LEES 10
Low Energy Electrodynamics in Solids

Les Diablerets, July 5-10, 2010

Program and Abstract Book

The 9th International Conference on Low Energy Electrodynamics in Solids

UNIVERSITÉ DE GENÈVE

Université de Genève
Genève, Switzerland
http://www.unige.ch

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Information for presenters

Oral sessions

Place: **Maison des congrès**
Presentation time:
25 min. talk + 4 min Q/A + 1 min transition

Oral presentations can only be presented by laptops. The auditorium is provided with one laptop with LCD projector. Presenters are requested to bring their presentation in powerpoint (ppt or pptx) or pdf-format on a USB stick. Presenters can use their own laptop, but experience has taught that 1 out of 10 times there are technical problems of unpredictable nature. Speakers who still prefer to use their own laptop: We recommend you to put your presentation also on the “central” computer to be on the safe side.

Poster sessions

Place: **Maison des congrès**
Poster Set-Up: Tuesday morning (July 5)
All posters can be displayed during the duration of the meeting.

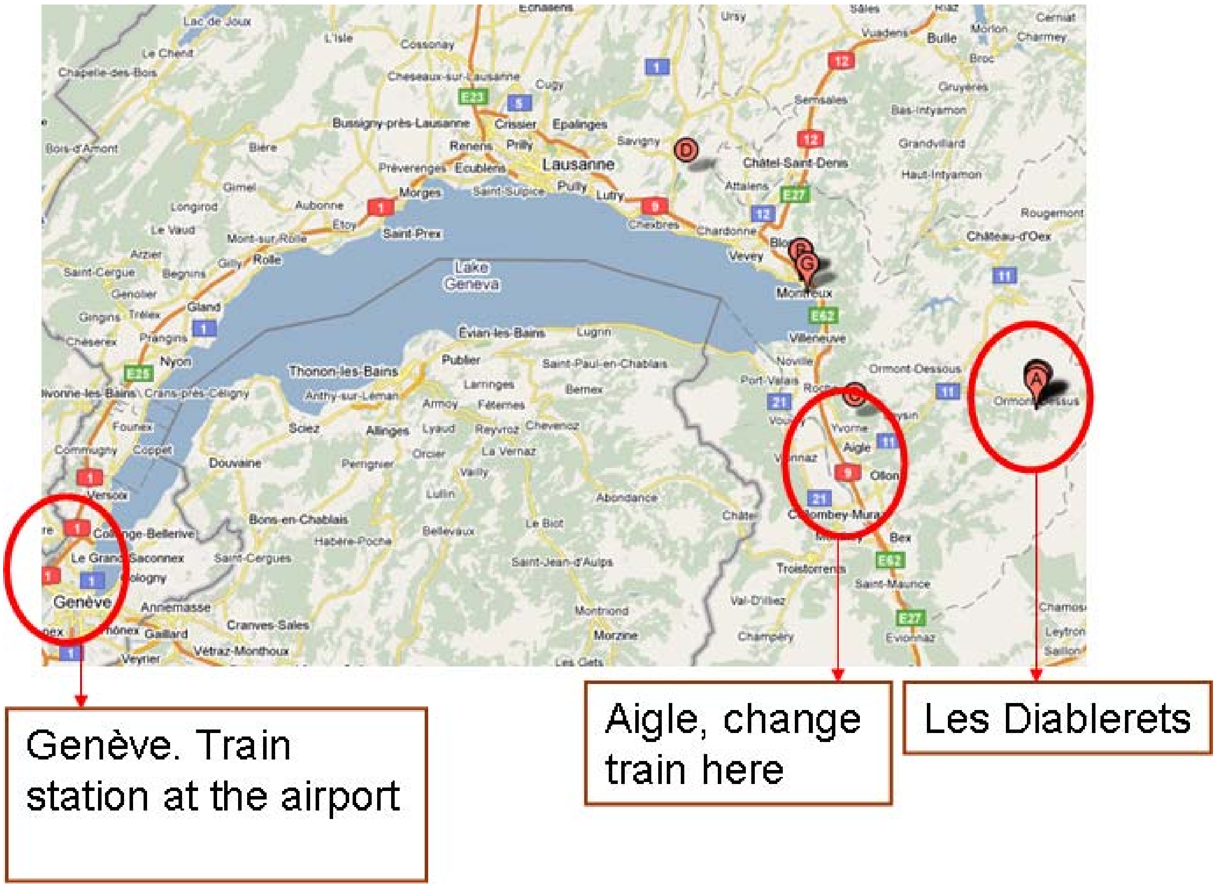
The dimensions of the poster boards are

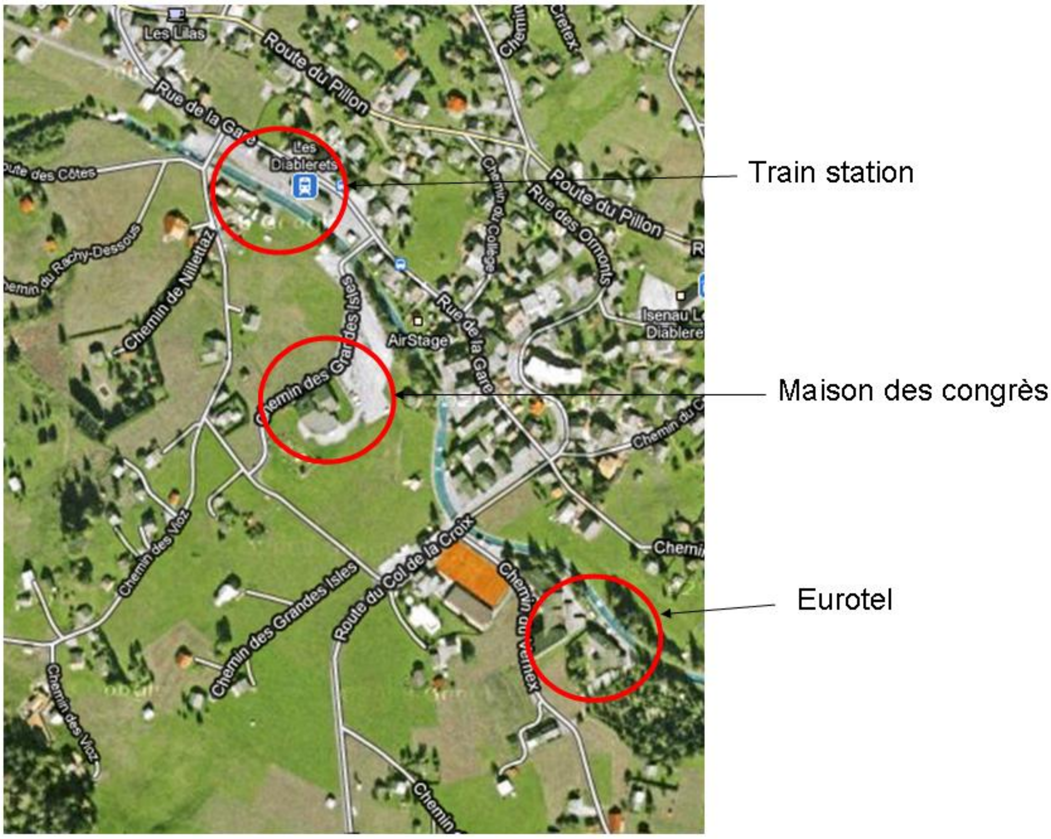
Width = 134 cm (47 inch)
Height = 112 cm (44 inch)

We thank you in advance to format your poster according to these dimensions.

Welcome reception

Place: Eurotel Les Diablerets
Date: 5 July, 20h00-22h00





Les Diablerets, Switzerland

	Monday 5	Tuesday 6	Wednesday 7	Thursday 8	Friday 9	Saturday 10
		High T_c cuprates	***High T_c pnictides***	***Heavy fermions and quantum criticality***	***Metal-insulator transitions***	***Multiferroics***
08:30-9:00		Proust	Sawatzky	Kimura	Basov	White
09:00-9:30		Razzoli	Hackl	Mercure	Lupi	Schleck
09:30-10:00		Tajima	Hanaguri	Scheffler	Kuntscher	Huvonen
10:00-10:30		Perfetti	Lucarelli	Gerber	Okamura	Pimenov
10:30-11:00		*Coffee*	*Coffee*	*Coffee*	*Coffee*	*Coffee*
		Dilute charge carriers	***High T_c cuprates***	***Novel experimental techniques***	***Spin-orbit interaction***	***Transition metal oxides***
11:00-11:30		Ciucchi	Sacuto	Thirunavukkuarasu	Hasan	Zhou
11 30-12:00		Carr	Auerbach	Mühlbauer	Dil	Shen
12:00-12:30		van Loosdrecht	van Heumen	***Ludwig Genzel Prize***	van Mechelen	Calvani
		Lunch	*Lunch*	12:00-12:15 Roskos 12:15-12:45 Leitenstorfer	*Lunch*	*Concluding remarks (van der Marel)*
		Non-equilibrium superconductivity	***High T_c cuprates***	*Excursions, etc…*	***Graphene***	
14:00-14:30		Tanner	Damascelli		Potemski	
14:30-15:00		Kadowaki	Grioni		Kuzmenko	
15:00-15:30		Fausti	Piriou		Nicol	
15:30-16:00		*Coffee*	*Coffee*		*Coffee*	
		Magnetism	***High T_c cuprates***		***High T_c superconductivity***	
16:00-16:30	*Registration*	Hirjibehedin	Gedik		Davis	
16:30-17:00		Ruegg	Carbone		Boebinger	
17:00-17:30		Berthier	Giannetti		Dubroka	
17:30-18:30		*Posters*	*Posters*		*Posters*	
					Conference banquet	
19:30-20:30		*Dinner*	*Dinner*	*Dinner*		
20:30-22:00	*Welcome reception*	Concert V. Mercier P. Ehinger	*Business meeting*			

Conference Program

Monday, July 5

16:00-18:00	Registration	
20:00-22:00	Welcome reception	

Tuesday, July 6

High T_c cuprates *(Chair: A. Georges)*

Or-Tu-01	08:30-09:00	**C. Proust**	***Quantum oscillations, magnetotransport and the Fermi surface of high Tc superconductors***
Or-Tu-02	09:00-09:30	**E. Razzoli**	***ARPES studies of electronic excitations in the pseudogap phase of La2-xSrxCuO4***
Or-Tu-03	09:30-10:00	**S. Tajima**	***View of multiple ordered states for high-Tc superconducting cuprates***
Or-Tu-04	10:00-10:30	**L. Perfetti**	***Time resolved photoemission and time resolved THz of highly correlated materials***
	10:30-11:00	*Coffee*	

Dilute charge carriers *(Chair: Ø. Fischer)*

Or-Tu-05	11:00-11:30	**S. Ciucchi**	***Band-like motion and mobility saturation in organic molecular semiconductors***
Or-Tu-06	11:30-12:00	**G. L. Carr**	***Time-resolved far-IR magnetospectroscopy of photoexcited carriers and excitons in GaAs***
Or-Tu-07	12:00-12:30	**P.H .M. van Loosdrecht**	***Optically induced non thermal phase transition in the A7 metals***
	12:30-14:00	*Lunch*	

Non-equilibrium superconductivity (*Chair: K. Burch)*

Or-Tu-08	14:00-14:30	**D. Tanner**	***Quasiparticle recombination in a type II superconductor***
Or-Tu-09	14:30-15:00	**K. Kadowaki**	***Coherent and Continuous Terahertz Emission from High-Tc Superconductor Intrinsic Josephson Junctions: the Synchronization Mechanism***
Or-Tu-10	15:00-15:30	**D. Fausti**	***Photo-induced superconductivity in charge ordered La1.8-xEu0.2SrxCuO4***
	15:30-16:00	*Coffee*	

Magnetism *(Chair: T. Giamarchi)*

Or-Tu-11	16:00-16:30	**C. Hirjibehedin**	***The impact of the local environment on the Kondo screening of a high-spin atom***

Or-Tu-12	16:30-17:00	**C. Ruegg**	***Bose-Einstein Condensation of Elementary Excitations in Solids***
Or-Tu-13	17:00-17:30	**C. Berthier**	***High field NMR quantum antiferromagnets: Wigner crystallization versus Bose-Einstein condensation***

Poster session 1

17:30-18:30	*Posters*	
19:30-20:30	*Dinner*	

Concert **P. Ehinger (clarinette) and V. Mercier (piano)**

20:30-22:30 *Compositions by C.M. von Weber, R. Schumann, and J. Brahms*

Wednesday, July 7

High T_c pnictides *(Chair: J. P. Carbotte)*

Or-We-01	08:30-09:00	**G.A. Sawatzky**	***Where are the extra d electrons in transition-metal substituted Fe pnictides?***
Or-We-02	09:00-09:30	**R. Hackl**	***Band and momentum dependence of the electronic properties in Co-doped Ba122***
Or-We-03	09:30-10:00	**T. Hanaguri**	***Phase-sensitive spectroscopic-imaging STM studies of unconventional superconductors***
Or-We-04	10:00-10:30	**A. Lucarelli**	***Optical investigation of the charge dynamics in Ba(CoxFe1-x)2As2***
	10:30-11:00	*Coffee*	

High T_c cuprates *(Chair: F. Marsiglio)*

Or-We-05	11:00-11:30	**A. Sacuto**	***Loss of coherent Quasi-Particles in under doped cuprates: an electronic Raman scattering study***
Or-We-06	11:30-12:00	**A. Auerbach**	***Lattice bosons and underdoped cuprates***
Or-We-07	12:00-12:30	**E. van Heumen**	***Optical determination of the relation between the electron-boson coupling function and the critical temperature in high Tc cuprates***
	12:30-14:00	*Lunch*	

High T_c cuprates *(Chair: R. Greene)*

Or-We-08	14:00-14:30	**A. Damascelli**	***Loss of nodal quasiparticle integrity in underdoped YBa2Cu3O6+x***
Or-We-09	14:30-15:00	**M. Grioni**	***Evidence for extended magnetic interactions in the cuprates from the magnon dispersion of SrCuO2Cl2***
Or-We-10	15:00-15:30	**A. Piriou**	***First direct observation of the van Hove singularity in the tunneling spectra of cuprates***
	15:30-16:00	*Coffee*	

High T_c cuprates (Chair: G. Blumberg)

Or-We-11	16:00-16:30	**N. Gedik**	***Ultrafast electronic and structural dynamics in high temperature superconductors***
Or-We-12	16:30-17:00	**F. Carbone**	***The symmetry and strength of the electron-phonon coupling in cuprates single crystals by Ultrafast Electron Crystallography***
Or-We-13	17:00-17:30	**C. Giannetti**	***Ultrafast dynamics of the interband spectral weight in superconducting cuprates***

Poster Session 2

17:30-18:30	*Posters*	
19:30-20:30	*Dinner*	
20:30-21:30	*Business meeting*	

Thursday, July 8

Heavy fermions and quantum criticality (Chair: P. Armitage)

Or-Th-01	08:30-09:00	**S. Kimura**	***Electronic structure of heavy fermions near QCP probed by optical and photoemission spectroscopy***
Or-Th-02	09:00-09:30	**J.-.F Mercure**	***The de Haas-van Alphen effect near a quantum critical end point in Sr3Ru2O7***
Or-Th-03	09:30-10:00	**M. Scheffler**	***Drude response of slow and fast electrons in the heavy-fermion compound UNi2Al3***
Or-Th-04	10:00-10:30	**S. Gerber**	***Evidence for magnetically driven superconducting Q phase of CeCoIn5***
	10:30-11:00	*Coffee*	

Novel experimental techniques (Chair: Th. Room)

Or-Th-05	11:00-11:30	**K. Thirunavukkuarasu**	***Coherent broadband continuous-wave THz spectrometry: A powerful tool for low-energy solid-state spectroscopy***
Or-Th-06	11:30-12:00	**S. Muehlbauer**	***Morphology, elastic constants and slow dynamics of superconducting vortex lattices investigated with time resolved stroboscopic neutron scattering***

Ludwig Genzel Prize Session

	12:00-12:15	**H. Roskos**	Attribution of the Ludwig Genzel Prize
Or-Th-07	12:15-12:45	**A. Leitenstorfer**	***Ultrabroadband Terahertz Analysis and Coherent Control of Oxidic Systems***
	13:00-18:30	*Excursions, etc.*	
	19:30-20:30	*Dinner*	

Friday, July 9

Metal-insulator transitions			*(Chair: R. DeSousa)*
Or-Fr-01	08:30-09:00	**D.N. Basov**	***Infrared nanoscopy of complex electronic materials***
Or-Fr-02	09:00-09:30	**S. Lupi**	***Low-energy electrodynamics and metal to insulator transitions in strongly correlated materials (VCr)2O3***
Or-Fr-03	09:30-10:00	**C. Kuntscher**	***Metal-insulator transition in NiS2-xSex***
Or-Fr-04	10:00-10:30	**H. Okamura**	***Pressure tuning of an ionic insulator into a heavy electron metal: An infrared study of YbS***
	10:30-11:00	*Coffee*	
Spin-orbit interaction			*(Chair: M. Golden)*
Or-Fr-05	11:00-11:30	**Z. Hasan**	***Discovery of Topological Insulators and related Superconductors***
Or-Fr-06	11:30-12:00	**H. Dil**	***Spin and angle resolved photoemission on model systems for spintronics***
Or-Fr-07	12:00-12:30	**J.L.M. van Mechelen**	***Ferromagnetic spin resonance in EuTiO3 probed by time-domain THz ellipsometry***
	12:30-14:00	*Lunch*	
Graphene			*(Chair: L.A. Falkovsky)*
Or-Fr-08	14:00-14:30	**M. Potemski**	***Magneto-spectroscopy of the graphene Dirac fermions***
Or-Fr-09	14:30-15:00	**A. B. Kuzmenko**	***Gate-tunable bandgap and infrared phonon anomalies in bilayer graphene***
Or-Fr-10	15:00-15:30	**E.J. Nicol**	***Effect of electron-phonon interaction on spectroscopies in graphene***
	15:30-16:00	*Coffee*	
High T_c superconductivity			*(Chair: I. Maggio-Aprile)*
Or-Fr-11	16:00-16:30	**J.C. Davis**	***Nematic electronic structure in the parent state of the iron-based superconductor Ca(Fe1-xCox)2As2***
Or-Fr-12	16:30-17:00	**G. Boebinger**	***Specific heat of the cuprate superconductors at high magnetic fields***
Or-Fr-13	17:00-17:30	**A. Dubroka**	***The phase diagram of precursor superconductivity as obtained from the infrared c-axis conductivity of RBa2Cu3O7-d***

Poster Session 3

17:30-18:30	*Posters*	
19:00-21:00	*Banquet*	

Saturday, July 10

Multiferroics *(Chair: M. Gruninger)*

Or-Sa-01	08:30-09:00	**J. White**	***High field and low temperature neutron diffraction studies of the triangular-lattice multiferroic RbFe(MoO4)2***
Or-Sa-02	09:00-09:30	**R. Schleck**	***The magneto-electric coupling in multiferroic materials***
Or-Sa-03	09:30-10:00	**D. Huvonen**	***Magnetic excitations and optical transitions in the multiferroic spin-1/2 system LiCu2O2***
Or-Sa-04	10:00-10:30	**A. Pimenov**	***Magnetoelectric coupling in split ring resonator metamaterials***
	10:30-11:00	*Coffee*	

Transition metal oxides *(Chair: A. Zheludev)*

Or-Sa-05	11:00-11:30	**K. Zhou**	***Electronic structure of charge carriers of LaAlO3/SrTiO3 heterostructure investigated by resonant inelastic x-ray scattering***
Or-Sa-06	11:30-12:00	**K. Shen**	***Dimensional crossovers and metal-insulator transitions in manganite superlattices LMO/SMO and La1-xSxMnO3 as studied by in situ MBE-ARPES***
Or-Sa-07	12:00-12:30	**P. Calvani**	***Infrared synchrotron-radiation studies of the charge order in manganites at normal and high pressure (LMO)***

Concluding remarks and Farewell

12:30-12:45	**D. van der Marel**	

LEES 2010 is supported by

The 9th International Conference on Low Energy Electrodynamics in Solids

Les Diablerets, July 5-10, 2010

Abstracts

Oral Presentations

INVITED

Quantum oscillations, magnetotransport and the Fermi surface of high T_c superconductors

Cyril Proust
Laboratoire National des Champs Magnétiques Intenses (CNRS) Toulouse - France

A central issue to understand the phase diagram of high temperature superconductors is the origin of the differences in the physical properties to opposite sides of the superconducting region. In the overdoped regime, the material behaves as a reasonably conventional metal, with a large Fermi surface, as confirmed by the large frequency observed by quantum oscillations measurements in overdoped $Tl_2Ba_2CuO_{6+\delta}$ [1]. The origin of the anomalous behavior in the underdoped regime, however, is still debated. The observation of quantum oscillations in the electrical resistance and in the magnetization of the underdoped $YBa_2Ba_2CuO_{6.5}$ [2,3] and $YBa_2Cu_4O_8$ [4] compound, establishing the existence of a coherent closed Fermi surface at low temperature. The low oscillation frequency reveals a Fermi surface made of small pockets and the negative sign of the Hall effect at low temperature reveals that these small pockets are electron-like. We propose that the Fermi surface in the underdoped regime most probably arise from a reconstruction of the large Fermi surface observed in the overdoped side [5]. Finally, I will discuss c-axis magnetoresistance in underdoped $YBa_2Ba_2CuO_y$ revealing a coherent 3D Fermi surface in an underdoped cuprate.

