TT 35: PhD Symposium: Quantum Phase Transitions: Emergent Phenomena beyond Elementary Excitations (organized by MA, jDPG)

Organizers: G. Benka, P. Geselbracht, F. Rucker, S. Säubert, and C. Schnarr (TU München)

Traditionally, physics has focused on understanding the stable phases of matter like superconductivity or magnetism. Particle like states, dominating the low-energy physics of such systems, so-called elementary excitations, have been studied extensively in the past century and play an important role in our understanding of solid state physics. Modern material science and new experimental techniques, however, led to the discovery of completely different types of states, in which all electronic properties are dominated by a continuum of fluctuations. Such states arise in the vicinity of phase transitions, which are accessed by the variation of a non-thermal control parameter at zero temperature, so-called quantum phase transitions. Even though quantum phase transitions are strictly defined to be at zero temperature, the quantum critical continuum which surrounds continuous quantum phase transitions can influence electronic systems over a wide range of the phase diagram. This leads to the emergence of unique properties, new phenomena as unconventional superconductivity and the breakdown of the concept of elementary excitations. While the research on quantum phase transitions has started in a small community with the investigation of materials with strong electronic correlations, the interest in this field of research has grown fundamentally in the past years. This is attributed to the discovery of materials, which are much easier to access experimentally, as well as to the fact that the theoretical concepts are relevant to a broad range of physics. This makes quantum phase transitions one of the most vivid research topics in physics over the past decade. This symposium brings together the most recognized international speakers of this field to give a tutorial introduction to conventional and unconventional quantum criticality as well as to highlight recent experimental and theoretical advances. The interplay between tutorials and up to date research talks addresses a very broad audience and will stimulate an interdisciplinary exchange of knowledge which makes this field of research attractive for a larger community. Quantum phase transitions represent a very important area of research for a broad community of PhD students with rather different background. Keeping up to date with such an active field of research, however, is very demanding and time consuming for PhD students, as appropriate further training possibilities are only rarely offered and often focus on extremely specialised topics. This symposium will offer such an opportunity for PhD students working on quantum phase transitions, as well as for students and physicists working in other areas.

Time: Tuesday 9:30–16:30 Location: EB 301

Invited Talk TT 35.1 Tue 9:30 EB 301
Experimental Studies of Quantum Phase Transitions — •Andrew Mackenzie — Max-Planck-Institute for Chemical Physics of Solids, Dresden, Germany

In my lecture I will review what is known about quantum criticality produced by tuning systems close to magnetic instabilities. I will discuss the key physics behind quantum criticality, and then describe some model experimental systems. I will concentrate on the importance of thermodynamic measurements in classifying both quantum criticality and the novel phases that form in its vicinity.

Invited Talk TT 35.2 Tue 10:15 EB 301
Metallic Quantum Ferromagnets — •Manuel Brando — Max Planck Institute for Chemical Physics of Solids, Noethnitzer Str. 40, 01187 Dresden, Germany

In my talk I will review studies on quantum criticality with focus on metallic ferromagnets. The existence of a ferromagnetic quantum critical point has been a matter of discussion as long as 40 years ago, but had been dismissed in the past 15. During the last years several ferromagnetic metals have been tuned across the ferromagnetic quantum phase transition. Here, astonishing discoveries were made that are extending our understanding of ferromagnetic quantum criticality.

TT 35.3 Tue 10:45 EB 301
Neutron-Depolarisation Imaging of the Ferromagnetic Quantum Phase Transition in ZrZn2 — •Philipp Schmakat[1,2], Marco Halder[1], Georg Brandl[1,2], Michael Schulz[2], Stephen Hayden[3], Robert Georgii[2], Peter Böni[1], and Christian Pfleiderer[1] — [1]Physik Department E21, Technische Universität München, Germany — [2]Forschungs-Neutronenquelle Heinz Maier-Leibnitz, D-85748 Garching, Germany — [3]H. H. Wills Physics Laboratory, University of Bristol, Bristol BS8 1TL, United Kingdom

When a polarised neutron beam traverses a ferromagnetic material, the orientation and strength of the polarisation changes sensitively as a function of the ferromagnetic moment and the size of the ferromagnetic domains. We have developed an experimental set up that allows to perform neutron depolarisation imaging as a function of magnetic field. In a study of the ferromagnetic quantum phase transition in the weak itinerant ferromagnet ZrZn2 under pressure we find, that a peculiar field dependence of the neutron depolarisation survives on the paramagnetic side of the temperature versus pressure phase diagram. This provides putative evidence for the emergence of complex magnetic textures.

