M.K. Tran, D. Pouliot, C.N. Presura, L.H. Greene, J.N. Eckstein, J. Uccelli, E. Giannini, G. D. Gu, A.J. Leggett and D. van der Marel; Phys. Rev. X 6, 031027 (2016).

Notes:

SwissFEL: recent achievements and future plans

Luc Patthey

Paul Scherrer Institut, Villigen, Schweiz

The new X-Ray Free Electron Laser (SwissFEL) facility at PSI delivers fsec photon pulses of coherent x-rays in the wavelength range 0.1 to 7 nm, with extremely high peak brightness. These characteristics will provide opportunities for new experiments in chemistry, solid state physics, biology and materials science. The first pilot experiments by Aramis hard x-ray FEL branch start in December 2017 and the normal user operation will start in 2019 with two dedicated end-stations. The *Alvra* end-station is focused on using time resolved x-ray spectroscopy (XAS/XES) to investigate femtosecond chemical processes and time-resolved x-ray diffraction for serial femtosecond crystallography (SFX) experiments on proteins. The *Bernina* end-station is designed for femtosecond time-resolved pump-probe hard x-ray diffraction and scattering experiments in condensed matter systems. The Athos soft x-ray FEL branch is in the early phase of construction and should provide its first FEL light to experiments in 2020 in the field of Atomic, molecular, and optical physics (AMO), condensed matter and non-linear x-ray Science.

Notes:

Two-dimensional materials and hetero-structures for new topological phases and tailored electronic structures

Shuyun Zhou

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Two-dimensional (2D) materials (e.g. graphene, transition metal dichalcogenides) provide an important playground for exploring fundamental physics and potential applications. Probing the electronic struture is critical for revealing the fundamental physics and angle-resovled photoemission spectroscpy (ARPES) is a direct and powerful technique. In this talk, I will present our recent progress in searching novel topological phases and new spin physics in transition metal dichalcogenides using ARPES and Spin-ARPES. I will also show that by stacking simple 2D materials together to form heterostructures, we can use the band structure engineering at the interface to obtain new properties that are not otherwise possible in a single material.

Notes:

Topological Larkin-Ovchinnikov phase and Majorana zero mode chain in bilayer superconducting topological insulator films

Fu-Chun Zhang

Kavli Institute for Theoretical Sciences, Univ. of Chinese Academy of Sciecnes

Abstract

We theoretically study bilayer superconducting topological insulator film, in which superconductivity exists for both top and bottom surface states. We show that an in-plane magnetic field can drive the system into Larkin-Ovchinnikov phase, where electrons are paired with finite momenta. The Larkin-Ovchinnikov phase is topologically non-trivial and characterized by a Z2 topological invariant, leading to a Majorana zero mode chain along the edge perpendicular to in-plane magnetic fields.

This work is in collaboration with Lunhui Hu in Zhejiang Univ. and Chao-Xing Liu in Penn State Univ.

Notes:

Abstracts of talks:
Session 8

The 4D quantum Hall effect as a parent Hamiltonian for topological phenomena

Oded Zilberberg

Institute for Theoretical Physics, ETHZ, Switzerland

The introduction of topological concepts in physics has revolutionized our understanding of different phases of matter. Seminal example of topological phases of matter include, (i) 1D topological superconductors, (ii) 2D Chern insulators, (iii) 3D topological insulators, (iv) the 4D quantum Hall effect, and recently also (v) higher-order topological insulators. Interestingly, (i) and (iii) are respectively related to (ii) and (iv) through a procedure called "dimensional-reduction". In my talk, I will review this connection and explain how 4D topological systems can be used to similarly derive (v).

Notes:

Quantum Phase Transitions in Magnetic Topological Insulators

Yayu Wang

Tsinghua University

The interplay between nontrivial topology and broken time reversal symmetry in topological insulator (TI) can lead to exotic quantum phenomenon such as the quantum anomalous Hall effect. However, there are still many open questions regarding the mechanism of magnetic order and magneto transport in TI, as well as the quantum phase transitions between various ground states. In this talk, we present transport studies on magnetically doped TI thin films grown by molecular beam epitaxy. In Cr doped BiSeTe, we observe a magnetic quantum phase transition accompanied by the sign reversal of the anomalous Hall effect induced by Se substitution of Te. ARPES band mapping reveals that the ferromagnetic order is favored by the nontrivial bulk band topology, revealing a close correlation between the magnetism and topology. More recently, we found a gate-tuned ferromagnetic to paramagnetic phase transition near the topological quantum critical point. We propose that the most likely mechanism is the Stark effect induced electronic energy level shift, which causes a topological quantum phase transition followed by magnetic phase transition. More recently, we found that with increasing disorderness, there is a quantum Hall liquid to quantum Hall insulator phase transition. The scaling analysis indicates that the nature of this quantum phase transition is unique to the quantum anomalous Hall effect.

Notes:

Majorana bound state in iron-based superconductor Fe (Te, Se)

Hong Ding

Institute of Physics, Chinese Academy of Sciences

In this talk I will report our recent discoveries of topological superconductivity and Majorana bound state in Fe-based superconductor Fe(Te, Se). We have obtained convincing ARPES evidence of superconducting topological surface state of Fe(Te, Se) single crystal with Tc ~ 14.5K. By using low-temperature STM on this maeteial, we clearly observe a pristine Majorana bound state inside a vortex core, well separated from non-topological bound states away from zero energy due to the high ratio between the superconducting gap and the Fermi energy in this material. This observation offers a new, robust platform for realizing and manipulating Majorana bound states at a relatively high temperature.

Notes:

List of speakers and chairs:

(last name, first name)

Aeppli Gabriel (PSI)
Brantut Jean-Philippe (EPFL)
Chang Johan (Uni. of Zurich)
Chen Xianhui (Uni. of Science and Technology of China)
Ding Hong (IOP)
Gerber Simon (PSI)
Kapitulnik Aharon (Stanford Uni.)
Kenzelmann Michel (PSI)
Mesot Joël (PSI)
Morpurgo Alberto (Uni. of Geneva)
Mudry Christopher (PSI)
Müller Markus (PSI)
Nolting Frithjof (PSI)
Patthey Luc (PSI)
Rüegg Christian (PSI)
Radovic Milan (PSI)
Rice T. Maurice (ETHZ)
Shi Ming (PSI)
Si Qimiao (Rice Uni.)
Staub Urs (PSI)
Triscone Jean-Marc (Uni. of Geneva)
Van der Marel Dirk (Uni. of Geneva)
Wang Enge (CAS)
Wang Nanlin (Peking Uni.)
Wang Shancai (Remin Uni. of China)
Wang Yayu (Tsinghua Uni.)
Wen Yongzheng (Tsinghua Uni.)
Willmott Phil (PSI)
Werner Philipp (Uni. of Fribourg)
Xiang Tao (IOP)
Yang Fuhua (Institute of Semiconductor, CAS)
Yang Guoqiang (Institute of Chemistry, CAS)
Yuan Huiqiu (Zhejiang Uni.)
Zhang Fu-Chun (Uni of CAS)
Zhou Shuyun (Tsinghua Uni.)
Zhou Xingjiang (IOP)
Zilberberg Oded (ETHZ)