[1] N. Doiron-Leyraud et al, Nature 447, 565 (2007)
[2] C. Jaudet et al, Phys. Rev. Lett 100, 187005 (2008)
[3] A. Bangura et al, Phys. Rev. Lett 100, 047004 (2008)
[4] B. Vignolle et al, Nature 455, 952 (2007)
[5] D. LeBoeuf et al, Nature 450, 533 (2007)

CONTRIBUTED

ARPES studies of electronic excitations in the pseudogap phase of $La_{2-x}Sr_xCuO_4$

Elia Razzoli[1,2], Martin Månsson[2,3], Yasmine Sassa[3], Milan Radovic[1,2], Amit Keren[4], N. Monomo[5], M. Oda[5], M. Ido[5], Joël Mesot[6] and Ming Shi[1]

(1) Swiss Light Source, Paul Scherrer Institute, CH-5232 Villigen PSI, Switzerland
(2) Laboratory for synchrotron and neutron spectroscopy, EPF Lausanne, Switzerland
(3) Laboratory for Neutron Scattering, ETH Zürich and Paul Scherrer Institut, CH-5232 Villigen PSI, Switzerland
(4) Physics Department, Technion-Israel Institute of Technology, Haifa 32000, Israel
(5) Department of Physics, Hokkaido University Sapporo 060-0810, Japan
(6) Paul Scherrer Institute, ETH Zurich and EPF Lausanne, 5232 Vil ligen PSI, Switzerland

Despite a lot of efforts have been devoted to the study of high-temperature superconducting cuprates, the microscopic mechanism that is capable to explain their rich phase diagram has not been identified yet. One of the most striking features of these compunds is that, over a wide region of the phase diagram, the spectroscopic signature of a gap remains long after the signatures for phase coherence have vanished. So far it is still unclear whether this "pseudogap" regime is a phase precursor to superconductivity or whether it is a distinct phase that competes with it. In this contribution we will present angle-resolved photoemission results on $La_{2-x}Sr_xCuO_4$ over a wide doping range $0.03 < x < 0.17$. We shall show how the underlying Fermi surface, the superconducting and pseudogaps evolute from a highly underdoped insulator ($x = 0.03$) to a overdoped superconductor ($x = 0.17$). We will also show the dichotomy of the dispersion observed in the gapless and the gaped regions of the Brillouin zone in the pseudogap phase of the underdoped cuprate. The implication of the dichotomy of the dispersion in the pseudogap phase will be discussed.

CONTRIBUTED

View of Multiple Ordered States for High-T_c Superconducting Cuprates

Setsuko Tajima, Takahiko Masui, Shigeki Miyasaka, Kiyohisa Tanaka, Ece Uykur and Hiroaki Tadatomo
Dept. of Physics, Osaka University

In many of the 3d transition metal oxides, strong interactions between electrons or electron-phonon or orbital are comparable in energy scale. This leads to the system to a variety of ordered states, giving various phase transitions or giant effects.

High T_c superconducting cuprates are in the same class of materials. However, there is a difference between them. What is peculiar to the cuprates is the coexistence of different ordered states instead of a clear phase transition. One example is the stripe ordered state, in which magnetic and charge orders are coexisting. The charge stripes in the cuprates are partially filled and conductive, while the stripes in the nickelates and maganites are insulating. In the cuprates, superconductivity can coexist with the stripe order.

Although a clear stripe order is observed only in limited compositions of the cuprates, there are many experimental results suggesting the ubiquitous coexistence of metallic (superconducting) state and ordered state, such as the checkerboard pattern in STM and the ARPES data for superconducting gap in the pseudo-gapped state. The former is the evidence in real space, while the latter in the k-space.

In my presentation, unusual optical conductivity, Raman responses and inelastic X-ray scattering are reconsidered from the viewpoint of coexistence of competing orders.

INVITED

Time resolved photoemission and time resolved THz of highly correlated materials

Luca Perfetti
Laboratoire des Solides Irradies, Ecole Polytechnique, 91128 Palaiseau Cedex, France

Albeit most of the experiments are performed in equilibrium conditions, new horizons of condensed matter physics can be explored when a strong perturbation drives the system into a highly exited state. After the absorption of an ultrashort laser pulse, the interatomic forces that bind the atoms can be substantially altered, leading to the propagation of lattice waves or to sudden structural changes. Since the pathway to non equilibrium states evolves on the femtosecond timescale, any experimental observation of the nuclei and electrons motion is especially challenging. In our approach, an intense and ultrashort laser pulse perturbs the system, while a probe pulse detects the material response after a variable time delay. Such technique is suitable for the investigation of ultrafast insulator-metal transitions in Mott insulators, the coherent lattice motion in charge density wave materials, and the electron-phonon coupling in high temperature superconductors. We will show that time resolved techniques provide novel information on many-body interactions that would not be accessible by standard means.

CONTRIBUTED

Band-like motion and mobility saturation in organic molecular semiconductors

Sergio Ciuchi[1] and Simone Fratini[2]
(1) Dipartimento di Fisica Università dell'Aquila & Istituto dei Sistemi Complessi-CNR, via Vetoio, I-67010 Coppito-L'Aquila, Italy
(2) Institut Néel - CNRS & Université Joseph Fourier BP 166, F-38042 Grenoble Cedex 9, France

We analyze a model that accounts for the inherently large thermal lattice fluctuations associated to the weak van der Waals inter molecular bonding in crystalline organic semiconductors.

In these materials the charge mobility generally exhibits a "metallic-like" power-law behavior, with no sign of thermally activated hopping characteristic of carrier self-localization, despite apparent mean-free-paths comparable or lower than the inter-molecular spacing. A comparative analysis of the spectral and transport properties [1] show that such puzzling transport regime can be understood from the simultaneous presence of band carriers and incoherent states that are dynamically localized by the thermal lattice disorder.

[1] S. Fratini and S. Ciuchi Phys. Rev. Lett. **103**, 266601 (2009)

CONTRIBUTED

Time-Resolved Far-IR Magnetospectroscopy of Photoexcited Carriers and Excitons in GaAs

S.N. Gilbert[1] and G.L. Carr[2]
(1) Department of Physics and Astronomy, Vanderbilt University
(2) National Synchrotron Light Source, Brookhaven National Laboratory

We have used far-IR time-resolved spectroscopy to study the relaxation of photogenerated free carriers and excitons in bulk GaAs at low temperatures. Picosecond near-IR pulses at a 53 MHz rate from a Ti:sapphire oscillator create free electrons and holes that can form into excitons. At temperatures below 10K, the exciton lifetime exceeds the 19 ns between laser pulses such that a large quasistatic exciton population can develop. Our time-resolved photo-induced spectra at T=5K show free carrier absorption from the photoelectrons, plus a bleaching feature associated with exciton dissociation. The exciton bleach lags the free carrier absorption by a short (~100 ps) amount of time, suggesting that the background population of excitons is playing a role in the relaxation of the hot photoelectrons (and photoholes) toward their respective band edges. An applied magnetic field gives rise to additional features (e.g., free electron cyclotron resonance and Zeeman splitting of the exciton), plus the opportunity to study the relaxation dynamics under conditions of quantized Landau levels.

S.N.G gratefully acknowledges support from NSF. J.J. Tu (City College of CUNY) provided access to the high-field magnet. The NSLS is operated for the U.S. Dep't. of Energy under contract DE-AC02-98CH10886.

CONTRIBUTED

Optically induced non thermal phase transition in the A7 metals.

Paul H.M. van Loosdrecht[1] and Daniele Fausti[2]
(1) Zernike Institute for Advanced Materials, University of Groningen, Groningen, The Netherlands
(2) Max Plank Research Group for Structural dynam- ics, CFEL, Hamburg, Germany.

Due to the strong electron-phonon coupling the A7 elemental metals like antimony and bismuth do not have the more usual cubic structure, but rather a distorted R-3m rhombohedral structure. It has been anticipated that by optical excitation one should be able to induce a phase transition from this Jones-Peierls distorted structure into a simple cubic one. Using picosecond time resolved Raman scattering we show that one can indeed optically induce a non thermal phase transition. Suprisingly, however, the induced transition is not into the higher symmetry cubic structure, but rather into a lower symmetry phase. A second surprise is that this transition occurs on an ultrafast time scale, making this one of the few examples of an ultrafast symmetry lowering transition.

CONTRIBUTED

Quasiparticle recombination in a type II superconductor

D.B. Tanner[1], Xiaoxiang Xi[1], C. Martin[1], D.H. Reitze[1], C.J. Stanton[1], J. Hwang[2], H. Zhang[3] and G.L. Carr[4]

(1) Department of Physics, University of Florida
(2) Department of Physics, Pusan National University
(3) Department of Physics, SUNY Buffalo
(4) NSLS, Brookhaven National Laboratory

When nonequilibrium quasiparticles are generated in a BCS superconductor, such as by breaking Cooper pairs with an external excitation, they will relax to the gap edge and recombine with partners of opposite spin, releasing energy mainly as phonons. The relaxation of excess quasiparticles is known to depend on quantities such as the quasiparticle phonon density of states, and their coupling [Kaplan et al, Phys. Rev. B **14**, 4854, (1976)]. An applied magnetic field can disrupt superconductivity, as evidenced by a reduced T_C. In our pump-probe experiments on NbTiN, a type II superconductor, a linear relation is found between the photoinduced transmission signal $S(t)$ and a time-dependent effective recombination rate $1/\tau = -[dS/dt]/S$ at high pump laser fluence, consistent with a bimolecular recombination. When a magnetic field is applied parallel to the sample surface, this rate shows a strong field dependence. We will propose a model for the recombination process and stress the magnetic field induced pair breaking, which depresses the energy gap and consequently influences the recombination process.

Supported by the U.S. Department of Energy under contracts DE-FG02-02ER45984 at the University of Florida and DE-AC02-98CH10886 at the NSLS.

INVITED

Coherent and Continuous Terahertz Emission from High-Tc Superconductor Intrinsic Josephson Junctions: the Synchronization Mechanism

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Since the discovery of a novel phenomenon that considerable power of electromagnetic waves at a terahertz frequency region was detected from a mesa structure fabricated from a piece of high temperature superconductor $Bi_2Sr_2CaCu_2O_{8+\delta}$ single crystal, intensive study on the radiation mechanism has been carried out. Accumulating experimental data on the radiation spectra, the spatial distribution, the higher harmonics, the poralization effect of the emission, etc. two effects are recognized to be needed for the emission of radiation: the ac-Josephson effect, which generates superconducting current oscillation in proportion to the applied dc-voltage following the equation $h\nu = 2eV/N$, where h is the Planck constant, ν the frequency of ac supercurrent, e the elementary charge of an electron, V the voltage appearing between two electrodes of the mesa, and N stands for the number of the intrinsic Josephson junctions involved in the mesa. The other important fact is that the frequency of the terahertz emission is determined by the narrower width of the rectangular mesa irrespective of the size of the longer side. This simple relation indicates that the mesa is working as a resonant cavity, followed by an equation $\nu = c_0/2nw = c_0/n\lambda$, where c_0 is the light velocity in vacuum, n is the refractive index of the superconductor, w the narrower width of the rectangular mesa and λ the wave length. When the mesa is not the rectangular, but square, even a circular shape, the similar resonance condition can be found. After analyzing the anisotropic emission data done in various mesas with different sizes and shapes, we finally found the standing electromagnetic modes excited inside the mesa, which can be explained by the two radiation source model developed by us. The stimulated emission of radiation from the coupled intrinsic Josephson junctions will be discussed as a source of the coherent terahertz electromagnetic wave emission.

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CONTRIBUTED

Photo-induced Superconductivity in Charge Ordered La1.8-xEu0.2SrxCuO4

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By using strong-field, femtosecond optical pulses in the mid infrared (17-956;m wavelength), we excite large amplitude Cu-O vibrations in the low temperature phase of striped La1.8-xEr0.2SrxCuO4 (LESCO 1/8). The striped phase is in this way de-stabilized, resulting in the ultrafast formation of a transient state that exhibits quantum coherence, as revealed by the appearance of a Josephson Plasma Resonance in the transient c-axis optical reflectivity. The photo-induced JPR is at the same 1.8 THz observed in optimally doped LSCO. This photo-induced state can only be achieved if excitation is performed in the plane of the stripes. It is quite likely that this phase is a superconductor, formed in less than 2 ps by condensation of low temperature quasi-particles.

INVITED

The impact of the local environment on the Kondo screening of a high-spin atom

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Kondo screening is a many-body phenomenon arising from the interaction between a localized magnetic moment and the conduction electrons in a metal. Spin 1/2 Kondo systems have been investigated extensively in theory and experiments. However the magnetic atoms that give rise to the Kondo effect in metals often have a larger spin, which makes the properties of the system more complex. Using a low-temperature scanning tunneling microscope, we explore the Kondo effect of individual high-spin magnetic atoms on surfaces. Using a combination of elastic and inelastic tunneling spectroscopy, we determine the spin of the atom and explore its impact on the Kondo resonance. We demonstrate that the local magnetic anisotropy plays a decisive role in the physics of Kondo screening. In addition, we can tune the Kondo resonance through other parameters, such as coupling to a neighboring unscreened spin and a magnetic field.

INVITED

Bose–Einstein Condensation of Elementary Excitations in Solids

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Dimerised quantum magnets are systems perfectly suited to the study of Bose–Hubbard–type models with well–defined dimensionality and tunable particle density, hopping and interactions. In arrays of coupled dimers, a quantum critical point (QCP) occurs at a magnetic field H_c, where the spin gap between singlet ($S = 0$) and excited triplet states ($S = 1$) is closed by the Zeeman effect. At this generic QCP, the ground state changes from being non–magnetic and quantum–disordered to a magnetic phase with long–range order and a coherent superposition of singlets and triplets on each dimer. This latter phase is best described as a Bose–Einstein condensate (BEC) of the elementary dimer excitations [1]. That quasi–particles – the triplet bosons in spin–dimerised materials (triplons) and excitations in other systems (magnons, exciton polaritons) – can form a BEC is an idea that is gaining considerable momentum in solid–state physics. These systems are competitive alternatives with many available probes and a surprising level of control to research on gases of ultracold atoms. I will review recent developments in the field, presenting the *classic* BEC, but also Mott insulating and spin Luttinger-liquid phases [1].

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CONTRIBUTED

High Field NMR Quantum Antiferromagnets: Wigner crystallization versus Bose-Einstein Condensation.

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Numerous systems of coupled dimers of spin 1/2 have a collective singlet ground state separated by a gap from the first excited triplet band. Applying a external magnetic field closes the gap and the triplets introduced in the system can be described as interacting hard core bosons on a lattice, in which the magnetic field plays the role of the chemical potential. In the absence of frustration, the field induced magnetic phase turns out to be a Bose Einstein Condensate [1,2]. However, in presence of strong frustration, the kinetic energy of the bosons which favors the condensation is strongly reduced, although it barely affects the repulsion, thus leading to the crystallization of the magnetic excitations when the boson density is commensurate with the lattice. This corresponds to plateaus in the magnetization curves, appearing at fractional values of the saturation magnetization. The most famous example is $SrCu_2(BO_3)_2$, in which dimers are arranged on a 2D frustrated Shastry-Sutherland lattice [3]. Recent NMR experiment have revealed between 27 and 34 T the existence of four plateaus at 1/8, 2/15, 1/6 and 1/4 of the saturation magnetization , that we shall discussed in details [4,5,6]. We shall also discuss the microscopic picture of the Bose Einstein Condensation in the so called Han Purple compound $BaCuSi_2O_6$ [7,8], in which two different gaps are present every second layer. This, added to frustration between adjacent layers, gives rise in half of the dimer layers to a new quantum magnetic state, with a finite concentration of uncondensed bosons at $T \simeq 0$ [9].

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INVITED

Where Are the Extra d Electrons in Transition-Metal Substituted Fe Pnictides?

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Transition-metal and other substitutions in Fe pnictides affecting superconductivity is usually interpreted in terms of carrier doping to the system. We have recently used density functional calculations of the local substitute electron density and demonstrate that substitutions like Co and Ni for Fe do not carrier dope but rather are isovalent to Fe. We find that the extra d electrons for Co,Ni,Cu,Zn and now extended to Rh and Pd are almost totally located within the muffin-tin sphere of the substituted site. We suggest that Co,Ni, Rh,Pd act more like random scatterers scrambling momentum space and washing out (parts) of the Fermi surface. In this talk we also discuss experimental evidence for momentum space scrambling concentrating on photoemission and quantum oscillations as well as the effects this can have on other spectroscopies. We provide theoretical evidence for the size of the impurity scattering for various types of impurities and discuss the possible relation to the phase diagram of the Pnictide superconductors.

INVITED

Band and momentum dependence of the electronic properties in Co-doped Ba122

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Results from electronic Raman scattering experiments on differently doped $Ba(Fe_{1-x}Co_x)_2As_2$ (Ba122:Co) single crystals will be presented. The data reveal details of the electronic properties in the normal and in the superconducting states. We show that Raman scattering is capable of projecting out the hole and the electron bands separately by using different polarizations of the incident and scattered photons. The experiments indicate a strong band and momentum anisotropy of the electron dynamics above and below the superconducting transition highlighting the importance of complex band-dependent interactions. The presence of low energy spectral weight deep in the superconducting state suggests a gap with accidental nodes which may be lifted by doping and/or impurity scattering. Both, the normal state relaxation and the superconducting gap vary substantially with doping x. In Ba122:Co we do not find evidence of true gap nodes at any x. The synopsis of the existing experimental data suggests that the properties of the iron-based superconductors, in contrast to the cuprates, depend substantially on the material class indicating a subtle interplay of doping, structure and Fermi surface effects.

INVITED

Phase-sensitive spectroscopic-imaging STM studies of unconventional superconductors

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Spectroscopic-imaging STM (SI-STM) is a powerful spectroscopic tool because it can explore not only real space but also momentum space through the Fourier transformation of interference patterns generated by the quasi-particle scatterings. Indeed, SI-STM has elucidated various aspects of electronic states of high-T_c cuprate superconductors. We show that SI-STM is also capable of obtaining information on the phase of superconducting gap function. Quasi-particle interference in the superconducting state is governed by the coherence factor of scattering process which contains information of the phase. Although the effect of coherence factor is hidden in real samples because there are many unknown scatterers, it will be highlighted in the magnetic field because superconducting vortices work as controllable scatterers. We show that the sign alternation in the d-wave gap of a cuprate is detected by this technique and will discuss the gap structure of iron-based superconductors.

CONTRIBUTED

Optical Investigation of the Charge Dynamics in $\mathbf{Ba(Co_xFe_{1-x})_2As_2}$

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We report on a thorough optical investigation of Co-doped $BaFe_2As_2$ over a broad spectral range (from the far infrared up to the ultra-violet) and as a function of temperature. An optical experiment measures the dynamical response of the electron and facilitates monitoring of many-body effects experienced by the electron in the material. For x=0 we observe a depletion in the far infrared energy interval of the optical conductivity below the spin-density-wave (SDW) phase transition at T_{SDW}=135 K, ascribed to the formation of a pseudogap-like feature. This is accompanied by the narrowing of the Drude term, consistent with the dc transport results and suggestive of a suppression of scattering channels in the SDW state, as well as by an important reshuffling of spectral weight over a broad energy interval. We will also present novel optical data for various Co-dopings in the spectral ranges of relevance for the pseudogap excitation as well as the superconducting gap. We will address their evolution when mapping the phase diagram of $Ba(Co_xFe_{1-x})_2As_2$ and discuss the optical fingerprints due to the interplay between structural/magnetic and superconducting phase transitions.

INVITED

Loss of coherent Quasi-Particles in under doped cuprates: an electronic Raman scattering study

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Conventional superconductors described by the Bardeen-Cooper-Schrieffer theory are characterized by a single energy scale, the superconducting gap, also proportional to the critical temperature Tc below which superconductivity appears. In the hole-doped high-Tc copper oxide superconductors, previous experimental works have established the existence of two distinct energy scales for doping levels below the optimal one. The origin and the significance of these two energy scales are largely unexplained, however. Here we show that these two energy scales result from the fact that coherent Bogoliubov quasiparticles exist only over a restricted region of momentum-space, in contrast to conventional superconductors in which superconductivity develops uniformly along the normal-state Fermi surface. We have conducted electronic Raman scattering experiments on Bi-2212 and Hg-1201 compounds for several temperatures and doping below and above Tc. These experiments reveal that the spectroscopic peaks associated with both energy scales disappear at Tc, hence establishing that they are coherence peaks associated with excitations of the superconducting state. We show that our data can be simply explained by a d-wave superconducting state with coherent pair-breaking excitations restricted to a momentum-space region centered around the nodal points. This analysis is shown to reconcile a number of spectroscopic data obtained by Raman scattering angular resolved photoemission and scanning tunneling microscopy , as well as specific heat and thermal conductivity measurements. These results have bearing on the fundamental problem of how superconductivity emerges as holes are doped into a Mott insulating state.