30 min. Coffee Break

Invited Talk TT 35.4 Tue 11:30 EB 301
Theoretical Concepts of Quantum Phase Transitions — •Matthias Vojta — Technische Universität Dresden, Germany

This tutorial will cover theoretical concepts and ideas for the description of quantum phase transitions. Starting from order parameters and order-parameter field theories, it will discuss critical exponents and scale invariance, the fascinating interplay of classical and quantum mechanical fluctuations at finite temperatures, and the quantum-to-classical correspondence. Further topics will include interaction-driven metal-insulator transitions, topological phase transitions, and the role of quenched disorder. Throughout the talk, microscopic models will be used for illustration.

Invited Talk TT 35.5 Tue 12:15 EB 301
Quantum criticality and beyond — •Andrew Schofield — School of Physics and Astronomy, University of Birmingham, Edgbaston, Birmingham, B15 2TT United Kingdom.

The exploration of quantum critical points has provided an extraordinarliy fruitful direction for experimentalists and theorists alike to investigate new ordering principles for correlated matter. Beyond the basic concepts, the field has a number of outstanding questions which motivate current research - from the interplay between critical fluctuations and other forms of order, to the theoretical framework which governs quantum critical behaviour in physical systems. My talk will explore these questions and their context.

TT 35.6 Tue 12:45 EB 301

Universal Postquench Prethermalization at a Quantum Critical Point — •Pia Gagel[1], Peter Orth[1], and Jörg Schmalian[1,2] — [1]Institute for Theory of Condensed Matter, Karlsruhe Institute of Technology (KIT), 76131 Karlsruhe, Germany — [2]Institute for Solid State Physics, Karlsruhe Institute of Technology (KIT), 76021 Karlsruhe, Germany

We consider an open system near a quantum critical point that is suddenly moved towards the critical point. The bath-dominated diffusive nonequilibrium dynamics after the quench is shown to follow scaling behavior, governed by a critical exponent that emerges in addition to the known equilibrium critical exponents. We determine this exponent and show that it describes universal prethermalized coarsening dynamics of the order parameter in an intermediate time regime. Implications of this quantum critical prethermalization are: (i) a power law rise of order and correlations after an initial collapse of the equilibrium state and (ii) a crossover to thermalization that occurs arbitrarily late for sufficiently shallow quenches.

Lunch Break

Invited Talk TT 35.7 Tue 14:00 EB 301

Quantum Criticality in Quantum Magnets — •Christian Rüegg — Paul Scherrer Institute, Laboratory for Neutron Scattering and Imaging, Switzerland — University of Geneva, Department of Quantum Matter Physics, Switzerland

Quantum magnets are exceptional solid-state model systems for high-precision studies of quantum criticality [1]. Recent results from such studies include complex phases like spin Luttinger-liquids and excitations realized in low-dimensional and frustrated systems [2-4], the exciting physics of impurities and quenched disorder [5], and fractionalization and the emergence of novel excitations near quantum critical points [2,6]. Studies of model oxides and halides by neutron scattering and complementary experimental techniques will be presented. These experimental results will be discussed in the context of recent developments of powerful computational methods enabling fully quantitative analysis and of related work on other model systems like gases of ultracold atoms.

[1] T. Giamarchi et al., Nature Physics 4, 198 (2008). [2] B. Thielemann et al., Phys. Rev. Lett. 102, 107204 (2009). [3] Y. Kohama et al., Phys. Rev. Lett. 109, 167204 (2012). [4] F. Casola et al., Phys. Rev. Lett. 110, 187201 (2013). [5] S. Ward et al., J. Phys.: Condens. Matter 25, 014004 (2013). [6] P. Merchant et al., Nature Physics 10, 373 (2014).