CONTRIBUTED

Lattice Bosons And Underdoped Cuprates

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We describe electronic properties of cuprates in the underdoped regime using models of strongly interacting lattice bosons. These are motivated by experimental indication that holes are tightly paired below the pseudogap temperature. In the hard core limit, lattice bosons can be treated by analytical and numerical techniques developed for models of quantum magnetism.

We find[1] that for quasi-two dimensional systems, the temperature dependent order parameter is characterized by a 'trapezoidal' shape.The theoretical curves compare favorably (more than the BCS expressions) to c-axis superfluid density data, and the transverse nodal velocity measured in ARPES.

The AC conductivity[2], temperature dependent resistivity[2], vortex dynamics and Hall effect[3], are calculated for a two dimensional model of hard core bosons. We have employed non perturbative tools such as continued fractions, series expansions and exact diagonalization. We find a large temperature range with linearly increasing resistivity and broad dynamical conductivity, signaling a breakdown of Boltzmann-Drude quasiparticle transport theory. At zero temperature, a high frequency peak in the dynamical conductivity appears above a "Higgs mass" gap, and corresponds to order parameter magnitude fluctuations. We discuss the apparent similarity between conductivity of hard core bosons and phenomenological characteristics of cuprates, including the universal scaling of Homes et. al. (Nature 430, 539 (2004)).

The vortex effective mass at half filling is found to be as light as a boson. The Hall conductivity computed using Chern numbers, reverses its sign abruptly as a function of filling. Also at half filling, an SU(2) point group symmetry of the gauged torus, endows each vortex with spin half quantum number (v-spin). V-spins, which are associated with charge density waves in the vortex cores.

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CONTRIBUTED

Optical determination of the relation between the electron-boson coupling function and the critical temperature in high T_c cuprates.

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Ever since the discovery of high temperature superconductivity the issue whether or not the pairing is either mediated by a bosonic glue or by a radically different mechanism, and the nature of a glue if it exists, have been highly debated. If the 'glue picture' is applicable, infrared optical spectroscopy can be used to measure the spectrum describing the bosonic glue and its coupling to electrons, $\alpha^2F(\omega)$. From optical spectra of Bi-2201, Bi-2212, Bi-2223, and Hg-1201 at various doping levels we observe that the two main components of $\alpha^2F(\omega)$ are (i) a peak at 50 meV and a broad temperature and doping dependent background. The 50 meV peak is most likely due to vibrational modes, in view of the fact that this feature is practically independent of doping, temperature and stoichiometry. The background, which extends up to approximately 0.3 eV for optimally doped compounds, is found to depend strongly on doping and temperature. The two observations, (i) that $\alpha^2F(\omega)$ is temperature dependent and (ii) that the corresponding coupling constant is huge ($\sim$ 3-4), together indicate that the strong coupling formalism probably needs to be revised or extended. This is confirmed by the observation that the temperature dependence of the optical spectra predicted by the strong coupling formalism shows significant deviations from experiments for underdoped compounds, where the temperature dependence of $\alpha^2F(\omega)$ and coupling constants are largest. By estimating the contribution to T_c of the different components of our glue spectra, we show that phonons alone cannot explain the phenomenon of high T_c superconductivity: the major contribution comes from excitations with an energy scale larger than 100 meV.

CONTRIBUTED

Loss of nodal quasiparticle integrity in underdoped $YBa_2Cu_3O_{6+x}$

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Arguably the most intriguing aspect of the physics of layered cuprates is the close proximity between the record high-T_c superconductivity (HTSC) and the antiferromagnetic charge-transfer insulating state driven by Mott-like electron correlations. The latter are responsible for the intimate connection between high and low-energy scale physics [1], and their key role in the mechanism of HTSC was conjectured very early on [2]. More recently, the detection of quantum oscillations in high-magnetic field experiments on $YBa_2Cu_3O_{6+x}$ (YBCO) has suggested the existence of a Fermi surface of well-defined quasiparticles in underdoped cuprates [3,4], lending support to the alternative proposal that HTSC might emerge from a Fermi liquid across the whole cuprate phase diagram [5,6]. Discriminating between these orthogonal scenarios hinges on the quantitative determination of the elusive quasiparticle weight Z, over a wide range of hole doping p. By means of angle-resolved photoemission spectroscopy on in-situ doped YBCO [7], and following the evolution of bilayer band-splitting, we show that the overdoped metal electronic structure (0.25p0.37) is in remarkable agreement with density functional theory and the $Z = 2p/(p+1)$ mean-field prediction [8,9]. Below p0.10 − 0.15, we observe the vanishing of the nodal quasiparticle weight Z_N; this marks a clear-cut departure from Fermi liquid and a more rapid crossover to the Mott physics than expected for the doped resonating valence bond spin liquid [8,9].

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INVITED

Evidence for extended magnetic interactions in the cuprates from the magnon dispersion of $Sr_2CuO_2Cl_2$

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$Sr_2CuO_2Cl_2$ (SCOC) is an insulating parent compound of the high-T_c cuprates, and an almost ideal realization of a spin-1/2 2D antiferromagnetic Heisenberg insulator. We exploited high-resolution resonant inelastic x-ray scattering (RIXS) at the Cu L_3 edge (2p to 3d; 930 eV) to map for the first time the dispersion of magnetic excitations over the whole magnetic Brillouin zone. We find a large (∼60 meV) difference between the magnon energies at the (π,0) and (π/2, π/2) points. This observation is incompatible with magnetic interactions involving only nearest-neighbor Cu spins. The data are on the other hand well reproduced by an extended t-t'-t"-U single-band Hubbard model, which generates various 2- and 4-spin interactions. Together with neutron data on La_2CuO_4 (LCO; R. Coldea et al. Phys. Rev. Lett. 86, 5377 (2001)) our RIXS results suggest that extended magnetic interactions are a general feature of the insulating cuprates, and set new constraints on theoretical models of these materials.

CONTRIBUTED

First direct observation of the Van Hove singularity in the tunneling spectra of cuprates

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In quasi-two dimensional compounds such as Bi-based cuprates, the normal state band structure displays a van-Hove singularity (VHS). In 1961, Harrison claimed that this should not been seen in a planar tunnel junction [1]. More recently, a great debate has occurred over the longstanding question of whether it is possible to see this singularity in tunneling spectra.

We have performed a detailed scanning tunneling spectroscopy study of the pure $Bi_2Sr_2CuO_{6+\delta}$ (Bi-2201) compound. In macroscopically non-superconducting strongly-overdoped samples, we unambiguously observe the VHS with no sign of the superconducting gap. This singularity is localized near the Fermi level. As one moves to lower doping levels and enters the superconducting dome, the VHS gradually moves to negative energies, while a superconducting gap opens. We show how this behavior can be understood and its relation with what has been observed in other Bi-based cuprates.

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INVITED

Ultrafast electronic and structural dynamics in high temperature superconductors

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I will present time resolved measurements of electronic and structural dynamics in high temperature superconductors. In these experiments, an excited state is created by shining an ultrashort laser pulse on to the sample and the temporal evolution of the system is recorded as it relaxes back to the ground state. In order to probe the electronic excitations, we measure the photo-induced reflectivity change of a second laser pulse delayed in time with respect to the excitation pulse. Measuring this transient reflectivity change at different delay times yields the temporal evolution of the electronic excitations. We have used this technique to study quasiparticle recombination in pnictide superconductors. We found that quasiparticles relax through bimolecular kinetics and the thermal equilibrium recombination rate increases quadratically with temperature. The technique described above can successfully be applied to many other systems to study electronic excitations but can not directly couple to the structural degree of freedom. In order to directly probe structural dynamics, we use ultrafast electron diffraction (UED). In UED, the probing is done by using high energy electron packets generated from the laser pulse via photoelectric effect. Recording the diffraction pattern of these electron packets at different times after the photo-excitation of the sample provides a movie of the laser induced structural change with sub-picosecond temporal and sub-Angstrom spatial resolution. We have used UED to observe lattice dynamics in response to photo-excitation of the charge carriers in cuprate superconductors. Above certain threshold laser intensity, we find direct conversion between two structures with different c axis lattice constants indicating a non-equilibrium structural phase transition.

CONTRIBUTED

The symmetry and strength of the electron-phonon coupling in cuprates single crystals by Ultrafast Electron Crystallography.

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The phonon-mediated attractive interaction between carriers leads to the Cooper pair formation in conventional superconductors. Despite decades of research, the glue holding Cooper pairs in high-temperature superconducting cuprates is still controversial, and the same is true as for the relative involvement of structural and electronic degrees of freedom. Ultrafast electron crystallography (UEC) offers, through observation of spatio-temporally resolved diffraction, the means for determining structural dynamics and the possible role of electron-lattice interaction. A polarized femtosecond (fs) laser pulse excites the charge carriers, which relax through electron-electron and electron-phonon coupling, and the consequential structural distortion is followed diffracting fs electron pulses. In this talk, the recent findings obtained on single crystal samples are summarized. In particular, we discuss the strength and symmetry of the directional electron-phonon coupling in BSCCO, and the theoretical implications of these results are discussed with focus on the possibility of charge stripes being significant in accounting for the observed polarization anisotropy. We show that while the average electron-phonon coupling at optimal doping is rather weak, consistent with literature reports, selected atomic motions can be coupled much stronger to polarized excitations. The coupling to the out-of plane motions of oxygen ions is also found to gain strength and exhibit a dramatic temperature dependence at lower doping. The characteristic time for electron-phonon scattering is obtained for these particular modes, and is found to be comparable to the time-scale associated to the magnetic exchange energy J.

CONTRIBUTED

Ultrafast dynamics of the interband spectral weight in superconducting cuprates

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The way the spectral weight of the interband transitions is modified in the pseudogap and superconducting phases is one of the most intriguing problems of high-temperature superconductivity (HTSC) [1]. The investigation of this physics is mandatory to discriminate between a kinetic-energy driven superconductivity [2] and a BCS-like scenario and to assess the role of the high-energy excitations in the superconducting phase transition. Standard spectroscopic ellipsometry evidenced in Bi2212 an anomalous transfer of the spectral weight associated to interband transitions ($h\nu$>1.2 eV), at energy scales larger than what would be expected for a BCS-like transition [3,4]. However, a univocal interpretation of the experimental evidences has not been achieved, due to the temperature-dependence of the cutoff necessary to analyze optical data [5].

A different approach is based on the investigation of the non-equilibrium dynamics in HTSC. A femtosecond laser pulse can be used to inject excitations, removing spectral weight from the condensate [6], while a delayed pulse probes the dynamics of the optical properties [7]. In this work we report on a novel time-resolved technique [8] with both time- and frequency-resolution over a broad spectral range ($1.2<h\nu<2$ eV). We show, for the first time, that the impulsive quenching of the condensate spectral weight induces deep modifications in the interband energy region, well beyond a simple quasi-thermal broadening of the intraband peak. In particular, in under- and optimally-doped $Bi_2Sr_2Ca_{0.92}Y_{0.08}Cu_2O_{8+\delta}$ crystals an impulsive decrease of the interband spectral weight is observed in the pseudogap phase (T<T*), as excitations are photoinjected in the system. Crossing T_C, the decrease of the condensate weight induces an increase of the interband spectral weight, associated to a sharp increase of the relaxation time. These evidences strongly suggest that the transition from the pseudogap to the superconducting phase is associated to a gain in kinetic energy, in contrast with BCS-like models. In overdoped samples no signal related to the pseudogap phase is measured, while an impulsive decrease of the interband spectral weight is evidenced, in agreement with a BCS-like scenario. Our results demonstrate that the high-energy scale of the interband transitions is intimately related to the low-energy physics of the pseudogap and superconducting phases.

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CONTRIBUTED

Electronic structure of heavy fermions near QCP probed by optical and photoemission spectroscopy

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Heavy fermion compounds have a drastic phase transition from the local to itinerant characters at a quantum critical point (QCP). In the fully itinerant and local phases, it is well-known that the $4f$ electronic structure can be explained by LDA and LDA+U band calculations, respectively [1, 2]. There is open question that which model is suitable for the electronic structure near QCP. Photoemission and optical conductivity spectroscopies are good probes for the $4f$ electronic structure. In order to investigate whether the $4f$ electronic structure near QCP can be explained by the itinerant band structure or not, we systematically measured the photoemission and optical conductivity spectra of $CeNi_{1-x}Co_xGe_2$ (x = 0–1, x = 0.3 is located at QCP.) [3, 4] and compared with corresponding spectra derived from the LDA band calculation. As a result, not only the electronic structures of $CeCoGe_2$ that is located in the itinerant phase but also that of $CeNiGe_2$ in the local phase near QCP can be explained by the LDA calculation. This result indicates that the main part of the $4f$ electronic structure even in the slightly local phase can be described by the itinerant band structure. We also present the comparison between the calculated and measured optical conductivity spectra of other Ce and Yb compounds for reference [5, 6].

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CONTRIBUTED

The de Haas-van Alphen effect near a quantum critical end point in $SR_3Ru_2O_7$

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Highly correlated electron materials are systems in which many new states of matter can emerge. A particular situation which favours the formation of exotic phases of the electron liquid in complex materials is that where a quantum critical point (QCP) is present the phase diagram. Neighbouring regions in parameter space reveal unusual physical properties, described as non-Fermi liquid behaviour. One remarkable example is the bilayer strontium ruthenate Sr3Ru2O7, in which the appearance of an anomalous phase has been observed featuring nematic-like electronic properties [1]. One of the important problems in quantum criticality is to find out how the Fermi surface (FS) of a material evolves near a QCP. We thus present a study of the FS of $SR_3Ru_2O_7$ using the de Haas van Alphen effect (dHvA). We have shown the existence of two dHvA frequencies inside of the anomalous phase [2]. Their variation as a function of magnetic field is explained in terms of a chemical potential shift produced by reaching a peak in the density of states. Moreover, quasiparticle mass measurements were performed in the vicinity of the anomalous phase. Contrary to conclusions previously drawn by some of us, none of the five FS branches give evidence of a field dependence of the the mass [3]. These results have important implications for the understanding of quantum criticality in $SR_3Ru_2O_7$.

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CONTRIBUTED

Drude response of slow and fast electrons in the heavy-fermion compound UNi_2Al_3

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The unusual metallic behavior of heavy-fermion compounds at low temperatures is caused by mobile charge carriers with a large effective mass. This mass enhancement (compared to normal electrons) goes hand in hand with a reduction of the transport scattering time, which can directly be studied with optical spectroscopy: the characteristic Drude roll-off moves to very low frequencies. Here we combine microwave and THz spectroscopy to study thin films of the heavy-fermion compound UNi_2Al_3 in a broad frequency range.

At frequencies of less than 1 cm^{-1}, a full Drude response indicates the dynamics of the heavy electrons in UNi_2Al_3. Surprisingly, at considerably higher frequencies (around 10 cm^{-1}) we observe a similar structure that is very reminiscent of Drude behavior. We interpret these two features as the Drude response of - at low frequencies - correlated, slow electrons and - at higher frequencies - uncorrelated, fast electrons. The temperature dependence and anisotropy of these two Drude roll-offs correspond to each other. These results also shed new light on previous studies of the related material UPd_2Al_3 [1,2] and of heavy-fermion compounds in general.

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CONTRIBUTED

Evidence for magnetically driven superconducting Q phase of $CeCoIn_5$

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We have studied the magnetic order inside the superconducting phase of $CeCoIn_5$ for fields along the [1 0 0] crystallographic direction using neutron diffraction. We find a spin-density wave order with an incommensurate modulation $\mathbf{Q} = (q, q, 1/2)$ and $q = 0.45(1)$, which within our experimental uncertainty is indistinguishable from the spin-density wave found for fields applied along [1 -1 0]. The magnetic order is thus modulated along the lines of nodes of the $d_{x^2-y^2}$ superconducting order parameter, suggesting that it is driven by the electron nesting along the superconducting line nodes. We postulate that the onset of magnetic order leads to reconstruction of the superconducting gap function and a magnetically-induced pair density wave.

CONTRIBUTED

Coherent broadband continuous-wave THz spectrometry: A powerful tool for low-energy solid-state spectroscopy

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We present the development of a continuous-wave THz spectrometer and its application to solid-state spectroscopy at low temperatures as well as high magnetic fields. This spectrometer is based on the principle of THz generation using frequency mixing of two near-infrared distributed feedback diode lasers with frequency stabilization. The laser beat is converted into THz radiation by a photomixer, which efficiently generates THz radiation from 60 GHz to 1.8 THz. The THz radiation is detected by a second photomixer via homodyne mixing of the THz signal and the laser beat. A phase modulation technique is used to accurately determine the amplitude and the phase at a given frequency. Also, a photocurrent correction is implemented to account for the drifts in the THz intensity using the dc photocurrents measured at the photomixers. The complex optical functions can then be evaluated from the full phase information of the THz beam, and a very high spectral resolution in the MHz range can be achieved. Furthermore, this compact spectrometer can be integrated within a magnetic cryostat eliminating the need for optical windows. In this way, investigations at high magnetic fields up to 16 T and low temperatures down to 2 K can be performed without loss of intensity. Thus, a new door is opened for exploring low-energy electronic excitations of novel materials, lying in the sub-phonon energy regime.

CONTRIBUTED

Morphology, Elastic Constants and Slow Dynamics of Superconducting Vortex Lattices Investigated with Time Resolved Stroboscopic Neutron Scattering.

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Superconducting vortex lattices (VL), glasses and liquids attract great interest not only as a source of microscopic information of the nature of the superconductivity but also as model systems of crystallization. The elastic matrix $\Phi_{\alpha\beta}$ of a VL describes the energy associated with a VL distortion due to thermal fluctuations, gradients of magnetic field or temperature, pinning and in the presence of transport currents. The elastic constants of the VL c_{11}, c_{44} and c_{66} hence reflect the microscopic nature of the superconductivity, the number and symmetry of superconducting gaps as well as impurity or surface properties due to pinning. The microscopic access to the intrinsic elastic constants of VLs however is strongly hampered by surface induced pinning effects in the commonly used thin film samples.

With its low Ginzburg-Landau parameter κ, situated at the border of type-I and type-II behaviour, the superconductivity in Nb is ideally suited as model system for systematic studies of vortex matter [1]. We report direct microscopic measurements of the VL tilt modulus c_{44} in bulk ultra-pure Nb without surface induced limitations using a time-resolved stroboscopic small angle neutron scattering technique [2] in combination with a tailored magnetic field setup. The observed relaxation process shows increasing VL stiffness with increasing magnetic field and reduced damping with increasing temperature. The behaviour agrees well with calculations performed within a VL diffusion model [3]. Besides this general trend, we observe a dramatic changeover of the relaxation process associated with the non-trivial VL morphology in the intermediate mixed state. Our study represents a show-case how to access directly VL melting, the formation of vortex glass states and slow vortex dynamics in unconventional superconductors, notably the cuprates, heavy-fermion systems, boro-carbide or ironarsenide systems.

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INVITED

Ultrabroadband Terahertz Analysis and Coherent Control of Oxidic Systems

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Based on ultrashort laser pulses in the sub-10-fs regime, ultrabroadband terahertz measurements give access to amplitude and phase of elementary excitations over almost the entire infrared frequency range and with a time resolution limited exclusively by the uncertainty principle. Very recently, the field amplitudes available from this technology have been extended far beyond 1 MV/cm, allowing for experiments under nonlinear terahertz pumping. The talk will present results concerning various aspects of low-energy dynamics and quantum correlations in oxidic materials: (i) A detailed lineshape analysis gives unprecedented insight into the dynamics of optical phonon modes and the superconducting condensate in $YBa_2Cu_3O_{7-\delta}$ after photogeneration of quasiparticles via femtosecond near-infrared excitation. (ii) Ultrafast exciton formation in Cu_2O is investigated and intra-excitonic transitions are controlled coherently. (iii) Using the magnetic field component of intense terahertz transients, coherent excitation and control of magnons in antiferromagnetic NiO is demonstrated.

INVITED

Infrared Nanoscopy of Complex Electronic Materials

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Numerous advances in scattering scanning near field infrared nanoscopy pioneered by Dr. Fritz Keilmann and his collaborators have facilitated a broader use of this technique across disciplines. A steadily growing number of experimental groups world-wide are now employing infrared nanoscopy to address and resolve long-standing problems in physics, chemistry and materials science. In this talk I will review recent progress in the infrared nanoscopy of correlated electron oxides, graphene and magnetic semiconductors. I will also touch upon instrumental innovations aimed at expanding the frequency range accessible through nanoscopy studies including the extension to the far infrared as well as experiments with widely tunable mid-infrared lasers.

CONTRIBUTED

Low-Energy Electrodynamics and Metal to Insulator Transitions in Strongly Correlated Materials

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The emergence of a metallic behavior from a correlated insulator represents a paradigm of modern Solid-State Physics. In correlated systems electronic delocalization is strongly reduced due to Coulomb repulsion so that the interplay among competing energy scales: spin, charge and lattice, might determine different states with exotic physical properties. Those properties span from thermal decoherence of quasi-particles, mesoscopic phase separations, to Metal-to-Insulator transitions and can be observed in several complex oxides like $(V_{1-x}Cr_x)_2O_3$ and cuprates. In this talk I will present a complete investigation of the low-energy electrodynamics of this system. Optical, Resistivity, Photoemission and Diffraction measurements have been performed in a wide range of temperature, pressure and doping, using synchrotron radiation and compared with theoretical results based on DMFT+LDA calculations. This study clarifies most of the intriguing properties of this material.

CONTRIBUTED

Metal-insulator transition in $NiS_{2-x}Se_x$

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The cubic pyrite $NiS_{2-x}Se_x$ is an important model system for studying the metal-insulator transition (MIT) due to electronic correlations, where the MIT can be controlled by varying the Se content x, temperature or external pressure [1]. In the Zaanen-Sawatzky-Allen scheme NiS_2 has been classified as a charge-transfer insulator, with the gap between the S-p band and the upper Hubbard band of Ni-d e_g character [2]. The MIT has been commonly attributed to the broadening of the Ni-d band.

With our new infrared spectroscopic studies on $NiS_{2-x}Se_x$ single crystals as a function of external pressure we investigated the response of the charge dynamics of $NiS_{2-x}Se_x$ regarding the application of pressure for various Se contents x. These studies also allowed a comparison of the effects of chemical pressure (i.e., Se content) and external pressure on the electronic properties of NiS_2. Combining our optical results with results of *ab initio* band structure calculations, obtained in the local-density approximation and the dynamical mean-field theory, we elucidate the mechanism of the MIT in $NiS_{2-x}Se_x$. According to our findings [3] the most important aspect for the MIT in NiS_2 is the bonding-antibonding splitting between the p_σ - and p_σ^*-bands of the S-S dimer, which result from the strong hybridization between the S-p orbitals pointing along the S-S dimer.

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CONTRIBUTED

Pressure tuning of an ionic insulator into a heavy electron metal: An infrared study of YbS

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In the studies of strongly correlated electron systems, the application of an external pressure has been a powerful tool to induce novel physical properties. Recent examples include a pressure-induced superconductivity at 34 K in $SrFe_2As_2$ [1] and magnetic quantum criticality in Ce compounds [2]. A great advantage of the pressure technique is that it can cleanly tune the electronic structures by changing the interatomic distance, without introducing a lattice disorder unlike the case of chemical alloying. However, low-energy electrodynamics under high pressure has not been well explored, since spectroscopic studies on a sample confined in a pressure cell is technically challenging. In particular, a pressure study is practically impossible for photoemission and tunneling spectroscopies.

We have used infrared (IR) spectroscopy to study the electronic structures of YbS under pressure up to 20 GPa [3]. YbS, a divalent ($Yb^{2+}S^{2-}$) and ionic insulator at ambient pressure, had been known to become mixed-valent above 10 GPa [4], but its low-energy electronic structures had been unclear. High pressure was generated by a diamond anvil cell, and a synchrotron radiation at SPring-8 was used as a highly bright IR source. The obtained optical conductivity [$\sigma(\omega)$] has shown that the high pressure phase of YbS is a metal, associated with an enhanced carrier mass and a marked mid-IR peak in $\sigma(\omega)$. We show that the peculiar metallic state at high pressure results from a pressure-induced shift of Yb $4f$ level, which causes a strong hybridization between the $4f$ and conduction electrons.

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INVITED

Discovery of Topological Insulators and related Superconductors

M.Z. Hasan
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Topological insulators are a fundamentally new phase of quantum matter, which exhibits exotic quantum-Hall-like behavior even in the absence of an applied magnetic field due to strong spin-orbit interactions and time-reversal symmetry and unlike the quantum Hall liquids can be turned into superconductors [1]. In this talk, I will briefly review the realization of the topological insulator state in Bi-Sb, and then report our observation of a new generation of topological insulators with order-of-magnitude larger bulk band gaps and a single spin-helical surface Dirac cone and experimentally demonstrate all defining properties of topological insulators such as (1) Topological Spin-Textures, (2) Spin-momentum helical locking, (3) Non-trivial Berrys phases, (4) Absence of backscattering or no U-turn, (5) Protection by time-reversal symmetry, (6) Room temperature topological order, (7) Realization of superconductivity and quantum magnetism in doped topological insulators.

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CONTRIBUTED

Spin and angle resolved photoemission on model systems for spintronics

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Combining an angle-resolved photoelectron spectrometer equipped with a three-dimensional spin polarimeter[1] and a new two-step fitting routine[2] we can measure absolute spin polarization vectors for individual bands intersected in a particular set of ARPES data. This procedure is crucial when analyzing strongly overlapping peaks or weak signals sitting on a large unpolarized background, especially in the presence of non-collinear spins.
The method is applied to two-dimensional systems where Rashba-type spin-orbit effects lead to spin splittings and complex momentum-dependent spin structures[3]. In ultrathin Pb layers on Si(111) Rashba splittings of the order of 10 meV could be resolved by introducing the electron spin as an additional tag[4]. It is further shown how this spin splitting may be tuned through interface and substrate engineering, which could provide a prototype spin field-effect transistor. In the same system we show how hybridization effects can cause spin-flips, which in turn result in non-trivial spin topologies.
In order to create a spin-polarized current, it is typically assumed that magnetic materials are needed. However, here we will show that it is possible to create a current with up to 80% spin polarization by careful alignment of the Fermi level of a Rashba system[5]. This could provide an alternative pathway to create a tunable source of polarized electrons.
Further it will be shown how this powerful experimental technique can be applied to increasingly complex systems, such as quantum spin Hall phases and topological insulators[6,7] or a one-dimensional parent compound[8].

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CONTRIBUTED

Ferromagnetic spin resonance in $EuTiO_3$ probed by time-domain THz ellipsometry

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A time-domain study in the THz range on insulating $EuTiO_3$ has revealed the existence of a strong magnetic circular dichroism which manifests itself as a gigantic Faraday rotation of THz light up to 340 deg $mm^{-1}T^{-1}$. We have performed ellipsometric transmission measurements at 4.5 K in a magnetic field up to 1.6 T, from which we deduced the dielectric permittivity and the magnetic permeability for right and left handed circularly polarized light. Due to the spin-only character of $EuTiO_3$ the dichroism is present for *purely* magnetic dipole transitions inside the Zeeman split Eu 4f levels and shows up as a ferromagnetic spin resonance absorption for only one chirality. We present a spectral weight analysis for the spin resonance using a newly derived optical spin sum rule based on the Landau-Lifshitz-Gilbert theory.

INVITED

Magneto-optics of graphene structures

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The results of magneto-spectroscopy studies of different graphene structures will be presented. Band structure, scattering efficiency and effects of electron-phonon interactions in these systems will be discussed. Special attention will be focused on the properties of multilayer epitaxial graphene, which unique properties resemble very much those of a single graphene sheet [1-4]. The extraordinary quality of the graphene flakes on natural graphite substrate, which may lead to the appearance of Landau quantization even in magnetic fields of $\sim$ 1Gs, will be demonstrated [5]. Resonant coupling between phonons and inter Landau level excitations in different graphene systems, including bulk graphite, will be discussed from the viewpoint of magneto-Raman scattering studies [6].

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CONTRIBUTED

Gate-tunable bandgap and infrared phonon anomalies in bilayer graphene

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Applying external electric field to bilayer graphene has a remarkably strong effect on its electronic and vibrational properties, in part via electrostatic doping and in part due to a breaking of the interlayer symmetry. Using infrared microscopy, we studied two electric-field effects in bottom gated exfoliate bilayer graphene: (i) a gate-controlled opening of a gap between hole and electron bands, (ii) a giant variation of the optical intensity and a Fano-like asymmetry of an infrared phonon peak at 0.2 eV as a function of the gate voltage. The combined analysis of these phenomena allows us to extract detailed information about the electronic structure and electron-phonon interaction in this system.

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CONTRIBUTED

Effect of electron-phonon interaction on spectroscopies in graphene

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We calculate the effect of the electron-phonon interaction on the electronic density of states (DOS), the quasiparticle properties and on the optical conductivity of graphene.[1,2] In metals with DOS constant on the scale of phonon energies, the electron-phonon renormalizations drop out of the dressed DOS, however, due to the Dirac nature of the electron dynamics in graphene, the band DOS is linear in energy and phonon structures remain, which can be emphasized by taking an energy derivative. There is a shift in the chemical potential and in the position in energy of the Dirac point. Also, the DOS can be changed from a linear dependence out of value zero at the Dirac point to quadratic out of a finite value. The scattering rate $1/\tau$ sets the energy scale for the rise of the optical conductivity from its universal DC value $4e^2/\pi h$ (expected in the simplest theory when chemical potential and temperature are both $\ll 1/2\tau$) to its universal AC background value ($\sigma_0 = \pi e^2/2h$). As in ordinary metals the DC conductivity remains unrenormalized while its AC value is changed. The optical spectral weight under the intraband Drude is reduced by a mass renormalization factor as is the effective scattering rate. Optical weight is transferred to an Holstein phonon-assisted side band. Due to Pauli blocking the interband transitions are sharply suppressed, but also nearly constant, below twice the value of renormalized chemical potential and also exhibit a phonon-assisted contribution. The universal background conductivity is reduced below σ_0 at large energies.

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CONTRIBUTED

Nemetic Electronic Structure in the Parent State of the Iron-Based Superconductor Ca(Fe1-xCox)2As2

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The mechanism of high-temperature superconductivity in the newly discovered iron-based superconductors is unresolved. We use spectroscopic imaging STM to study the electronic structure of a representative compound CaFe1.94Co0.06As2 in the parent state from which this superconductivity emerges. Static unidirectional electronic nanostructures of dimension eight times the inter-iron atom distance aFeFe and aligned along the crystal aaxis, are observed. By contrast, the delocalized electronic states detectable by quasiparticle interference imaging are dispersive along the b axis only, and are consistent with a nematic alpha-2 band with an apparent q=2pi/8aFeFe folding along the a-axis. All these effects rotate through 90o at orthorhombic twin-boundaries indicating thatm they are bulk properties. Since none of these effects are expected due merely to the crystal symmetry, the underdoped ferropnictide parent state from which superconductivity emerges appears to be a more complex electronic nematic than originally expected. These new perceptions of its electronic structure should inform revised theories for the mechanism of the high temperature superconductivity.

INVITED

Specific heat of the cuprate superconductors at high magnetic fields.

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The nature of the magnetic-field-induced resistive state in the underdoped regime of the high temperature cuprate superconductors remains the subject of much debate. One view is that the magnetic field destroys the d-wave superconducting gap to uncover the Fermi surface of the competing state that behaves like a conventional (i.e. Fermi Liquid) metal. Another view is that an applied magnetic field destroys long range phase coherence but the superconducting gap amplitude survives. By measuring the specific heat of ultra-clean YBa2Cu3O6.55 up to 45T, we provide the first look at the evolution of the quasi-particle density of states through the resistive transition. At high magnetic fields the specific heat exhibits both the conventional temperature dependence and quantum oscillations expected for a Fermi Liquid. However, the quasi-particle density of states also increases as the square root of magnetic field right through the superconducting transition, evidencing a fully developed d-wave superconducting gap at least up to 45T and well into the fully resistive state where quantum oscillations are observed. This thermodynamic measurement imposes severe restrictions on both the interpretation of quantum oscillation data as well as theories of the underdoped resistive state of the cuprate superconductors.

This work results from a delightful collaboration among Scott Riggs, Oskar Vafek, Jon Kemper, Jon Betts, Albert Migliori, Walter Hardy, Ruixing Liang, and Doug Bonn

CONTRIBUTED

The phase diagram of precursor superconductivity as obtained from the infrared c-axis conductivity of $RBa_2Cu_3O_{7-\delta}$

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The anomalous normal state properties of the cuprate high temperature superconductors are the subject of an ongoing debate. Most controversial is the origin of the so-called pseudogap phenomenon which gives rise to a gradual depletion of the low-energy electronic states that sets in well above the superconducting transition temperature, T_c, in samples that are underdoped [1]. In this work, we present results from infrared spectroscopy probing the charge excitations and their coherency throughout the phase diagram, both below and above T_c.

We present a multilayer analysis of the infrared c-axis conductivity of $RBa_2Cu_3O_{7-\delta}$ single crystals which reveals important differences in the electronic conductivities between the pairs of closely and widely spaced CuO_2 planes, corresponding to the intra- and inter-bilayer regions. The intra-bilayer conductivity is weakly coherent and in the normal state, below a certain temperature, T^{on}, exhibits an increase of low frequency spectral weight with lowering temperature. The inter-bilayer response is dominated by an opposite trend, i.e., a gap-like suppression of the low energy electronic states below a temperature T^* that gives rise to an insulator-like behaviour and likely competes with superconductivity. We outline that these opposite normal state spectral weight shifts likely correspond to different electronic phenomena originating from different regions of the Fermi surface which are preferentially probed by the intra- and the inter-bilayer charge transports. We track the doping dependence of T^{on} and T^* from the spin glass phase to the optimal doping. We discuss our results in terms of a precursor superconducting state. Our infrared reflectivity measurements at high magnetic field up to 8 T bring additional support for this interpretation. They show that the phonon anomalies are susceptible to the magnetic field at temperatures up to T^{on}.

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CONTRIBUTED

High field and low temperature neutron diffraction studies of the triangular-lattice multiferroic $RbFe(MoO_4)_2$

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$RbFe(MoO_4)_2$ (RFMO) provides a rare example of an essentially two-dimensional Heisenberg XY antiferromagnet on a perfect triangular lattice. As the magnetism is dominated by the intraplanar, rather than interplanar, exchange, the low dimensionality and simple crystal structure mean that studies of RFMO provide important tests of the theory of magnetoelectric coupling.

For magnetic fields applied parallel to [1,-1,0], RFMO exhibits a rich magnetoeletric phase diagram [1]. At zero field, and for temperatures below T_N, the magnetic structure is characterized by an incommensurate propagation vector $\mathbf{Q}$=(1/3,1/3,q_z), and it is a structure that does not exhibit inversion symmetry. At T_N, the magnetic order is accompanied by the onset of ferroelectric polarization, thus demonstrating RFMO as multiferroic. Increasing the field to ∼5 T at 0.1 K leads to a discontinuous collapse of the multiferroicity, as the incommensurate magnetic structure is instead replaced by an inversion symmetric structure with a commensurate propagation vector $\mathbf{Q}$=(1/3,1/3,1/3). Finally, on further increase of the field, by ∼10 T at 0.1 K, another discontinuous transition marks the re-emergence of an incommensurate magnetic structure $\mathbf{Q}$=(1/3,1/3,q_z). However, interestingly in this high field phase, ferroelectricity is absent.

The absence of ferroelectricity in the high field incommensurate phase suggests that the magnetic structure will respect inversion symmetry. To test this prediction, we report neutron diffraction measurements of the magnetic structure in RFMO for fields up to 14.9 T, and at temperatures down to 0.1 K. We use representational analysis and symmetry-based phenomenological theory [2,3] in order to interpret our measurements.

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CONTRIBUTED

The magneto-electric coupling in multiferroic materials

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In multiferroic materials, the coupling between magnetism and electricity has two aspects: a static and a dynamic coupling. On the one hand, the static coupling is responsible for the existence of a spontaneous electric polarization intimately linked to the magnetic order. On the other hand, the dynamic magneto-dielectric coupling is responsible for the existence of the mixed dielectric-magnetic excitations termed electromagnons discovered in these materials.

One of the most intriguing enigma about multiferroics is the microscopic mechanisms which originate these couplings. At the present time, we do not know whether there is a direct coupling between magnetism and ferroelectricity or rather an interaction mediated by a third party. One approach is to consider that the strong correlations present in many of these materials can lead to a direct coupling between electronic spin and charge degrees of freedom. An alternative approach is to envision a coupling mechanism that involves a third party, such as the lattice, as mingling partner.

To address this question, infrared spectroscopy is an invaluable tool as it probes any dipole active excitations of the material, including the polar phonons which provide insight into the lattice dynamics and the electromagnons. In order to find the effects which are specific to multiferroics, we studied MnF_2 which is only antiferromagnetic and the multiferroics $TbMnO_3$ and $MnWO_4$. We analyse of the thermal evolution of the infrared phonons and their renormalizations across the antiferromagnetic and ferroelectric transitions and we compare them to the evolutions of the electromagnons. We show that the magnon-phonon coupling is almost undetectable in MnF_2 whereas it is conspicuous in $TbMnO_3$ as the whole spectral weight of the electromagnon comes from the phonons. $MnWO_4$ has a particular behavior where the lattice does not react to the magnetic transitions and an external magnetic field, hence it is a good candidate for a direct coupling between magnetic and dielectric orders.

CONTRIBUTED

Magnetic excitations and optical transitions in the multiferroic spin-$\frac{1}{2}$ system $LiCu_2O_2$

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A class of materials where multiferroicity can exist are spin cycloidal compounds. $LiCu_2O_2$ is known to be the first copper-based multiferroic material where spin cycliodal and polar orders develop simultanously and is also one of the very few spin-$\frac{1}{2}$ multiferroics. Coupled ferroelectric and magnetic orders in multiferroics can lead to strong mixing between phonons and magnons rendering some magnons electric dipole active. These electroactive magnons or electromagnons can give, due to their low resonance frequency, significant contribution to the static dielectric constant. We explore magnetic excitations in $LiCu_2O_2$ using THz absorption spectroscopy in magnetic fields up to 30 T. Below the cycloidal ordering temperature, T=24 K, eight optically active transitions are observed in the spin system of $LiCu_2O_2$ in the range from 4 to 30 cm^{-1}. In magnetic field the number of modes increases, some modes anticross and the electric polarization flop is seen as a change in magnetic field dependence of mode energies. The polarization dependence of two of the modes fits the selection rules for the spin cycloid tilted from the *bc* plane. For the remaining six modes electric and magnetic dipole approximations cannot explain the observed polarization dependence. The electromagnon is not directly seen in the explored energy range although there is evidence that it could exist below 4 cm^{-1}. Comparisons will be made to non-multiferroic isostructual spin cycloidal compound $NaCu_2O_2$.

CONTRIBUTED

Magnetoelectric coupling in split ring resonator metamaterials

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Split ring resonators represent essential elements in modern design of metamaterials. These elements can be seen as the smallest possible representation of the LC-circuit with only a single inductance loop as given by the metallic ring and a tiny capacitance produced by the gap in the ring. As has been realized recently, the split rings strongly modify the interactions with electromagnetic radiation by introducing a magnetoelectric term into the set of basic equations. This additional term in the material equations cross-couples the magnetic and electric fields within a metamaterial. Making the full analysis of the problem more complicated, the magnetoelectric susceptibility offers another degree of freedom in controlling the properties of light. As a characteristic example, magnetic resonances can be excited using the electric component of the electromagnetic wave. In order to measure the magnetoelectric coupling, specific experimental geometries should be utilized. We show that split ring resonator metamaterials reach the maximum theoretical value of the magnetoelectric susceptibility which is equal to the geometrical average of the magnetic and electric susceptibilities. This value appears to be about two orders of magnitude above the typical coupling constants for conventional magnetoelectrics like Cr_2O_3.

CONTRIBUTED

Electronic structure of charge carriers of $LaAlO_3/SrTiO_3$ heterostructure investigated by resonant inelastic x-ray scattering

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Oxide heterostructures have been attracting great attention due to extraordinary phenomena occurring at the interface and their potential application for device design employing oxide materials. A particularly fascinating system is the two-dimensional conducting interface between the band insulators $LaAlO_3$ (LAO) and $SrTiO_3$ (STO) which can be even driven to magnetic and superconducting phase at low temperature [1-5]. The electron transfer conduction mechanism was proposed to be due to polar discontinuity created between the polar LAO and non-polar STO. The increased electric potential thereby induces the system to reconstruct by moving half an electron from the surface into the interface, avoiding the polar catastrophe. However, systematic studies of carrier densities upon various oxygen deposition pressures have elucidated that oxygen vacancies (Vos) in STO are also a vital ingredient to the conduction mechanism [6-7]. As Vos normally bind to Ti ions and create Ti^{3+} state, unravelling the existence of multivalent Ti ions is a key issue for understanding the conduction mechanism.