TT 35.8 Tue 14:30 EB 301

Spin Hall effect in two-dimensional systems — •Annika Johansson[1], Christian Herschbach[1,2], Dmitry Fedorov[2,1], and Ingrid Mertig[1,2] — [1]Martin Luther University Halle-Wittenberg, Halle, Germany — [2]Max Planck Institute of Microstructure Physics, Halle, Germany

A relativistic phase shift model (RPSM), derived as a generalization of the resonant scattering model [1-4], was introduced recently [5] to describe the skew-scattering mechanism of the spin Hall effect (SHE) caused by impurities in bulk crystals. The RPSM was found to be an appropriate model to obtain a simple qualitative description of the SHE for dilute bulk alloys based on host crystals with free-electron like Fermi surfaces and weak spin-orbit coupling [6].

Here, we present its analogue for two-dimensional (2D) systems. The proposed 2D-RPSM provides good qualitative agreement with *ab initio* results obtained for dilute alloys based on one-monolayer noble metal films. However, the colossal SHE caused by Bi impurities [7] is not reproduced due to a strong influence of vertex corrections for these systems not properly taken into account by the model. The relation of the 2D-RPSM to the 2D resonant scattering model [8] is also discussed.

[1] A. Fert *et al.*, J. Magn. Magn. Mater. **24**, 231 (1981); [2] G.Y. Guo *et al.*, PRL **102**, 036401 (2009); [3] A. Fert and P.M. Levy, PRL **106**, 157208 (2011); [4] P.M. Levy *et al.*, PRB **88**, 214432 (2013); [5] D.V. Fedorov *et al.*, PRB **88**, 085116 (2013); [6] A. Johansson *et al.*, J. Phys.: Condens. Matter **26**, 274207 (2014); [7] C. Herschbach *et al.*, PRB **90**, 180406(R) (2014); [8] B. Gu *et al.*, arXiv:1402.3012.

Invited Talk TT 35.9 Tue 14:45 EB 301

Beyond quantum phase transitions — •Wilhelm Zwerger — TU Muenchen

The talk will discuss quantum phase transitions in the context of ultra cold gases in optical lattices. Moreover, it will address the issue of quantum phase transitions which show up only in dynamical properties, the so called many-body localization.

TT 35.10 Tue 15:15 EB 301

Topological superconductivity and unconventional pairing in oxide interfaces — •Mathias Scheurer[1] and Jörg Schmalian[1,2] — [1]Institut für Theorie der kondensierten Materie (Karlsruher Institut für Technologie), Karlsruhe, Deutschland — [2]Institut für Festkörperphysik (Karlsruher Institut für Technologie), Karlsruhe, Deutschland

To pinpoint the microscopic mechanism for superconductivity has proven to be one of the most outstanding challenges in the physics of correlated quantum matter. Thus far, the most direct evidence for an electronic pairing mechanism is the observation of a new symmetry of the order parameter, as done in the cuprate high-temperature superconductors. Alternatively, global, topological invariants allow for a sharp discrimination between states of matter that cannot be transformed into each other adiabatically. In this talk we present an unconventional pairing state for the electron fluid in two-dimensional oxide interfaces and establish a direct link to the emergence of nontrivial topological invariants. Topological signatures, in particular Majorana edge states, can then be used to detect the microscopic origin of superconductivity. In addition, we show that the density wave states that compete with superconductivity have very rich spatial textures (magnetic vortices, Skyrmions) and sensitively depend on the nature of the pairing interaction.

TT 35.11 Tue 15:30 EB 301

Quantum criticality in frustrated $\mathbf{CePd_{1-x}Ni_xAl}$ — •Akito Sakai[1], Stefan Lucas[2], Veronika Fritsch[1,3], Philipp Gegenwart[1], Oliver Stockert[2], and Hilbert v. Löhneysen[3] — [1]Universität Augsburg, Institut für Physik, Elektronische Korrelationen und Magnetismus, Germany — [2]Max-Planck-Institut für chemische Physik fester Stoffe, Dresden, Germany — [3]Karlsruher Institut für Technologie, Physikalisches Institut, Germany

Various interesting behaviors such as non-Fermi liquid and unconventional superconductivity have been observed in the vicinity of quantum critical points (QCPs), which are induced by the competition between Kondo effect and RKKY interaction. Another route to achieve the QCP is geometric frustration. CePdAl is one of the candidates of such quantum critical frustrated systems [1, 2]. In addition to the heavy fermion behaviors, a partial antiferromagnetic ordering is revealed below $T_{\rm N}$ = 2.7 K, where one third of the Ce moments in the distorted kagomé lattice are still paramagnetic [1]. In this presentation, we discuss the possible QCP in $CePd_{1-x}Ni_xAl$ revealed by the specific heat measurement in the dilution refrigerator.