We applied RIXS to investigate the electronic structure of LAO/STO interfaces not only since RIXS can efficiently probe low energy excitations (*dd* or *charge transfer* excitations), but especially, since the signature of conducting, Ti^{3+} states clearly display a strong *dd* excitation around 2 eV while Ti^{4+} states exhibit no excitations up to 4 eV [8]. Using Ti L-edge RIXS to study $[(LAO)_m/(STO)_{10}]_{10}$ superlattices prepared by Pulsed Laser Deposition, we found two types of carriers, namely, localized states and delocalized bands around Ti ions. The dual character of these carriers is even preserved after annealing under O_2 atmosphere and high temperature. Investigations on various thicknesses of LAO, *i.e.*, variation of m, showed that Vo-contributed carriers increase for larger m but saturate at a certain value. For higher m, electron transfer conduction mechanism begins to set in and compensate the electric potential, keeping the whole system well in balance.

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CONTRIBUTED

Dimensional Crossovers and Metal-Insulator Transitions in Manganite Superlattices ($[LaMnO_3]_n$ / $[SrMnO_3]_{2n}$) and $La_{1-x}Sr_xMnO_3$ as studied by *in situ* MBE-ARPES

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High-resolution angle-resolved photoemission spectroscopy (ARPES) has played a pivotal role in our understanding of the high-Tc cuprates and other layered materials. However, a wide range of correlated systems has remained largely beyond the reach of high-resolution ARPES, including three-dimensional structures and artificially synthesized oxide superlattices or interfaces.

I will present new high-resolution ARPES studies of these once-inaccessible systems which have been made possible by a powerful new tool : an integrated state-of-the-art oxide molecular beam epitaxy growth chamber with an *in situ* high-resolution ARPES system. These include the first ARPES studies of the ferromagnetic metal-insulator transition in $Eu_{1-x}Gd_xO$ and the first measurements of quasiparticle renormalization and Fermi surface of the ruthenate 4d ferromagnet $SrRuO_3$.

I will primarily focus on the pseudocubic perovskite colossal magnetoresistive manganite $La_{1-x}Sr_xMnO_3$ as an example. The first detailed ARPES measurements of the full Fermi surface topology of this well-studied compound will be presented along with studies of the quasiparticle renormalization and comparisons to first-principles calculations. In addition to the alloyed compound $La_{1-x}Sr_xMnO_3$, manganite superlattices of ($[LaMnO_3]_n$ / $[SrMnO_3]_{2n}$) have also been studied by ARPES and show progressive transitions as a function of superlattice thickness n : from three-dimensional bulk-like behavior, to quasi-two-dimensional metallic interfaces, finally to localized insulating behavior.

CONTRIBUTED

Infrared synchrotron-radiation studies of the charge order in manganites at normal and high pressure

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Mixed-valence manganites with general formula $L_{1-x}A_xMnO_3$, where L is a lanthanoid and A a divalent ion, show commensurate charge order (CO) for suitable values of $0.5 \leq x \leq 0.85$ and for temperatures below a remarkably high temperature T_{CO}. The traditional picture of these phases in terms of polaronic arrays has been recently questioned on the basis of new experiments which exclude strong localization. These results suggest that the CO phase can be described in terms of the charge density waves (CDW) model, which predicts weak electron-phonon coupling . We have explored the optical conductivity of several manganites in the sub-THz range and in the infrared by using coherent (at BESSY-II) and incoherent (at SPRING-8) synchrotron sources, respectively.

At normal pressure in the sub-THz range we found sharp peaks which disappear above TCO, similar to those reported for one-dimensional CDWs. These spectral features have been assigned to collective modes of the CDW condensate [1]. The parameters extracted from the spectra, like the electron-phonon coupling, are consistent with a description of the charge order in La-Ca manganites in terms of CDW.

Under pressure, we measured in a diamond anvil cell the reflectivity of a single crystal of $Nd_{0.5}Sr_{0.5}MnO_3$. Therein, we observed the collapse of the CDW at temperatures as low as 30 K. At a few GPa, the far-infrared spectral weight of the ferromagnetic metallic phase was approximately recovered at just a few Gpa, thus confirming the weak-coupling nature of the CO in that manganite.

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The 9th International Conference on
Low Energy Electrodynamics in Solids

Les Diablerets, July 5-10, 2010

Posters

List and abstracts

LEES 2010 - Posters

Po-01	**Falkovsky**	**Leonid**	Leonid Falkovsky	Landau Institute for Theoretical Physics (Russia) / High Pressure Physics Institute (Russia)	***Gate-tunable bandgap in bilayer graphene***
Po-02	**Pfuner**	**Florian**	F. Pfuner, P. Lerch, J.-H. Chu, I.R. Fisher and L. Degiorgi	ETH Zurich (Switzerland) / PSI (Switzerland) / Stanford University (USA)	***Temperature dependence of the single particle excitation in the charge-density-wave ErTe3 and HoTe3 systems***
Po-03	**Sharapov**	**Sergei**	Artur O. Slobodeniuk, Sergei G. Sharapov and Vadim M. Loktev	Bogolyubov Institute for Theoretical Physics of the National Academy of Sciences of Ukraine (Ukraine)	***Aharonov-Bohm effect in relativistic and nonrelativistic 2D electron gas: a comparative study***
Po-04	**Laad**	**Mukul, Suresh**	Mukul Suresh Laad and Luis Craco	Institut fuer Theoretische Physik Aachen (Germany) / Max Planck Institut fuer Chermische Physik fester Stoffe Dresden (Germany)	***Superconductivity in The Iron Age: The Curious Case of the Ferropnictides.***
Po-05	**Fanfarillo**	**Laura**	Laura Fanfarillo, Lara Benfatto, Sergio Caprara, Claudio Castellani and Marco Grilli	Università di Roma ``La Sapienza'' (Italy)	***Theory of fluctuations in multiband superconductor: Application to pnictides***
Po-06	**Schafgans**	**Alexander**	Alexander Schafgans, Seiki Komiya, Yoichi Ando and Dimitri Basov	University of California San Diego (USA) / Central Research Institute of the Electric Power Industry Kanagawa (Japan) / Osaka University (Japan)	***Breakdown of the universal Josephson relation in spin ordered La-based cuprate superconductors***
Po-07	**Wu**	**Dan**	D. Wu, B. Gorshunov, A.A. Voronkov, P. Kallina, K. Iida, S. Haindl, F Kurth, L. Schultz, B. Holzapfel and M. Dressel	Universität Stuttgart (Germany) / Prokhorov Institute of General Physics (Russia) / IFW Dresden (Germany)	***Direct observation of the superconducting energy gap in the optical conductivity of iron-pnictides***
Po-08	**Prsa**	**Krunoslav**	Krunoslav Prsa, Henrik Ronnow, Niels Christensen, Jens Jensen, Oksana Zaharko, Johan Chang, Sabine Streule, Monica Jiménez-Ruiz, Helmuth Berger, Mladen Prester and Joël Mesot	ETHZ and PSI (Switzerland) / EPFL (Switzerland) / Technical University of Denmark Roskilde (Denmark) / University of Copenhagen (Denmark) / Niels Bohr Institute (Denmark) / Institut Laue-Langevin Grenoble (France) / Institute of Physics Zagreb (Croatia)	***Anomalous magnetic excitations of co-operative tetrahedral spin clusters***
Po-09	**Nicol**	**Elisabeth**	E.J. Nicol, K.A.G. Fisher, J.P. Carbotte and J.P.F. LeBlanc	University of Guelph (Canada) / McMaster University Hamilton (Canada) / The Canadian Institute for Advanced Research Toronto (Canada)	***Effect of pseudogap formation on the penetration depth of underdoped high Tc cuprates***
Po-10	**Jörger**	**Michael**	Michael Jörger and Günter Zachmann	Bruker Optik GmbH Ettlingen (Germany)	***CryoSAS: Far Infrared Silicon Impurity Analysis down to the low ppta level***
Po-11	**Gasparov**	**Lev**	Lev Gasparov, Viktor Struzhkin, Alexander Gavriliuk and Helmuth Berger	University of North Florida Jacksonville (USA) / Carnegie Institution of Washington (USA) / Institute for High Pressure Physics (Russia) / Russian Academy of Sciences Moscow (Russia) / EPFL (Switzerland)	***Raman study of the Verwey transition in Magnetite (Fe3O4) at high-pressure and low-temperature; effect of Al-doping.***
Po-12	**Cappelluti**	**Emmanuele**	Emmanuele Cappelluti, Lara Benfatto and Alexey Kuzmenko	CNR Rome (Italy) / University "La Sapienza" Rome (Italy) / University of Geneve (Switzerland)	***Unified Fano-Rice theory and phonon peak anomalies in bilayer graphene***

LEES 2010 - Posters

Po-13	**Deisenhofer**	**Joachim**	Joachim Deisenhofer, Yurii Goncharov, Franz Mayr, Dat Quach, Joanna Groza, Vladimir Tsurkan and Alois Loidl	Augsburg University (Germany) / General Physics Institute of the Russian Academy of Sciences Moscow (Russia) / University of California Davis (USA)	***THz and infrared spectroscopy in FeCr2S4: direct evidence for a transition from a dynamic to a static Jahn-Teller distortion***
Po-14	**LeBlanc**	**James**	J. P. F. LeBlanc, J. P. Carbotte and E. J. Nicol	University of Guelph (Canada) /McMaster University Hamilton (Canada) / The Canadian Institute for Advanced Research Toronto (Canada)	***Signatures of Fermi Surface Reconstruction in Raman Spectra of Underdoped Cuprates.***
Po-15	**Sichelschmidt**	**Jörg**	J. Sichelschmidt, S. Kimura, A. Herzog, C. Geibel, H. Jeevan and F. Steglich	Max Planck Institute for Chemical Physics of Solids Dresden (Germany) / UVSOR Okazaki (Japan)	***Far-infrared optical conductivity of CeCu2Si2***
Po-16	**Litvinchuk**	**A.P.**	A. P. Litvinchuk, J. Vermette, S. Jandl, M.N. Iliev, and M.M Gospodinov	University of Houston (USA) / Université de Sherbrooke (Canada) / Institute for Solid State Physics Sofia (Bulgaria)	***Crystal-Field Spectroscopy of Multiferroic Hexagonal RMnO3***
Po-17	**Kuntscher**	**Christine A.**	A. Pashkin, M. Dressel, S. G. Ebbinghaus, M. Hanfland and C. A. Kuntscher	Universität Augsburg (Germany) / Universität Stuttgart (Germany) / Martin-Luther-Universität Halle-Wittenberg (Germany) / \ESRF Grenoble (France)	***Pressure-induced electronic and structural phase transitions in the quasi-one-dimensional Bechgaard-Fabre salts***
Po-18	**Burch**	**Kenneth**	Kenneth Burch, Luke Sandilands, Grigory Chugunov, Frank Zhao, Jim Shen, Shimpei Ono, Philip Kim and Yoichi Ando	University of Toronto (Canada) / Columbia University (USA) / Osaka University (Japan)	***Spectroscopy of Exfoliated Thin Cuprates***
Po-19	**Sassa**	**Yasmine**	Yasmine Sassa, Milan Radovic, Martin Mansson, Xiaoyu Cui, Stéphane Pailhès, Elia Razzoli, Sébastian Guerrero, Ming Shi, Philip R. Willmott, Fabio Miletto, Joël Mesot and Luc Patthey	ETH Zurich and PSI (Switzerland) / EPFL (Switzerland) / CEA, CNRS, CE Saclay Laboratoire Léon Brillouin Gif Sur Yvette (France) / CNR-INFM Coherentia Napoli (Italy)	***Revealing the Ortho II Band Folding in YBa2Cu3O7-delta Films***
Po-20	**Nicoletti**	**Daniele**	D. Nicoletti, E. Chiadroni, P. Calvani, O. Limaj, A. Nucara, M. Ferrario, M. Castellano, M. Boscolo, C. Vaccarezza, G. Di Pirro and S. Lupi	Università di Roma "La Sapienza" (Italy) / INFN-LNF Roma (Italy)	***Characterization of a pulsed THz source at the free electron laser SPARC***
Po-21	**Gusynin**	**Valery**	Valery Gusynin, Olexandre Gamayun, Eduard Gorbar	Bogolyubov Institute for Theoretical Physics (Ukraine)	***Gap generation and semimetal-insulator phase transition in monolayer graphene***
Po-22	**Iizuka**	**Takuya**	Takuya Iizuka, Takafumi Mizuno, Chan-Ik Lee, Yong-Seung Kwon and Shin-ichi Kimura	The Graduate University for Advanced Studies Okazaki (Japan) / Sungkyunkwan University (Korea) / Institute for Molecular Science Okazaki (Japan)	***Pressure-Dependent Terahertz Reflectivity Spectra of a Heavy Fermion Material CeIn3***
Po-23	**Pronin**	**Artem**	A. V. Pronin, T. Fischer, J. Wosnitza, K. Iida, T. Niemeier, S. Haindl, L. Schultz and B. Holzapfel	Dresden High Magnetic Field Laboratory (Germany) / Leibniz Institute for Solid State and Materials Research Dresden (Germany)	***Optical conductivity of Ba(Fe1-xCox)2As2 and LuNi2B2C in the terahertz range***
Po-24	**Gavilano**	**Jorge**	Jorge Gavilano, Simon Gerber, Nikola Egetenmeyer, Michel Kenzelmann, Jonathan White and Andrea Bianchi	ETHZ and PSI (Switzerland) /University of Montreal (Canada)	***Small-Angle Neutron Scattering Studies of Some Unconventional Superconductors***
Po-25	**Munzar**	**Dominik**	Dominik Munzar, Jirí Chaloupka, Christian Bernhard, Adam Dubroka, Jirí Vasátko, Lukás Chvátal and Jirí Marek	Masaryk University Brno (Czech Republic) / Department of Physics and Fribourg Center for Nanomaterials (Switzerland)	***Theory of the c-axis optical response of bilayer superconductors and of layered systems exhibiting density waves coexisting with superconductivity***

Po-26	**Radovic**	**Milan**	Milan Radovic, Yasmine Sassa, Martin Mansson, Elia Razzoli, Xiaoyu Cui, Jochen Stahn, Ming Shi, Luc Patthey and Joel Mesot	EPFL (Switzerland) / ETH Zurich and PSI (Switzerland)	***Relationship Between High-temperature superconductivity and magnetic order in YBa2Cu3O7-x/(La0.7Sr0.3MnO3 Bilayers: Angle Resolved Photoemission Spectroscopy and Polarized Neutron Reflectometry studies***
Po-27	**White**	**Jonathan Stuart**	J S White, P Das, M R Eskildsen, L DeBeer-Schmitt, E M Forgan, A D Bianchi, M Kenzelmann, M Zolliker, S Gerber, J L Gavilano, J Mesot, R Movshovich, E D Bauer, J L Sarrao and C Petrovic	PSI (Switzerland) / University of Birmingham (UK) / University of Notre Dame (USA) / Université de Montréal (Canada) / ETH Zurich and EPF Lausanne (Switzerland) / Los Alamos National Laboratory (USA) / Brookhaven National Laboratory (USA)	***Observations of Pauli paramagnetic effects on the flux line lattice in CeCoIn5***
Po-28	**Grüninger**	**Markus**	Markus Grüninger, Julia Küppersbusch, Agung Nugroho and Thom Palstra	University of Cologne (Germany) / Rijksuniversiteit Groningen (Netherlands)	***Orbital correlations in RVO3 studied by ellipsometry***
Po-29	**Egetenmeyer**	**Nikola Anna**	Nikola Egetenmeyer, Simon Gerber, Jorge Gavilano, Michel Kenzelmann, Gabriel Seyfarth, Alexander Maisuradze, Rustem Khasanov, Baines Christopher, Alexandre Desilets-Benoit, Andrea Bianchi and Douglas MacLaughlin	ETHZ and PSI (Switzerland) / Université de Genève (Switzerland) / Univerisité de Montréal (Canada) / Babes-Bolyai University (Romania) / University of California Riverside (USA)	***MuSR studies of the pressure-induced superconductor CeRhSi3***
Po-30	**LaForge**	**Andrew**	Andrew LaForge, Alex Frenzel, Brennan Pursley, Tao Lin, Xinfei Liu, Jing Shi and Dimitri Basov	University of California San Diego (USA) / University of California Santa Cruz (USA) / University of California, Riverside (USA)	***Magnetoelectric coupling in the topological insulator material Bi2Se3 uncovered by infrared magneto optics***
Po-31	**de Sousa**	**Rogério**	Rogério de Sousa and Markku P. V. Stenberg	University of Victoria (Canada)	***Model for twin electromagnons and magnetically induced oscillatory polarization in multiferroic RMnO3***
Po-32	**Averitt**	**Richard**	M. Liu, B. Pardo, M.M. Qazilbash, S.J. Yun, B.G. Chae, B.J. Kim, H.T. Kim, D.N. Basov and R.D. Averitt	Boston University (USA) / University of California at San Diego (USA) / Electronics and Telecommunications Research Institute, Daejeon (Korea)	***Conductivity Dynamics in the Correlated Metallic State of V2O3***
Po-33	**Perucchi**	**Andrea**	Andrea Perucchi, Leonetta Baldassarre, Alessandro Nucara, Paolo Calvani, Carolina Adamo, Darrell G Schlom, Luigi Maritato and Stefano Lupi	Sincrotrone Trieste (Italy) / Universita di Roma ' Sapienza' (Italy) / Cornell University (USA) / Universita di Salerno (Italy)	***Optical properties across metal-insulator transitions in (SrMnO3)n/(LaMnO3)2n superlattices***
Po-34	**Mansson**	**Martin**	Ryota Akiyama, Martin Mansson, Yutaka Ikedo, Tatsuo Goko, Jun Sugiyama, Daniel Andreica, Alex Amato, Kittiwit Matan and Taku J. Sato	University of Tokyo (Japan) / ETHZ and PSI (Switzerland) / EPFL (Switzerland) / Toyota Central Research and Development Laboratories (Japan) / TRIUMF Vancouver (Canada) / Babes-Bolyai University (Romania)	***Short-range spin correlations in b-LiFeO2 from bulk magnetization, neutron diffraction, and mSR experiments***
Po-35	**Mansson**	**Martin**	Martin Mansson, T. Claesson, A. Önsten, M. Shi, Y. Sassa, S. Pailhès, J. Chang, L. Patthey, J. Mesot, T. Muro, T. Nakamura, N. Momono, M. Oda, M. Ido and O. Tjernberg	EPFL (Switzerland) / ETHZ & PSI (Switzerland) / KTH, Royal Institute of Technology (Sweden) / CEA, CNRS, CE Saclay (France) / Japan Synchrotron Radiation Research Institute Sayo (Japan) / Hokkaido University (Japan)	***Soft X-ray ARPES of High-temperature Superconductors***

LEES 2010 - Posters

Po-36	**Mansson**	**Martin**	Martin Mansson, Hiroshi Nozaki, Jun Sugiyama, Yutaka Ikedo, Masashi Harada, Vladimir Pomjakushin, Vadim Sikolenko, Antonio Cervellino, Tatsuo Goko, Jess H. Brewer, Yasmine Sassa, Nikola Egetenmeyer, Oscar Tjernberg, Hiroya Sakurai and Bertrand Roessli	ETHZ and PSI (Switzerland) / EPFL (Switzerland) / Toyota Central Research and Development Laboratories (Japan) / TRIUMF Vancouver (Canada) / Royal Institute of Technology KTH (Sweden) / National Institute for Materials Science Tsukuba (Japan)	***Spin Density Wave Order in the Quasi-One-Dimensional Metallic Antiferromagnet NaV2O4: a study by muons, neutrons and photons***
Po-37	**Marsiglio**	**Frank**	Frank Marsiglio, Giang Bach and Jorge Hirsch	University of Alberta (Canada) / Univ. of California San Diego (USA)	***Spectroscopic Properties of the Dynamic Hubbard Model***
Po-38	**Maggio-Aprile**	**Ivan**	Ivan Maggio-Aprile, E. Treboux, Y. Fasano, N. Jenkins, A. Piriou, C. Berthod and O. Fischer	University of Geneva (Switzerland) / Instituto Balseiro and Centro Atómico Bariloche (Argentina)	***The spin-mediated pairing interaction of high Tc superconductors : clues from scanning tunneling spectroscopy on YBa2Cu3O7-delta single crystals***
Po-39	**Levallois**	**Julien**	Julien Levallois, Florence Lévy, John Mydosh and Dirk van der Marel	Université de Genève (Switzerland) / Universität zu Köln (Germany)	***On the nature of the hidden-order phase in URu2Si2 from optical conductivity measurements***
Po-40	**Bartkowiak**	**Marek**	Marek Bartkowiak, Oleg Ignatchik, Gabriel Seyfarth, Michel Côté, Andrea Bianchi and Joachim Wosnitza	PSI (Switzerland) / Hochfeld-Magnetlabor Dresden (Germany) / University of Geneva (Switzerland) / Université de Montréal (Canada)	***Exploring the Fermi Surface of Phosphorous-based Pnictides***
Po-41	**Jenkins**	**Nathan**	Nathan Jenkins, A. Piriou, C. Berthod, Y. Fasano, I. Maggio-Aprile, E. Giannini and O. Fischer	University of Geneva (Switzerland) / Instituto Balseiro and Centro Atómico Bariloche (Argentina)	***Collective Mode Energy Measured by Scanning Tunneling Spectroscopy Does Not Follow Tc in Bi2Sr2Ca2Cu3O10 + delta***
Po-42	**Hancock**	**Jason**	Jason Hancock, Seyed Iman Mirzaei, Romain Veinnois, Enrico Giannini, Jeremie Teyssier, Dirk van der Marel, Jack Gillett, Suchitra Sebastian, Erik van Heuman, David Parker and Igor Mazin	University of Geneva (Switzerland) / Cambridge University (UK) / University of Amsterdam (Netherlands) / Naval Research Laboratory Washington (USA)	***Charge dynamics of magnetism and superconductivity in the new iron-based systems***
Po-43	**Crassee**	**Iris**	Iris Crassee, Julien Levallois, Andrew L. Walter, Markus Ostler, Aaron Bostwick, Eli Rotenberg, Thomas Seyller, Dirk van der Marel and Alexey B. Kuzmenko	Université de Genève (Switzerland) / Lawrence Berkeley Laboratory (USA) / Fritz-Haber-Institut der Max-Planck-Gesellschaft Berlin (Germany) / Universität Erlangen-Nürnberg (Germany)	***Faraday rotation in graphene***
Po-44	**Greene**	**Richard**	Richard Greene	University of Maryland (USA)	***Evidence of a Universal and Isotropic 2D/kTc in Iron Pnictide Superconductors***
Po-45	**Veenstra**	**Christian**	C.N. Veenstra, G.L. Goodvin, M. Berciu and A. Damascelli	University of British Columbia Vancouver (Canada)	***Elusive electron-phonon coupling in quantitative spectral function analyses***
Po-46	**Blumberg**	**Girsh**	Girsh Blumberg	Rutgers University (USA)	***Low energy electronic Raman spectroscopy of novel multiband superconductors with competing order parameters***
Po-47	**Armitage**	**N. Peter**	L.S. Bilbro, R. Valdes Aguilar, G. Logenov, I. Bozovic and N. P. Armitage	Johns Hopkins University, Baltimore / Brookhaven National Laboratory (USA)	***Probing the extent and character of superconducting correlations in La2-xSrxCuO4 by THz spectroscopy***
Po-48	**Liu**	**Wei**	Wei Liu, Minsoo Kim, Tai-lung Wu, Sambandamurthy Ganapathy and Peter Armitage	Johns Hopkins University (USA) / SUNY-Buffalo (USA)	***A scaling analysis of the superconducting fluctuations in 2D InOx thin films***

Po-49	**Dal Conte**	**Stefano**	Stefano Dal Conte, Claudio Giannetti, Federico Cilento, Giacomo Coslovich, Gabriele Ferrini, Martin Greven, Hiroshi Eisaki, Markus Raichle, Ruixing Liang, Andrea Damascelli, Dirk van der Marel and Fulvio Parmigiani	Università degli studi Pavia (Italy) / Università Cattolica del Sacro Cuore Brescia (Italy) / Università degli studi di Trieste (Italy) / Laboratorio Nazionale TASC (Italy) / University of Minnesota (USA) / Stanford University (USA) / Nanoelectronics Research Institute Tsukuba (Japan) / University of British Columbia (Canada) / Université de Geneve (Switzerland) / Sincrotrone Trieste (Italy)	***Exploring the electron-boson coupling in cuprates by time and frequency resolved optical spectroscopy***
Po-50	**Chauviere**	**Ludivine**	Ludivine Chauvière, Yann Gallais, Maximilien Cazayous, Marie-Aude Méasson, Alain Sacuto, Dorothée Colson and Anne Forget	Laboratoire Matériaux et Phénomènes Quantiques Paris (France) / CEA Saclay (France)	***Superconducting Gap of Ba(Fe1-xCox)2As2 studied by Raman spectroscopy***

Poster 1

Gate-tunable bandgap in bilayer graphene

Leonid Falkovsky[1,2]
(1) Landau Institute for Theoretical Physics
(2) High Pressure Physics Institute

The tight-binding model of bilayer graphene is used to find the gap between the conduction and valence bands, as a function of both the gate voltage and as the doping by donors or acceptors. The total Hartree energy is minimized and the equation for the gap is obtained. This equation for the ratio of the gap to the chemical potential is determined only by the screening constant. Thus the gap is strictly proportional to the gate voltage or the carrier concentration in the absence of donors or acceptors. These our results contradict with calculations by E. McCann. In the opposite case, where the donors or acceptors are present, the gap demonstrates the asymmetrical behavior on the electron and hole sides of the gate bias. A comparison with experimental data obtained by Kuzmenko et al shows the good agreement.

Poster 2

Temperature dependence of the single particle excitation in the charge-density-wave $ErTe_3$ and $HoTe_3$ systems

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(2) Swiss Light Source, PSI Villigen, Switzerland
(3) Dep. of Applied Physics, Stanford University, Stanford, USA

We provide optical reflectivity data collected over a broad spectral range and as function of temperature on the $ErTe_3$ and $HoTe_3$ materials, which undergo two consecutive charge-density-wave (CDW) phase transitions at T_{CDW1}= 265 and 280 K and at T_{CDW2}= 160 and 120 K, respectively. We observe the temperature dependence of both the Drude component, due to the itinerant charge carriers, and the single-particle peak, ascribed to the charge-density-wave gap excitation. The CDW gap progressively opens while the metallic component gets narrow with decreasing temperature. An important fraction of the whole Fermi surface seems to be affected by the CDW phase transitions. Generally, it turns out that the temperature as well as the pressure dependence of the most relevant CDW parameters share several common features and behaviors.

Poster 3

Aharonov-Bohm effect in relativistic and nonrelativistic 2D electron gas: a comparative study

Artur O. Slobodeniuk, Sergei G. Sharapov and Vadim M. Loktev
Bogolyubov Institute for Theoretical Physics of the National Academy of Sciences of Ukraine

We carry out a comparative study of electronic properties of 2D electron gas (2DEG) in magnetic field of an infinitesimally thin solenoid with relativistic dispersion as in graphene and quadratic dispersion as in semiconductor heterostructures. The problem ambiguity of the zero mode solutions of the Dirac equation is treated by considering of a finite radius flux tube which allows to select unique solutions associated with each **K** point of graphene's Brillouin zone. Then this radius is allowed to go to zero and on the base of the analytical solutions in the Aharonov-Bohm potential the local and total density of states are calculated. These results for the Dirac theory of graphene are compared with the results obtained from the solutions of the Schrödiger equation for 2DEG. We discuss the application of the results for the local density of states for the scanning tunneling spectroscopy done on graphene.

Poster 4

Superconductivity in The Iron Age: The Curious Case of the Ferropnictides.

Mukul Suresh Laad[1] and Luis Craco[2]
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(2) Max Planck Institut fuer Chermische Physik fester Stoffe, Noethnitzer Strasse 40, 01187 Dresden, Germany

High-Temperature Superconductivity recently progressed from the "Ceramic Age" to the "Iron Age", and the highest $T_c = 55$ K promises to shed light on the ill-understood set of conditions required for producing future HTSCs.

In this talk, I will begin by presenting a chosen set of experimental data, and argue that these materials must be considered as strongly correlated, i.e, proximate to a correlation-driven Mott-Hubbard insulator. This is important because superconductivity in a doped Mott insulator arises in a way very different from the standard text-book BCS mechanism, and a proper understanding of the bad-metallic, incoherent "normal" state is crucial in order to pinpoint the specific correlations aiding the emergence of HTSC itself.

I will then present our theoretical results for the "1111"- and "11"- families of the Fe-based superconductors in detail. Using LDA+DMFT with strong multi-orbital electronic correlations, I will show how an incoherent metallic state gives way to an unconventional superconductor. I will present the very good quantitative agreement with a wide range of extant experiments in BOTH, normal and SC phases, on basis of which I will argue that these fall into the class of strongly correlated systems.

Poster 5

Theory of fluctuations in multiband superconductor: Application to pnictides

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CRS SMC, CNR-INFM and Dipartimento di Fisica, Università di Roma "La Sapienza", Piazzale A. Moro 2, 00185, Rome, Italy

We derive the effective action for superconducting fluctuations in a two band model discussing both cases of intraband and interband dominant pairing and pointing out the emergence of a single critical mode out of a dominant interband mechanism. Then we generalize the recipe for an arbitrary number of bands. Finally we apply our procedure to a four-band model, as appropriate for pnictides and calculate the paraconductivity in two-dimensional and layered three-dimensional systems in order to compare our results with recent resistivity measurements in $SmFeAsO_{0.8}F_{0.2}$.

L.Fanfarillo, L.Benfatto, S.Caprara, C.Castellani and M.Grilli, Phys. Rev. B.**79** 172508 (2009)
L.Fanfarillo, L.Benfatto, S.Caprara, C.Castellani and M.Grilli, in preparation.

Poster 6

Breakdown of the universal Josephson relation in spin ordered La-based cuprate superconductors

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(3) Institute of Scientific and Industrial Research, Osaka University , Ibaraki, Osaka 567-0047, Japan

We collect data from both infrared optics and DC transport on a number of doped La_2CuO_4 (La214) single crystals and show that there exists a peculiar superconducting state in which c axis phase coherence is lost while in-plane coherence remains. This anisotropy results in the breakdown along the c axis of the universal scaling relationship for the cuprate superconductors between the superfluid density ρ_s, the DC conductivity σ_{DC}, and the superconducting transition temperature T_c. We discuss how this dramatic breakdown of the Josephson scaling relationship and resultant decoupling of the CuO_2 planes is likely due to in-plane magnetic order induced either via doping or an applied external magnetic field and enumerate the necessary components of a complete theoretical description.

Poster 7

Direct observation of the superconducting energy gap in the optical conductivity of iron-pnictides

D. Wu[1], B. Gorshunov[1,2], A.A. Voronkov[2], P. Kallina[1], K. Iida[3], S. Haindl[3], F Kurth[3], L. Schultz[3], B. Holzapfel[3] and M. Dressel[1]

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(3) IFW Dresden, Institute for Metallic Materials, P. O. Box 270116, 01171 Dresden, Germany

The temperature-dependent optical reflection and complex transmissivity of a $Ba(Fe_{0.9}Co_{0.1})_2As_2$ thin film with a superconducting transition temperature $T_c = 20$ K was measured over a wide frequency range. The opening of the superconducting gap $2\Delta_0 = 3.7$ meV below $T_c \approx 20$ K is *directly* observed by a completely vanishing optical conductivity; this corresponds to $2\Delta_0/k_BT_c = 2.1 \pm 10\%$. The temperature and frequency dependent electrodynamic properties of $Ba(Fe_{0.9}Co_{0.1})_2As_2$ in the superconducting state agree well with the BCS predictions with no nodes in the order parameter. The spectral weight of the condensate 1.94×107 cm^{-2} corresponds to a London penetration depth $\lambda_L = 3600$ Å. The normal state conductivity shows an incoherent-like background up to mid-infrared range, which is very similar to the spectra obtained from single crystals, confirming the intrinsic property of this broad contribution in 122 pnictide systems.

Poster 8

Anomalous magnetic excitations of co-operative tetrahedral spin clusters

Krunoslav Prša[1], Henrik Rønnow[2], Niels Christensen[3,4], Jens Jensen[5], Oksana Zaharko[1], Johan Chang[1], Sabine Streule[1], Monica Jiménez-Ruiz[6], Helmuth Berger[7], Mladen Prester[8] and Joël Mesot[1]
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(3) Materials Research Division, Risø DTU, Technical University of Denmark, DK-4000 Roskilde, Denmark
(4) Nano-Science Center, Niels Bohr Institute, University of Copenhagen, DK-2100 Copenhagen, Denmark
(5) Niels Bohr Institute, Universitetsparken 5, 2100 Copenhagen, Denmark
(6) Institut Laue-Langevin, BP 156, 38042, Grenoble Cedex, France
(7) Institut de Physique de la Matière Complexe, Ecole Polytechnique Fédérale de Lausanne, CH-1015 Lausanne, Switzerland
(8) Institute of Physics, POB 304, HR-10 000, Zagreb, Croatia

A low-energy inelastic neutron scattering study of coupled antiferromagnetic tetrahedra system $Cu_2Te_2O_5X_2$ (X=Cl, Br) shows strong dispersive modes with large energy gaps persisting far above T_N, notably in $Cu_2Te_2O_5Br_2$. The anomalous features: a co-existing unusually weak Goldstone-like mode observed in $Cu_2Te_2O_5Cl_2$ and the size of the energy gaps cannot be explained by existing theories, such as our mean-field/random-phase approximation. We argue that our findings represent a new general type of behavior due to inter-cluster quantum fluctuations and call for development of a new theoretical approach.

Poster 9

Effect of pseudogap formation on the penetration depth of underdoped high T_c cuprates

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The penetration depth is calculated over the entire doping range of the cuprate phase diagram with emphasis on the underdoped regime.[1] Pseudogap formation on approaching the Mott transition, for doping below a quantum critical point, is described within a model due to YRZ[2] based on the resonating valence bond spin liquid which provides an ansatz for the coherent piece of the Green's function. Fermi surface reconstruction, which is an essential element of the model, has a strong effect on the superfluid density at $T = 0$ producing a sharp drop in magnitude, but does not change the slope of the linear low temperature variation. Comparison with recent data on Bi-based cuprates provides validation of the theory and shows that the effects of correlations, captured by Gutzwiller factors, are essential for a qualitative understanding of the data. We compare our results with those for the Fermi arc and the nodal liquid models.

[1] J.P. Carbotte, K.A.G. Fisher, J.P.F. LeBlanc, and E.J. Nicol, Phys. Rev. B **81**, 014522 (2010).

[2] K.-Y. Yang, T.M. Rice, and F.C. Zhang, Phys. Rev. B **73** 174501 (2006).

Poster 10

CryoSAS: Far Infrared Silicon Impurity Analysis down to the low ppta level

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Since many years strong efforts are undertaken to increase energy generation by photovoltaics. As Silicon is still the most important basic raw material for solar cells a strongly growing demand on pure Silicon was observed within the last decade. In order to satisfy this demand high capacities for Silicon mass production are built up for which a reliable and sensitive quality control is essential.

Early publications about Silicon impurity analysis[1] showed that Fourier transform infrared (FT-IR) spectroscopy at room and low temperature is the ideal technique for semiconductor research and Silicon quality control. For substitutional Carbon and interstitial Oxygen detection limits in the parts per billion atoms range (ppba) are achievable, corresponding to concentrations in the order of $10^{14}/\text{cm}^3$. For group III and V shallow impurities (B, P, As, Ga, Al, Sb) in single crystal Silicon close to liquid He temperature one can make use of far infrared electronic transitions for quantification. In this case even parts per trillion atoms (ppta) corresponding to a concentration in the order of $10^{11}/\text{cm}^3$ have been approved.

Indeed the use of a very flexible research spectrometer as well as the storage and handling of cryogenic liquids and cryostats need expertise which is usually not available in typical industrial laboratories. Therefore Bruker Optics has developed the Cryogenic Silicon Analysis System (CryoSAS) a dedicated all-in-one system for the low temperature impurity analysis and quality control of Silicon crystals.

Optimized for operation in the industrial environment CryoSAS combines a Bruker Optics high performance FT-IR interferometer with built-in, closed-cycle cryo-cooling technology that does not require any liquid Nitrogen or Helium. CryoSAS can be operated at a high level of automation including reporting of the analysis results according to SEMI and ASTM standards. The optical components of the CryoSAS are optimized for Silicon impurity analysis, covering the difficult accessible spectral range from approx. 1300cm^{-1} down to 270cm^{-1} within one single measurement.

[1] S. Charles Baber Thin Solid Films, 72 (1980, 201-2100)

Poster 11

Raman study of the Verwey transition in Magnetite (Fe_3O_4)at high-pressure and low-temperature; effect of Al-doping.

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(2) Geophysical Laboratory, Carnegie Institution of Washington, Washington, DC, USA
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(4) Institute of Crystallography, Russian Academy of Sciences, Moscow, Russia
(5) Ecole Polytechnique Federale de Lausanne, Switzerland

We report high-pressure low-temperature Raman studies of the Verwey transition in pure and Al-doped magnetite. Low temperature phase of magnetite displays a number of additional phonon modes that serve as transition markers. The diamond anvil cell in combination with these transition markers allows us to investigate the effect of hydrostatic pressure on the Verwey transition temperature. Pure magnetite (T_V=123K) displays nearly linear decrease of the transition temperature with increase of pressure yielding dT_V/dp= -5 K/GPa. In contrast, Al-doped magnetite (T_V=117K) displays reduced slope of the PT curve at low temperatures and high pressures with overall dT_V/dp around -10 K/GPa. These dependencies are directly related to the changes of the molar entropy and molar volume at the transition. We compare the data obtained in our Raman experiment with that obtained from the ambient pressure specific heat measurements.
This work was supported by the NSF DMR-0805073 award and ONR N00014-06-1-0133 award.

Poster 12

Unified Fano-Rice theory and phonon peak anomalies in bilayer graphene

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(2) Dept. Physics, University "La Sapienza", Rome, Italy
(3) Dept. Physics, University of Geneve, Geneve, Switzerland

Graphene-based materials represent nowadays one of the most important research topics, because of their possible applications from the technological point of view and because they provide an ideal playground for searching and testing the fingerprints of different fundamental physical effects. The phenomenology of the observed phonon peaks in Raman and optical spectroscopy provides an interesting bridge between these two research directions. On one hand it has been shown to represent an useful tool to characterize graphene-based systems (number of layers, charge concentration, band-structure gap). On the other hand, the very observation of a phonon peak in the optical conductivity, with a significant Fano-like asymmetry, in a non polar system as graphene, rises the question about its origin and its relation with quantum interference effects.

In this contribution we present an unifying microscopic theoretical description which permits to account at the same level for the origin and the strength of the phonon peaks observed in the infrared optical conductivity of bilayer graphene as well as for their quantum interference effects giving rise to sizable Fano-like lineshapes. We show that one can probe in the optical conductivity the antisymmetric E_u or the symmetric E_g phonon modes depending on the charge concentration n and on the bandgap Δ induced by the gate voltage. The properties (Fano asymmetry, strength) of these two phonon resonances are shown to behave very differently as function of n and Δ. The study of the complex phase diagram of the phonon peak properties points our how, under opportune conditions, a switching between the E_u and the E_g modes is possible in a controlled way as a function of the gate voltage. We show also that a similar approach applied to the Raman scattering permits to explain the lack of Fano asymmetry and the weak doping-dependence of the phonon peak intensity observed in Raman spectroscopy.

Poster 13

THz and infrared spectroscopy in $FeCr_2S_4$: direct evidence for a transition from a dynamic to a static Jahn-Teller distortion

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The low-temperature anomaly occurring at about 10K in the CMR spinel $FeCr_2S_4$ has been lively debated in the past and attributed to the Jahn-Teller active Fe^{2+} ions located in tetrahedrally coordinated sites. The anomaly was suggested to occur as a result of the rare case of a transition from a dynamic (paradistortive) Jahn-Teller regime to a static (antiferrodistortive) ground state. Using Thz and IR spectroscopy we find distinct phonon anomalies and the appearance of new low-energy excitations in the low-temperature phase, providing direct evidence of the ground-state electronic splitting due to the cooperative static Jahn-Teller distortion.

Poster 14

Signatures of Fermi Surface Reconstruction in Raman Spectra of Underdoped Cuprates.

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Applying a phenomenological model of the pseudogap state, due to Yang, Rice and Zhang [1], we have calculated the Raman B_{1g} and B_{2g} spectra as a function of temperature, as well as doping, for the underdoped cuprates [2]. Motivated by recent angle-resolved photoemission experiments (ARPES) [3], we discuss changes in intensity and peak position brought about by the presence of a pseudogap and the implied Fermi surface reconstruction which are elements of this model. Our calculations capture the main qualitative features revealed in the extensive data set on $HgBa_2CuO_{4+\delta}$.

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[3] Kondo et al. Nature 457, 296 (2009).

Poster 15

Far-infrared optical conductivity of $CeCu_2Si_2$

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We investigated the optical reflectivity of a S/A-type single crystal of the heavy-fermion metal $CeCu_2Si_2$ in the energy range 3 meV – 30 eV for temperatures between 8K – 300K. Our preliminary results for the charge dynamics indicate a behavior that is expected for a formation of a coherent heavy quasiparticle state [1]: Upon cooling we observe a narrowing of the Drude-like part of the optical conductivity corresponding to an enhancement of the quasiparticle effective mass and scattering time. Furthermore, towards cooling down to $T = 8$ K a redistribution of spectral weight occurs essentially from the energy region below 0.6 eV towards energies below 3 meV.