[1] A. Dönni *et al.*, J. Phys.: Condens. Matter **8**, 11213 (1996).
[2] V. Fritsch *et al.*, Phys. Rev. B **89**, 054416 (2014).

TT 35.12 Tue 15:45 EB 301

Resonant inelastic x-ray scattering of magnetic excitations in the novel 5d^4 iridate $\mathbf{Ba_2YIrO_6}$ — •Maximilian Kusch[1,2], T. Dey[1], A. Maljuk[1], S. Wurmehl[1], B. Büchner[1,2], V. M. Katakuri[3], B. H. Kim[3], D. V. Efremov[3], J. van den Brink[3], M. Moretti[4], M. Krisch[4], and J. Geck[1] — [1]Institute for Solid State and Materials Research, IFW Dresden, Helmholtzstrasse 20, 01069 Dresden, Germany — [2]Institut für Festkörperphysik, Technische Universität D-01062 Dresden, Germany — [3]Institute for Theoretical Solid State State Physics, IFW Dresden, Germany — [4]ESRF, B.P.220, 38043 Grenoble, France

In contrast to the much studied 5d^5 iridates with a spin-orbit coupled J=1/2 ground state, Ba_2YIrO_6 is a realization of a Ir-5d^4 system. For this case, a ground state J=0 is expected, i.e, Ba_2YIrO_6 should be non-magnetic. Surprisingly, our measurements of the magnetic susceptibility reveal sizable magnetic moments whose microscopic origin is still unclear. Theoretical studies indicate the important role of low-lying magnetic excitations, thereby providing a possible explanation for the unexpected magnetic susceptibility [Khaliullin Phys. Rev. Lett. 111 (2013)]. In addition, our theoretical models predict a considerable dispersion of the J=1 and J=2 excitations in Ba_2YIrO_6. To elucidate the unconventional magnetism of Ba_2YIrO_6 and to determine the dispersions of the J=1 and J=2 excitations experimentally, we performed RIXS studies of this novel 5d^4 compound. Here we present the results, focusing on the magnetic dispersions in a large region of q-space in comparison to our model calculations.

Posters

TT 35.13 Tue 16:15 EB 301

Fermi surface on the border of Mott transition in NiS_2 — •Hui Chang[1], Sven Friedemann[1,2], Monika Gamza[3], William Coniglio[4], David Graf[4], Stan Tozer[4], and Malte Grosche[1] — [1]Cavendish Laboratory, University of Cambridge, UK — [2]HH Wills Laboratory, University of Bristol, UK — [3]Department of Physics, Royal Holloway, University of London, Egham, UK — [4]National High Magnetic Field Laboratory, Tallahassee, Florida 32310, USA

The transition from a metallic to a correlated, or Mott, insulating state is a long-standing theme of fundamental interest in condensed matter research. Using quantum oscillation measurements in high magnetic fields to probe the electronic Fermi surface and effective carrier mass on the metallic side of the transition could provide much needed microscopic information. In the cuprates, such studies in samples doped into the metallic state have identified the Fermi surface structure in underdoped and overdoped regimes. Because the quantum oscillation signal is strongly suppressed in the presence of disorder, pressure rather than doping should ideally be used to reach the metallic state. We present the first observation of quantum oscillations from a pressure-metallised 3D Mott insulator. NiS_2 can be tuned through the Mott transition at a modest pressure of 30kbar. Quantum oscillations near the Mott transition are observed with the tunnel diode oscillator technique in magnetic fields up to 31T. The main observed oscillation frequency is consistent with the Fermi surface obtained within density functional theory, whereas the effective mass is significantly enhanced over the band mass.