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Poster 16

Crystal-Field Spectroscopy of Multiferroic Hexagonal $RMnO_3$

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Infrared transmission spectroscopy and photoluminescence are used to experimentally study crystal-field excitations in hexagonal $RMnO_3$ (R=Yb, Er, Tm, Ho) single crystals, which exhibit rather complex phase diagram as a function of temperature and applied external magnetic field. Apart from experimental determination of the energy diagram, temperature dependent measurements unambiguously reveal existence of various magnetic phases due to exchange-interaction-induced splitting of crystal-field transitions lines. It is shown that crystal field spectroscopy is a unique tool in determining magnetic structure of various rare earth $RMnO_3$ hexagonal compounds at low temperatures.

Poster 17

Pressure-induced electronic and structural phase transitions in the quasi-one-dimensional Bechgaard-Fabre salts

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The organic Bechgaard-Fabre salts are prime examples of strongly correlated quasi-one-dimensional systems, consisting of molecular stacks formed by TMTTF or TMTSF cations. The strength of the coupling between the conducting stacks is the crucial parameter which determines the electronic properties of these charge-transfer salts. External pressure provides a clean way to tune the interstack coupling over a broad range.

We report the optical response, down to the far-infrared range, of the Mott-Hubbard insulator $(TMTTF)_2PF_6$ and the metal $(TMTSF)_2PF_6$ as a function of pressure [1]. Furthermore, the results of the first high-pressure, low-temperature optical experiments on these organic salts are presented. Application of external pressure on $(TMTTF)_2PF_6$ leads to the rapid decrease of the Mott gap energy until the deconfinement transition occurs when the gap energy is approximately twice the interchain transfer integral. $(TMTSF)_2PF_6$ and $(TMTTF)_2PF_6$ in their deconfined state exhibit a dimensional crossover from a quasi-one-dimensional to a higher-dimensional metal with decreasing temperature. We quantitatively determine the dimensional crossover line in the pressure-temperature diagram based on the degree of coherence in the optical response perpendicular to the molecular stacks.

In addition, we present the pressure dependence of the unit cell parameters and report a pressure-induced structural phase transition in both studied salts [2]. The pressure offset for the structural phase transition and the dimensional crossover in $(TMTTF)_2PF_6$ compared to $(TMTSF)_2PF_6$ is in agreement with the generic phase diagram of the Bechgaard-Fabre salts [3].

We thank the ESRF and ANKA facilities for the provision of beamtime. Financial support by the DFG (Emmy Noether program, SFB 484, DR228/27) is gratefully acknowledged.

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[2] A. Pashkin et al., Synth. Met. 159, 2097 (2009).
[3] C. Bourbonnais and D. Jerome, Science 281, 1155 (1998).

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Poster 18

Spectroscopy of Exfoliated Thin Cuprates

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Electrostatic doping is a promising method for separating the effects of carrier density and disorder in the cuprates. To this end, we have produced exfoliated micro-samples of under-doped $Bi_2Sr_2Ca_{1-x}Dy_xCu_2O_8$ on SiO2/Si substrates. Using this method we reliably produce crystals on the order of hundreds of square microns and as thin as a few unit cells. We present the results of extensive atomic force and polarized Raman microscopy studies of these samples. Taken together these results clearly demonstrate these thin crystals must be properly handled to ensure they remain $Bi_2Sr_2Ca_{1-x}Dy_xCu_2O_8$. Furthermore the data also suggests as the crystals are thinned the Orthorhombic distortion of the lattice disappears.

Poster 19

Revealing the Ortho II Band Folding in $YBa_2Cu_3O_{7-\delta}$ Films

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Despite intense research in the field of high-temperature superconductivity, one of the remaining unsolved puzzles is the origin of the so-called pseudogap state. Recent quantum oscillations measurements on underdoped $YBa_2Cu_3O_{7-\delta}$ (Y123) under high magnetic fields indicate the existence of small Fermi surface pockets. So far, angle-resolved photoelectron spectroscopy (ARPES) data obtained from cleaved single crystals of Y123 seem to be inconsistent with the quantum oscillation experiments. Here, we present an ARPES study on Y123 films *in situ* grown by pulsed laser deposition (PLD) [1]. Through a careful control of the growth, we successfully produced underdoped surfaces with ordered oxygen vacancies within the CuO chains. The resulting Fermi surface displays a clear Ortho II band folding, emphasizing how order within the CuO chains strongly affects the electronic properties of the superconducting CuO_2 planes. Until now, the Ortho II band folding was not detected and consequently thought to be negligible in theoretical models.

[1] Y. Sassa *et al.*, submitted.

Poster 20

Characterization of a pulsed THz source at the free electron laser SPARC

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The interest for Terahertz (THz) radiation is rapidly growing, both as it is a powerful tool for investigating the behavior of matter at low energy, and as it allows for a number of possible applications spanning from medical science to security. During the last decade, a major effort has been devoted to fill the so-called "THz gap" which resulted in a great technological improvement. Even if being still in a developing stage, THz spectroscopy has already displayed its potential in several fields of science, including the solid state physics, in particular to measure low-energy excitations like the optical gap of superconductors [1] and those of the charge and spin density waves in solids [2]. Similarly to the conventional THz sources for time-resolved spectroscopy, a free electron laser (FEL) like SPARC (INFN Laboratories of Frascati, Rome) [3] can deliver broadband THz pulses with femtosecond shaping, but with the possibility to store much more energy in a single pulse. The high peak energy and the associated electric and magnetic field in the focus produced in an FEL, can be used to trigger new non-linear phenomena in matter. This provides a unique chance to realize THz-pump/THz-probe spectroscopy, a technique practically unexplored up to now. A THz radiation source has been produced at SPARC as pulsed coherent transition radiation emitted by either a compressed or longitudinally modulated beam intercepting a metal foil placed at 45° with respect to the beam propagation. We report the results on the characterization of the THz source at SPARC, using both a pyroelectric detector and a Golay cell. The pulse intensity has been studied in detail as a function of bunch charge and compression, thus revealing the characteristics of coherence of the THz radiation. Furthermore, the experimental results have been compared with simulations performed with the *THzTransport* code [4].

References

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Poster 21

Gap generation and semimetal-insulator phase transition in monolayer graphene

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The gap generation is studied in suspended clean graphene in the continuum model for quasiparticles with the Coulomb interaction. We solve the gap equation with the dynamical polarization function and show that, comparing to the case of the static polarization function, the critical coupling constant lowers to the value $\alpha_c = 0.92$, which is close to that obtained in lattice Monte Carlo simulations. It is argued that additional short-range four-fermion interactions should be included in the continuum model to account for the lattice simulation results. We obtain the critical line in the plane of electromagnetic and four-fermion coupling constants and find a second order phase transition separating zero gap and gapped phases with critical exponents close to those found in lattice calculations.

Poster 22

Pressure-Dependent Terahertz Reflectivity Spectra of a Heavy Fermion Material $CeIn_3$

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We report the pressure-induced change of the electronic structure of $CeIn_3$ due to the local-to-itinerant phase transition across the quantum critical point (QCP). $CeIn_3$, which is in the antiferromagnetic ground state below the Néel temperature of $T_N \sim 10$ K at ambient pressure, is changed to a heavy fermion ground state by applying pressure across QCP of $P_C \sim 2.6$ GPa. [1] To investigate the evolution of the heavy fermion state as well as the difference between the local and itinerant electronic structure, we measured pressure-dependent reflectivity spectra [$R(\omega)$] in the THz region at our accessible lowest temperature of 5.6 K. At 0.6 GPa, that is sufficiently lower pressure than P_C, $R(\omega)$ monotonically increases with decreasing photon energy indicating a normal metallic character. A shoulder at $h\nu \sim 18$ meV appears at $P \sim 1$ GPa, and shifts to the higher energy side with increasing pressure. The shoulder is clearly grown up before P_C, which indicates the evolution of the $c-f$ hybridization state predicted by the periodic Anderson model. [2]

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Poster 23

Optical conductivity of $Ba(Fe_{1-x}Co_x)_2As_2$ and $LuNi_2B_2C$ in the terahertz range

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Using a backward-wave-oscillator-based setup in a Mach-Zehnder interferometer arrangement, we have measured the temperature- and frequency-dependent transmission and phase-shift spectra of $Ba(Fe_{1-x}Co_x)_2As_2$ and $LuNi_2B_2C$ films in the terahertz range (100 GHz - 1.2 THz) and for temperatures from 2 to 300 K. From the measured spectra, we have directly calculated the complex optical conductivity. In the conductivity spectra below T_c, we observe clear signatures of the superconducting energy gap opening in both compounds. In the presentation, a comparison of the experimentally obtained spectra with theoretical predictions will be given.

Poster 24

Small-Angle Neutron Scattering Studies of Some Unconventional Superconductors

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We discuss results of recent measurements of Small Angle Neutron Scattering, SANS, applied to the study of the flux-line lattice (vortex lattice) of type II superconductors in the mixed stated. For unconventional superconductors SANS data reveal a rich variety of unexpected features. These include different phase transitions in the field-temperature phase diagram of the flux-line lattice, connected to subtle details of the superconducting state. In some cases the transitions involve changes of the symmetry. In other cases one observes a temperature-induced melting at temperatures, T_m, clearly below T_c and/or a field-induced decomposition of the flux lines at rather modest external magnetic fields ($H << H_{c2}$) at all temperatures. We discuss SANS results for selected heavy-Fermion and High-T_c, superconductors.

Poster 25

Theory of the c-axis optical response of bilayer superconductors and of layered systems exhibiting density waves coexisting with superconductivity

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First, we present our microscopic theory of the c-axis infrared conductivity of bilayer high-T_c cuprate superconductors [J. Chaloupka, C. Bernhard, D. Munzar, Phys. Rev. B 79, 184513 (2009)], which allows us to discuss relations between (c-axis) optical and photoemission data of these materials. The well-known peak around 400 cm^{-1} is attributed to a collective mode of the intrabilayer regions that is an analogue of the Bogoljubov-Anderson mode playing a crucial role in the theory of the longitudinal response of superconductors. For small values of the splitting between the bonding and the antibonding band of the bilayer unit, its properties are similar to those of the transverse plasmon of the phenomenological Josephson superlattice model [D. van der Marel and A. Tsvetkov, Czech J. Phys. 46, 3165 (1996)]; this provides a justification for using the model when analyzing infrared data of strongly underdoped materials.

The pseudogap in the underdoped cuprates is frequently associated with a (charge and/or spin) density wave competing with superconductivity. In order to examine, whether these ideas are consistent with the observed spectral weight transfers [Li Yu, D. Munzar *et al.*, Phys. Rev. Lett. 100, 177004 (2008)], we have performed calculations of the c-axis response of model systems exhibiting density waves coexisting with superconductivity. In the second part of our contribution, we report on our results and discuss consequences.

Poster 26

Relationship Between High-temperature superconductivity and magnetic order in YBa2Cu3O7-x/(La0.7Sr0.3MnO3 Bilayers: Angle Resolved Photoemission Spectroscopy and Polarized Neutron Reflectometry studies

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The relationship between High-temperature superconductivity (HTSC) and magnetic order is an essentially important phenomenon for both fundamental and applicative research (spintronics). Many studies showed an intimate connection between magnetic order and HTSC, but it is still under debate if the magnetic interactions could act as an attractive force between electrons and facilitate superconductivity [1] or if they compete with each other [2]. The recent progress in manufacturing heterostructures gives us the opportunity to engineer atomic-scale materials. This provides additional pathways to understand the mechanism behind HTSC. The interface between superconductors and giant magnetoresistive materials has rich physical properties. Having in mind that the valence electrons in cuprates as well as in manganites are subject to strong magnetic interactions, the magnetization at the interface is expected to have a crucial influence on the charge transfer in these systems. Our present study has demonstrated that in situ ARPES on YBCO thin films grown by laser Molecular Beam Epitaxy is a suitable experimental technique to reveal new physical phenomena, for example Fermi Surface folding [3]. Additionally, we started investigation on coexistence of HTC superconductivity and magnetism on a series of (nYBa2Cu3O7-x)/m(La0.7Sr0.3MnO3) bilayers (n-number of YBCO unit cells, m-number of LSMO unit cells). By fine tuning of the YBCO layer thickness and by using ARPES we were able to study the influence of magnetism on HTSC. Consequently, we performed a systematic investigation of the structural and magnetic properties of the YBCO/LSMO bilayers (films and interfaces) using Polarized Neutron Reflectometry (PNR). We believe that by combining the data obtained by ARPES and PNR, it will be able to better understand the connection between magnetic order and HTSC.

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[3] Y. Sassa, et al. Submitted manuscript.

Poster 27

Observations of Pauli paramagnetic effects on the flux line lattice in $CeCoIn_5$

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We report small-angle neutron scattering (SANS) studies of the flux line lattice (FLL) in the heavy-fermion superconductor $CeCoIn_5$ ($T_c = 2.3$ K) with field parallel to the crystal **c**-axis. Our measurements of the FLL form factor (FF) which provide a measure of the field contrast in the mixed state show that the effects of field-induced flux line core paramagnetism [2], which cause the field-enhancement of the FF previously reported at 50 mK [1], to persist to temperatures (T) up to 1250 mK (¿ T_c / 2) [3]. At all T, and for fields just below H_{c2}, the FF falls from a peak value. Our results suggest that this fall of the FF is unlikely to be associated with the onset of a novel superconducting phase, as was suggested in [1]. Instead, recent extensions to the theoretical predictions of [2] suggest that the fall is more likely to be explained by paramagnetic depairing effects within the flux line cores, which causes them to expand at high field. This core expansion is of unconventional origin, and only occurs as a consequence of field induced paramagnetic depairing. To provide experimental evidence for such a core expansion, we discuss results of new SANS measurements at high field, and compare them to the predictions of the core expansion model [3].

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Poster 28

Orbital correlations in RVO_3 studied by ellipsometry

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The orbital degree of freedom plays an important role in the $3d^2$ vanadates RVO_3 (R = Y or rare earth). These compounds display a variety of orbitally and/or magnetically ordered states, and orbital exchange interactions as well as orbital fluctuations are expected to be strong. Using ellipsometry, we study the excitations from the lower to the upper Hubbard band. We obtain a consistent description of the multi-peak structure in terms of the different d^3 multiplets, solving the discrepancies encountered in the literature. The optical spectral weight of the different absorption peaks shows a strong temperature dependence, which reflects nearest-neighbor spin-spin and orbital-orbital correlations. Comparison with theoretical predictions based on either 'classical' orbital order or strong orbital fluctuations strongly favors the latter.

Poster 29

MuSR studies of the pressure-induced superconductor $CeRhSi_3$

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$CeRhSi_3$ is a noncentrosymmetric heavy-fermion antiferromagnet with a Néel temperature of $T_N = 1.6\,\mathrm{K}$ and single-ion Kondo temperature of roughly $T_K = 50\,\mathrm{K}$. The magnetically ordered state is incommensurate with ordered Ce moments of about 0.1 μ_B. At external pressures of the order of 12 kbar and low temperatures, deep inside of the antiferromagnetic state, a superconducting phase develops and coexists with magnetic order. MuSR measurements on $CeRhSi_3$ were conducted at PSI at pressures between 0 to 12.5 kbar and temperatures between $T = 0.27$ and 2.2 K and at ambient pressure at temperatures between $T = 0.02$ and 2.2 K. Both experiments were performed using samples consisting of many co-aligned single crystals. The time and frequency spectra at ambient pressure revealed the presence of three muon precession frequencies in the antiferromagnetic phase, corresponding to internal fields of 5, 50 and 120 Gauss. We observe appreciable pressure-induced changes in the Néel temperature and drastic suppression of the internal fields. The pressure dependence of the Néel temperature displays a broad maximum around 6 kbar which is different from the behavior of the internal fields which decrease monotonically with increasing pressure. This suggests an unusual antiferromagnetic phase.

Poster 30

Magnetoelectric coupling in the topological insulator material Bi_2Se_3 uncovered by infrared magneto optics

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We present an infrared magneto-optical study of the highly thermoelectric narrow-gap semiconductor Bi_2Se_3. Far- and mid-infrared (IR) reflectance and transmission measurements have been performed in magnetic fields oriented both parallel and perpendicular to the trigonal c axis of this layered material, and supplemented with UV-visible ellipsometry to obtain the optical conductivity $\sigma_1(\omega)$. With lowering of temperature we observe narrowing of the Drude conductivity due to reduced quasiparticle scattering, as well as the increase of the absorption edge due to the band gap. Magnetic fields $H \parallel c$ dramatically renormalize and asymmetrically broaden the strongest far-IR optical phonon, indicating interaction of the phonon with the continuum free-carrier spectrum and significant magnetoelectric coupling. For the perpendicular field orientation, electronic absorption is enhanced, and the plasma edge is slightly shifted to higher energies. In both cases the band gap edge is softened in magnetic field.

Poster 31

Model for twin electromagnons and magnetically induced oscillatory polarization in multiferroic RMnO$_3$

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We propose a model [1] for the pair of electromagnon excitations observed in the class of multiferroic materials RMnO$_3$ (R is a rare-earth ion). The model is based on a harmonic cycloid ground state interacting with a zone-edge magnon and its twin excitation separated in momentum space by two times the cycloid wave vector. The pair of electromagnons is activated by cross coupling between magnetostriction and spin-orbit interactions. Remarkably, the spectral weight of the twin electromagnon is directly related to the presence of a magnetically induced oscillatory polarization in the ground state. This leads to the surprising prediction that TbMnO$_3$ has an oscillatory polarization with amplitude 50 times larger than its uniform polarization.

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Poster 32

Conductivity Dynamics in the Correlated Metallic State of V_2O_3

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V_2O_3 is a strongly correlated electron material that undergoes a transition from antiferromagnetic insulator at low temperatures to a strongly correlated metal above ∼140K. We report on time resolved spectroscopic studies of V_2O_3 thin films where we have observed coherent oscillations in the far-infrared conductivity following excitation with a 35-fs optical pulse. The resultant 100 ps conductivity oscillations result from the optically induced generation of strain which modulates the orbital overlap and hence the conductivity thus revealing a strong coupling of carriers to the lattice in the metallic state. This contrasts with other vanadates such as VO_2 where this effect is not observed. We will discuss the potential of V_2O_3 as a candidate material for investigating photoinduced phase transitions.

Poster 33

Optical properties across metal-insulator transitions in $(SrMnO_3)_n/(LaMnO_3)_{2n}$ superlattices

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Recent progresses in the growth of atomic-scale multilayers are opening new exciting possibilities in the design of material's properties. The so-called electronic reconstruction effect can give rise to new 2D metallic states at the interface between band and a Mott insulators as $SrTiO_3$ and $LaTiO_3$. Manganite superlattices with alternating layers of insulating anti-ferromagnets (AFI) $SrMnO_3$ and $LaMnO_3$ have been recently studied as well. Thanks to electronic reconstruction, metallicity and ferromagnetism can be induced in these nano-structures. We present infrared measurements of the $(SrMnO_3)_n/(LaMnO_3)_{2n}$ superlattices, as a function of Temperature, and for four different n values ($n = 1, 3, 5, 8$). Our data display a clear optical signature for the MIT observed as a function of temperature for SLs of short enough period. This provides the first optical characterization of a Double-Exchange driven FM-PI transition in the absence of random disorder.

Poster 34

Short-range spin correlations in β"-$LiFeO_2$ from bulk magnetization, neutron diffraction, and μ^+SR experiments

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We have performed bulk magnetization, neutron-diffraction, and muon-spin-rotation/relaxation (μ^+SR) measurements in order to study magnetic order in β"-$LiFeO_2$ [**1**]. At room temperature, structural short-range order of Fe atoms was observed with correlation length roughly corresponding to inter-Fe distance. Bulk magnetization, μ^+SR and neutron diffraction all suggest that β"-$LiFeO_2$ is similar to a superparamagnet in the range $110 < T < 170$ K, possibly due to the formation of small spin clusters attributable to atomic short-range order. At lower temperatures, gradual increase in the muon precession frequency as well as the neutron diffuse scattering intensity were observed below 110 K, indicating development of intercluster correlations. While a bulk magnetic ordering was detected in the μ^+SR results, neutron diffraction concludes that the intercluster correlations are definitely short ranged. The correlation length was estimated as $\xi_s \sim 12$ Å and it was found to be almost temperature independent.

[1] R. Akiyama *et al*. Phys. Rev. B **81**, 024404 (2010)

Poster 35

Soft X-ray ARPES of High-temperature Superconductors

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When performing angle-resolved photoelectron spectroscopy (ARPES) using conventional low photon energies (hν = 20 - 100 eV) the experiments suffer from a number of limitations. Particular attention should be paid to the limited probing depth. In connection, there have been questions raised regarding the electronic structure amongst the layered cuprates being 2D or 3D in nature. To discern a possible k_z-dependence using low photon-energies is, however, a very tricky task. To interpret the data correctly one needs to account for the fact that the final state is not free electron like. Further, at low photon energies the probe depth is of the order 4 Å, which implies a large uncertainty, $\Delta k_z \approx 1/4$ Å^{-1}. In most of the high-temperature superconductors, the lattice parameter c is large and the Brillouin zone (BZ) is hence "compressed" in this direction. Consequently, Δk_z is more than half the BZ. When using soft x-rays, the probe depth is $\sim$ 15 Å, i.e. $\Delta k_z \approx 1/15$ Å^{-1}. This improvement in k_z-resolution makes it much easier to distinguish a k_z-dependence of the Fermi surface (FS) topology.

Among other things [1,2], ARPES data probing the electronic structure of the Nd-substituted high-Tc cuprate $La_{1.48}Nd_{0.4}Sr_{0.12}CuO_4$ will be presented [3]. The data was acquired at both low and high photon energies, hν = 55 and 500 eV, respectively. The two FS show significant differences, which is attributed to either the change in probing depth suggesting dissimilarity of the intrinsic electronic structure between surface and bulk regions, or a considerable c-axis dispersion signaling a strong interlayer coupling.

[1] T. Claesson, M. Månsson et al. Phys. Rev. Lett **93**, 136402 (2004)
[2] A. Önsten, M. Månsson et al. Phys. Rev. B **76**, 115127 (2007)
[3] T. Claesson, M. Månsson et al. Phys. Rev. B **80**, 094503 (2009)

Poster 36

Spin Density Wave Order in the Quasi-One-Dimensional Metallic Antiferromagnet NaV_2O_4: a study by muons, neutrons and photons

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The microscopic magnetic nature of NaV_2O_4, in which the V ions form zigzag chains along the b-axis, was first investigated by positive muon-spin spectroscopy (μ^+SR) [**1**]. By studying powder samples for temperatures down to 1.8 K, we found that a static antiferromagnetic (AF) order appears below $T_N = 140$ K. In order to clarify the reason for the coexistence of long-range AF order and metallic conductivity in NaV_2O_4, a neutron scattering experiment was performed using a powder sample down to 20 K. The analysis of the magnetic Bragg peaks below $T_N = 140$ K demonstrated the formation of an incommensurate spin density wave order (IC-SDW) [**2**] with $k = (0, 0.191, 0)$; the ordered moment was estimated as $(0, 0, 0.77\mu_B)$ at 20 K. Further, from synhrotron radiation x-ray diffraction, we found no indication of structural phase transitions down to $T = 100$ K. Hence, the IC-SDW order is thought to be caused by an intrinsic instability of the V_2O_4 zigzag chain system at low T. Finally very recent angle-resolved photoelectron spectroscopy (ARPES) data from single crystal NaV_2O_4 samples will be presented [**3**].

[1] J. Sugiyama *et al*. Phys. Rev. B **78**, 224406 (2008)
[2] H. Nozaki *et al*., submitted
[3] M. Månsson *et al*., manuscript

Poster 37

Spectroscopic Properties of the Dynamic Hubbard Model

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The Dynamic Hubbard model (DHB) is representative of a new class of models that describes orbital relaxation effects due to double occupancy. In usual Hubbard-like models, rigid bands underlie the excitation spectrum, even when many-body effects are included. Yet, in real materials (and even in the lowly Helium atom!) orbitals become modified 'on the fly' so to speak, depending on the electron occupancy. We model this modification with an auxiliary pseudospin degree of freedom, and explore the consequences for photoemission and optical conductivity spectroscopy. A significant shifting of spectral weight, similar to that observed in the high temperature cuprate superconductors, results from these relaxation effects.

Poster 38

The spin-mediated pairing interaction of high T_c superconductors : clues from scanning tunneling spectroscopy on $YBa_2Cu_3O_{7-\delta}$ single crystals

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After two decades, the exact origin of the pairing interaction in cuprate superconductors still remains a mystery. Scanning tunnelling spectroscopy is a perfect tool to investigate this question. While it is well established that conventional superconductors reveal the existence of phononic excitations in the tunneling spectra, the identification of the so-called "dip-hump feature" in the tunnel conductance with bosonic excitations in high T_c superconductors is relatively recent and limited to Bi-based cuprates [1]. We present here very recent tunnelling spectroscopy measurements performed on $YBa_2Cu_3O_{7-\delta}$ single crystals and the first detailed analysis of the systematic signature of these bosonic collective modes in this compound. We show through numerical modelling that the dip-hump feature in YBCO can also be associated with the (π, π) spin resonance detected in neutron scattering experiments, and that the local doping dependence of the energy of this mode follows the same trend as for Bi-based cuprates. All evidence support that spin-mediated pairing plays an important role in high-T_c superconductivity.

[1] . Fischer et al., Rev. Mod. Phys. 79, 353 (2007)

Poster 39

On the nature of the hidden-order phase in URu_2Si_2 from optical conductivity measurements

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The origin of the enigmatic hidden-order state in URu_2Si_2 fascinates the physicists since more than two decades. At $T_0 = 17.5$ K, all the thermodynamical and transport measurements exhibit a clear anomaly and suggest a Fermi surface reconstruction. We performed far-infrared optical conductivity measurements on the *a* and *c* axis of the tetragonal crystal structure as a function of temperature. We show that the optical conductivity is very anisotropic. Moreover, we see a clear evidence of a sharp crossover at 25 K, which corresponds to a partial suppression of the optical conductivity for both axis. This is accompanied by a significant renormalization of the plasma frequency and the scattering rate. Those observations indicate that electronic bands located at few meV from the Fermi level start to slide when the temperature goes below 25 K, which in turn causes the thermodynamic phase transition at 17.5 K.

Poster 40

Exploring the Fermi Surface of Phosphorous-based Pnictides

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The discovery of the new iron based high T_C superconductors has spun up a completely new field of scientific interest. The competition between magnetic ordering and superconductivity seems to be a key aspect for the driving mechanism of superconductivity. The application of pressure, elemental substitution and doping can be used to tune the systems behavior between magnetic ordering and superconductivity. For a better understanding of the microscopic mechanisms driving all these ordering phenomena a precise knowledge of the Fermi surface topology is crucial. Quantum oscillation experiments together with density functional theory calculations are a powerful tool to obtain these information. We present de Haas-van Alphen measurements on various phosphorous pnictides performed at high magnetic fields. The angular dependence of the quantum oscillations is fond to be in good agreement with the corresponding DFT calculations.

Poster 41

Collective Mode Energy Measured by Scanning Tunneling Spectroscopy Does Not Follow T_c in $Bi_2Sr_2Ca_2Cu_3O_{10+\delta}$

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We report on a scanning tunneling microscopy (STM) study of the three-layer compound $Bi_2Sr_2Ca_2Cu_3O_{10+\delta}$ (Bi-2223). A realistic model including the (π, π) spin resonance mode seen by neutrons has previously been used [1] to give remarkably good fits to spectra in Bi-2223. We further showed that for a nearly-optimally doped sample, Ω and Δ are anticorrelated, that is Ω decreases as Δ increases [2]. We now have furthered these results by performing a doping dependence study of Ω. Three separate samples were looked at with three different dopings (underdoped, optimally doped, and overdoped). For the underdoped and optimally doped samples, results qualitatively followed the doping dependence found by neutron experiments. However, in the overdoped sample there is almost no dependence at all for $\Delta < 45$ meV. Thus Ω does not follow T_c. This finding necessitates further neutron experiements on overdoped samples to properly characterize the doping dependence of the (π, π) spin resonance.

[1] Giorgio Levy de Castro and Christophe Berthod and Alexandre Piriou and Enrico Giannini and Øystein Fischer, Phys. Rev. Lett. 101, 267004 (2008).
[2] Jenkins, N. and Fasano, Y. and Berthod, C. and Maggio-Aprile, I. and Piriou, A. and Giannini, E. and Hoogenboom, B. W. and Hess, C. and Cren, T. and Fischer, Ø. , Phys. Rev. Lett. 103, 227001 (2009).

Poster 42

Charge dynamics of magnetism and superconductivity in the new iron-based systems

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We present a comparative study of the dynamical charge response the iron pnictide and iron chalcogenide compounds using infrared and optical spectroscopy and resonant inelastic X-ray scattering. Consistent with previous studies, we find that strong temperature-dependent changes in the optical spectra accompany the magnetostructural phase transition of the pnictide system, but that these are strongly suppressed and qualitatively different in the chalcogenide. This diverse behavior is linked to the different magnetic ground state in each of these two systems, and portends an intimate connection between the magnetic degrees of freedom and the charge response. The importance of the spin degrees of freedom on the scattering process is thus made apparent in our studies as a direct extension of the anomalous dc transport in these systems. In the context of the optical spectra, we discuss the relatively strengths of the magnetic and superconducting energy scales in the phase diagram in each of these systems.

Poster 43

Faraday rotation in graphene

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Graphene demonstrates intriguing physics due to the massless and chiral character of the charge carriers. Placed in a perpendicular magnetic field, it shows non-equidistant Landau levels with a non-trivial level at zero energy. Optical transitions between various Landau levels give rise to a spectacular series of optical absorption peaks [1]. In this work we present experimental results on the Faraday rotation, which is directly related to the off-diagonal (Hall) optical conductivity $\sigma_{xy}(\omega)$. Measurements are conducted on monolayer and few layer graphene epitaxially grown on Si and C terminated SiC respectively, in the THz and far-infrared ranges, in fields up to 7 Tesla supplied by a split coil magnet. We demonstrate that a single atomic layer of carbon turns the polarization light by several degrees in modest magnetic fields. The sign of the rotation is a direct and contact-free way to determine the carrier type. The Faraday angle is strongly enhanced by resonances originating from the cyclotron effect in the semiclassical regime (high doping) and the inter-Landau-level transitions in the quantum regime (low doping).

[1] M.L. Sadowski, G. Martinez, M. Potemski, C. Berger and W.A. de Heer, Phys. Rev. Lett. 97, 266405 (2006).

Poster 44

Evidence of a Universal and Isotropic $2\Delta/kTc$ in Iron Pnictide Superconductors

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We have systematically investigated the doping and the directional dependence of the gap structure in the 122-type iron pnictide superconductors by point contact Andreev reflection spectroscopy (PCAR). The studies were performed on single crystals of Ba1-xKxFe2As2 (x= 0.29, 0.49, 0.77) and SrFe1.74Co0.26As2 with a sharp tip of Pb pressed along the c-axis or the ab-plane direction. The conductance spectra obtained on highly transparent contacts clearly show evidence of a robust superconducting gap. The normalized curves can be well described by the Blonder-Tinkham-Klapwijk model with lifetime broadening. The determined gap value scales very well with the transition temperature, giving the $2Delta/kTc$ value of 3.1. The results suggest the presence of a universal coupling behavior in this class of iron pnictides over a broad doping range and independent of the sign of doping. Moreover, conductance spectra obtained on c-junctions and ab-plane junctions indicate the presence of an isotropic gap in these superconductors for the first time. The isotropic gap, together with the constant coupling strength, provides a strong evidence for a universal pairing mechanism in the 122 type iron pnictides over a broad doping range. The inconsistencies found among the many prior PCAR measurements on pnictides most likely arise from non-ideal surface and interface conditions and a lack of high-transparency contacts. We resolved these problems in our work by using Pb as a counter electrode, where the observation of a weak-link Josephson coupling at low temperatures was used as an indication of the existence of a highly transparent junction interface.

Poster 45

Elusive electron-phonon coupling in quantitative spectral function analyses

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We examine multiple techniques for extracting quantitative information from ARPES data, and test them against simulated spectral functions for electron-phonon coupling [1]. We find that, in the low-coupling regime, it is possible to extract self-energy and bare-band parameters through a self-consistent Kramers-Kronig bare-band fitting routine. We also show that the effective coupling parameters deduced from the renormalization of quasiparticle mass, velocity, and spectral weight are momentum dependent and, in general, distinct from the true microscopic coupling; the latter is thus not readily accessible in the quasiparticle dispersion revealed by ARPES. For example, the velocity renormalization at the quasiparticle inflection point would overestimate λ by a factor of 2, 3, and 8 for $\lambda = 1$, 1.5, and 2.

[1] C.N. Veenstra, G.L. Goodvin, M. Berciu, A. Damascelli, arXiv:1003.0141.

Poster 46

Low energy electronic Raman spectroscopy of novel multiband superconductors with competing order parameters

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We will present a general overview of low energy electronic Raman spectroscopy in superconductors discussing the light coupling mechanisms to possible collective excitations out of the superconducting condensate with examples of modern experimental and theoretical results on multiband superconductors such as n-doped cuprates [1,2], MgB_2 [3], $NbSe_2$ [4], CaC_6 [6], Fe-pnictides in which the superconducting order parameter is complex, competes or coexists with variety of other states, such as charge or spin density wave orders. The relation of Raman spectroscopy to other spectroscopic methods will be reviewed.

*This work was done in collaboration with A. Gozar, R.L. Greene, J. Karpinski, J. S. Kim, M.V. Klein, R.K. Kremer, A. Mialitsin, M.M. Quazilbash.

1) M.M. Quazilbash et al., Phys. Rev. B 72 (2005) 214510.
2) J.-P. Ismer et al., http://arxiv.org/abs/0907.1296 .
3) G. Blumberg et al., Phys. Rev. Lett. 99 (2007) 227002.
4) R. Sooryakumar and M.V. Klein, Phys. Rev. Lett. 45 (1980) 660 and recent unpublished data by A. Mialitsin and G. Blumberg.
5) A. Mialitsin et al., Phys. Rev. B 79 (2009) 064503.

Poster 47

Probing the extent and character of superconducting correlations in $La_{2-x}Sr_xCuO_4$ by THz spectroscopy

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The nature of the pseudogap regime of the high-temperature superconductors has been a matter of long-term debate. Although there is ample evidence for superconducting correlations in the normal state, there has been disagreement about how high in temperature they extend and if they can account for the totality of the pseudogap. In this work we use time-domain THz spectroscopy (TTDS) to probe superconducting correlations above T_c in $La_{2-x}Sr_xCuO_4$ thin films over a broad doping range ($x = 0.07$ to 0.22). Among other things, TTDS allows us to measure the fluctuation conductivity on the time scales of interest and extract out a characteristic fluctuation rate. We find that the fluctuation signal persists in the conductivity at maximum only some 20K above T_c, which is in strong contrast to measurements like diamagnetism where the signal persists to some 100K above T_c. The characteristic fluctuation rate increases very quickly above T_c, but then surprisingly has a crossover to an explicitly quantum behavior where it grows at a much smaller rate that is proportional to temperature as $\alpha T/\hbar$.

Poster 48

A scaling analysis of the superconducting fluctuations in 2D InOx thin films

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We apply a broadband microwave Corbino spectrometer covering the range from 10MHz to 20GHz to study 2D disordered superconducting InOx thin films. Explicit frequency dependency of the superfluid stiffness and conductivity are obtained down to 300mK. We perform a scaling analysis in which we can extract characteristic relaxation time of superconducting fluctuations. We discuss our results in terms of prevailing scenarios for fluctuation superconductivity and make connection to other experimental results.

Poster 49

Exploring the electron-boson coupling in cuprates by time and frequency resolved optical spectroscopy

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We report here time and frequency resolved optical measurements on Y-Bi2212 samples at different temperature and doping regimes. Exploiting the large spectral content of supercontinuum light, used as probe beam, we are able to study, over a broad spectral window and with high temporal resolution, the time evolution of the dielectric function after that an intense pump laser pulse brings the system out of equilibrium. In particular we observe the transient modification of the 1.5 eV optical oscillator when the sample undergoes to the superconductive state. These experimental findings allow to go a step beyond the comprehension of the not yet solved mechanism of high temperature superconductivity because they show clearly that the occurrence of superconductivity in cuprates is accompanied by a true modification of electronic properties in the visible optical range that cannot be explained as a simple thermal effects. Starting from a strong coupling analysis of the equilibrium optical spectra we develop a differential model of the dielectric function to disentangle the temperature of the hot electronic carriers and the bosonic spectrum. These results open the possibility to clarify the character of the bosons (phonon or spin fluctuation) constituting the glue that binds electron together to form Cooper pairs.

Poster 50

Superconducting Gap of $Ba(Fe_{1-x}Co_x)_2As_2$ studied by Raman spectroscopy

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We report electronic Raman scattering measurements on the iron-pnictide superconductor $Ba(Fe_{1-x}Co_x)_2As_2$ single crystals. In the superconducting state, we observe a pair-breaking peak in the B_{2g} symmetry at around 75 cm^{-1} for optimal doping ($x = 0.065$). A weaker pair-breaking peak is also detected at higher energy in the A_{1g} symmetry but only in the optimal doped crystal. The two superconducting gaps likely originate from two different Fermi surface sheets. Analysis of the low energy response in the B_{2g} symmetry indicates a strongly anisostropic gap, possibly including nodes.

The 9th International Conference on Low Energy Electrodynamics in Solids

Les Diablerets, July 5-10, 2010

List of participants

LEES 2010 : List of participants

Armitage, N. Peter	Po-47
Auerbach, Assa	Or-We-06
Averitt, Richard	Po-32
Bartkowiak, Marek	Po-40
Basov, Dimitri	Or-Fr-01
Berthier, Claude	Or-Tu-13
Blumberg, Girsh	Po-46
Boebinger, Greg	Or-Fr-12
Burch, Kenneth	Po-18
Calvani, Paolo	Or-Sa-07
Cappelluti, Emmanuele	Po-12
Carbone, Fabrizio	Or-We-12
Carr, G. Lawrence	Or-Tu-06
Chauviere, Ludivine	Po-50
Ciucchi, Sergio	Or-Tu-05
Crassee, Iris	Po-43
Dal Conte, Stefano	Po-49
Damascelli, Andrea	Or-We-08
Davis, J.C. Seamus	Or-Fr-11
de Sousa, Rogério	Po-31
Deisenhofer, Joachim	Po-13
Dil, Hugo	Or-Fr-06
Dubroka, Adam	Or-Fr-13
Egetenmeyer, Nikola Anna	Po-29
Falkovsky, Leonid	Po-01
Fanfarillo, Laura	Po-05
Fausti, Daniele	Or-Tu-10
Gasparov, Lev	Po-11
Gavilano, Jorge	Po-24
Gedik, Nuh	Or-We-11
Gerber, Simon	Or-Th-04
Giannetti, Claudio	Or-We-13
Greene, Richard	Po-44
Grioni, Marco	Or-We-09
Grüninger, Markus	Po-28
Gusynin, Valery	Po-21
Hackl, Rudi	Or-We-02
Hanaguri, Tetsuo	Or-We-03
Hancock, Jason	Po-42
Hasan, M.K.	Or-Fr-05
Hirjibehedin, Cyrus	Or-Tu-11
Hüvonen, Dan	Or-Sa-03
Iizuka, Takuya	Po-22
Jenkins, Nathan	Po-41
Jörger, Michael	Po-10
Kadowaki, Kazuo	Or-Tu-09
Kimura, Shin-ichi	Or-Th-01
Kuntscher, Christine A.	Or-Fr-03, Po-17
Kuzmenko, Alexey	Or-Fr-09
Laad, Mukul, Suresh	Po-04
LaForge, Andrew	Po-30
LeBlanc, James	Po-14
Leitenstorfer, Alfred	Or-Th-07
Levallois, Julien	Po-39
Litvinchuk, A.P.	Po-16
Liu, Wei	Po-48
Lucarelli, Andrea	Or-We-04
Lupi, Stefano	Or-Fr-02
Maggio-Aprile, Ivan	Po-38
Mansson, Martin	Po-34, Po-35, Po-36
Marsiglio, Frank	Po-37
Mercure, Jean-Francois	Or-Th-02
Mühlbauer, Sebastian	Or-Th-06
Munzar, Dominik	Po-25
Nicol, Elisabeth	Or-Fr-10, Po-09
Nicoletti, Daniele	Po-20
Okamura, Hidekazu	Or-Fr-04
Perfetti, luca	Or-Tu-04
Perucchi, Andrea	Po-33
Pfuner, Florian	Po-02
Pimenov, Andrei	Or-Sa-04
Piriou, Alexandre	Or-We-10
Potemski, Marek	Or-Fr-08
Pronin, Artem	Po-23
Proust, Cyril	Or-Tu-01
Prsa, Krunoslav	Po-08
Radovic, Milan	Po-26
Razzoli, Elia	Or-Tu-02
Ruegg, Christian	Or-Tu-12
Sacuto, Alain	Or-We-05
Sassa, Yasmine	Po-19
Sawatzky, George Albert	Or-We-01
Schafgans, Alexander	Po-06
Scheffler, Marc	Or-Th-03
Schleck, Renaud	Or-Sa-02
Sharapov, Sergei	Po-03
Shen, Kyle	Or-Sa-06
Sichelschmidt, Jörg	Po-15
Tajima, Setsuko	Or-Tu-03
Tanner, David	Or-Tu-08
Thirunavukkuarasu, Komalavalli	Or-Th-05
van Heumen, Erik	Or-We-07
van Loosdrecht, Paul	Or-Tu-07
van Mechelen, Dook	Or-Fr-07
Veenstra, Christian	Po-45
White, Jonathan Stuart	Or-Sa-01
White, Jonathan Stuart	Po-27
Wu, Dan	Po-07
Zhou, Kejin	Or-Sa-05