TT 35.14 Tue 16:15 EB 301

Transport properties across the quantum phase transitions in $Mn_{1-x}Fe_xSi$ — •Fabian Jerzembeck[1], Marlies Gangl[1], Anna Kusmartseva[1,2], Andreas Bauer[1], and Christian Pfleiderer[1] — [1]Physik Department, Technische Universität München, D-85747 Garching, Germany — [2]Department of Physics, Loughborough University, UK-LE11 3TU Leicestershire, United Kingdom

Recent theory identify the thermal and electrical transport properties as a sensitive probe of the validity of the Fermi liquid description of the metallic state [1]. A prime example for a well understood, weakly spin-polarized Fermi liquid ground state has long been established in the weak itinerant helimagnet MnSi. We report a detailed study of the evolution of the thermal and electrical transport properties across the quantum phase transitions in $Mn_{1-x}Fe_xSi$ [2] down to temperatures of $\sim$2 K under magnetic fields up to 14 T. These data are complemented by additional selected measurements in $Mn_{1-x}Co_xSi$. As our main objective we consider the validity of the Wiedemann-Franz law across the quantum phase transitions in $Mn_{1-x}Fe_xSi$.

[1] R. Mahajan, M. Berkeshli, S. A. Hartnoll, Phys. Rev. B **88**, 125107 (2013). [2] A. Bauer *et al.*, Phys. Rev. B **82**, 064404 (2010).

TT 35.15 Tue 16:15 EB 301

Identification of a Brazovskii quantum phase transition in the Chiral Magnet MnSi — •Jonas Kindervater[1], Stefan Ernst[1], Andreas Bauer[1], Wolfgang Häussler[1,2], Nicolas Martin[1,2,3], Peter Böni[1], Markus Garst[4], and Christian Pfleiderer[1] — [1]Physik-Department, Technische Universität München, Germany — [2]Heinz Maier-Leibnitz Zentrum, Technische Universität München, Germany — [3]CEA Saclay, DSM/IRAMIS/Laboratoire Leon Brillouin, France — [4]Institute for Theoretical Physics, Universität zu Köln, Germany

In the chiral magnet MnSi the transition into the ordered phase is driven to first-order due to strongly interacting fluctuations, which can be explained within the framework of the Brazovskii scenario [1]. We report a small angle neutron scattering and high resolution neutron spin echo spectroscopy study on the quantum phase transition in $Mn_{1-x}Fe_xSi$. Upon suppressing the helimagnetic order by iron doping a putative quantum phase transitions is observed [2]. According to theory [3], a possible Brazovskii quantum phase transition might thereby be realized either as a first- or second-order transition or, alternatively, as a tricritical point. Our study gives insight in the precise nature of the strongly interacting chiral fluctuations and the nature of the quantum phase transitions realized in $Mn_{1-x}Fe_xSi$.

[1] M. Janoschek *et al.*, PRB **87**, 134407 (2013); [2] A. Bauer *et al.*, PRB **82**, 064404 (2010); [3] J. Schmalian and M. Turlakov, PRL **93**, 036405 (2004)

TT 35.16 Tue 16:15 EB 301

Tuning $ZrFe_4Si_2$ by Ge substitution: confirming the proximity to a magnetic quantum critical point — •Katharina Weber[1,2], Nandang Mufti[1], Til Goltz[2], Theo Woike[3], Hans-Henning Klauss[2], Christoph Bergmann[1], Helge Rosner[1], and Christoph Geibel[1] — [1]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany — [2]Institute of Solid State Physics, TU Dresden, Germany — [3]Institute for Structural Physics, TU Dresden, Germany

Magnetic systems with reduced dimensionality or frustration are attracting strong interest because these features lead to an increase of quantum fluctuations which often results in unusual, very interesting properties. Our previous studies evidence the AFe_4X_2 family (A = Y, Lu, Zr and X = Ge, Si) to cover the whole regime from frustrated antiferromagnetic (AFM) order up to the quantum critical point (QCP) separating the frustrated AFM ground state from the paramagnetic ground state. $ZrFe_4Si_2$ showed evidence for an unusual type of weak magnetic order and was therefore suspected to be near the QCP. In order to get a deeper insight into its ground state, we performed a detailed study of Ge substituted $ZrFe_4Si_2$, where Ge is suspected to stabilize the magnetic state because of a negative chemical pressure effect. We synthesized polycrystalline samples of $ZrFe_4(Si_{1-x}Ge_x)_2$ with $x = 2\,\%$ to $50\,\%$ and investigated their magnetic, thermodynamic, structural and transport properties. As expected with increasing Ge content the magnetic state is stabilized towards a well defined AFM order at high Ge content. This confirms the near-by QCP in $ZrFe_4Si_2$.