# TT 52: Quantum Impurities and Kondo Physics

Time: Thursday 9:30–12:45 Location: H7

TT 52.1 Thu 9:30 H7

**Drag of quantum impurities** — •Falko Pientka[1,2], Ovidiu Cotlet[3], Richard Schmidt[2,4], Gergely Zarand[5], Eugene Demler[2], and Atac Imamoglu[3] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [2]Department of Physics, Harvard University, Cambridge, Massachusetts, USA — [3]Institute of Quantum Electronics, ETH Zurich, Zurich, Switzerland — [4]Max Planck Institute of Quantum Optics, Garching, Germany — [5]Department of Theoretical Physics, Institute of Physics, Budapest University of Technology and Economics, Hungary

I will discuss transport of a mobile quantum impurity immersed in a moving bath. At strong interactions, the polaronic dressing of the impurity leads to a novel drag force exerted on the impurity by the bath. This drag force is absent for classical impurities and originates from coherent scattering events.

I will highlight experimental consequences of this effect for exciton polaritons in semiconductors, where the drag force allows for the control of photons by dc electric and magnetic fields as if they were charge carriers. Finally, I will mention an experiment which has recently demonstrated polariton drag in dc electric fields.

TT 52.2 Thu 9:45 H7

**Conventional and ferromagnetic Kondo regimes in frustrated quantum dot trimers coupled to ferromagnetic lead** — •Krzysztof Wójcik[1] and Ireneusz Weymann[2] — [1]Institute of Molecular Physics, Polish Academy of Sciences, 60-179 Poznań, Poland — [2]Faculty of Physics, Adam Mickiewicz University, 61-614 Poznań, Poland

Quantum dot trimers coupled to the metallic lead through one of the quantum dots are known to exhibit the quantum phase transition between the conventional anti-ferromagnetic Kondo regime and the ferromagnetic Kondo regime [1,2]. For geometrically symmetric case, the transition is protected by the symmetry arising from frustration in the nanostructure and has a level-crossing nature. On the contrary, for asymmetric trimers the level crossing may be avoided and the transition becomes of Kosterlitz-Thoules type [2,3]. In our contribution we examine the fate of this transition in the presence of ferromagnetic lead. We show that in the particle-hole symmetry (PHS) case the results remain qualitatively the same as in the non-magnetic case, and focus on presenting the consequences of the exchange field arising in the frustrated nanostructure outside the PHS point.

[1] A. K. Mitchell, T. F. Jarrold, D. E. Logan, Phys. Rev. B **79**, 085124 (2009).
[2] A. K. Mitchell, T. F. Jarrold, M. R. Galpin, D. E. Logan, J. Phys. Chem. B **117**, 12777 (2013).
[3] P. P. Baruselli, R. Requist, M. Fabrizio, E. Tosatti, Phys. Rev. Lett. **111**, 047201 (2013).

TT 52.3 Thu 10:00 H7

**Conductance of a molecular double-quantum dot in the Kondo regime: Effects of the Dzyaloshinskii-Moryia interaction** — •Peter Zalom, Richard Korytár, and Tomáš Novotný — Charles University, Prague, Czech Republic

Motivated by a recent experiment in a molecular junction [1], we investigate a double-dot singlet-triplet model in the Coulomb blockade by the means of a numerical renormalization group. We confirm that the magnetic-field induced degeneracy leads to a Kondo effect [2], which is perturbatively stable when Dzyaloshinskii-Moryia interaction (DMI) is included. Strong DMI suppresses the Kondo resonance in the differential conductance and leads to a non-trivial temperature dependence.

[1] M. Koole, J. C. Hummelen, H. S. van der Zant, Phys. Rev. B 94, 165414 (2016)
[2] M. Pustilnik, L. Glazman, Phys. Rev. B 64, 045328 (2001)

TT 52.4 Thu 10:15 H7

**Heat and charge transport in a charge 2-channel Kondo setup** — •Lars Fritz[1], Gerwin van Dalum[1], and Andrew Mitchell[2] — [1]Institute for Theoretical Physics and Center for Extreme Matter and Emergent Phenomena, Utrecht University, Leuvenlaan 4, 3584 CE Utrecht, The Netherlands — [2]School of Physics, University College Dublin, Dublin 4, Ireland

In this talk we describe charge and heat transport in a charge 2-channel Kondo setup. Charge transport in such a device has been measured recently and is theoretically well understood. We extend this work to study heat transport at the 2-channel non-Fermi liquid fixed point and find that the Wiedemann-Franz law is obeyed. We furthermore describe the Fermi liquid crossover towards the Kondo screened fixed point at which Wiedemann-Franz is violated. We end by connecting our findings at the non-Fermi-liquid fixed point to the Majorana character of the effective description of the critical point and argue that heat transport gives access to their central charge.

TT 52.5 Thu 10:30 H7

**Exploring Kondo lattices with inequivalent Ce-sites** — Jiří Pospíšil, Jiří Prchal, and •Jeroen Custers — Dept. of Condensed Matter Physics, Charles University, Ke Karlovu, 5, 121 16 Praha, Czech Republic

Strongly correlated electron systems with competing interactions provide a fertile ground for discovering exotic states of matter. As a particularly interesting setting we study heavy fermion (HF) systems with two crystallographically inequivalent local moment sites. These may lead to the formation of two Kondo sublattices with largely different Kondo temperatures. We expect such systems to show better tunability towards various kinds of quantum phase transitions than single-site Kondo systems, and to form novel phases. Here we present recent results on selected compounds, like $Ce_3Al_{11}$ [1], $Ce_3PtIn_{11}$ [2,3] and other. $Ce_3PtIn_{11}$ is highly interesting as it shows coexistence of antiferromagnetism ($T_N = 2$ K) and superconductivity ($T_c = 0.32$ K). From entropy analysis it has been speculated that in this compound the $Ce_I$ (2 ions) remains paramagnetic and at lower $T$ evokes superconductivity while the $Ce_{II}$ site is responsible for the magnetic ordering. Furthermore we will discuss several pressing questions: Do the two Kondo scales compete or cooperate? Can the interplay lead to Kondo breakdown, partially screened phases, or even fractionalized Fermi liquids?

[1] A. Berton *et al.*, J. Magn. Magn. Mat. **15-18,** 379 (1980)
[2] M. Kratochvílová *et al.*, J. Cryst. Growth **387**, 47 (2014)
[3] J. Prokleška *et al.*, Phys. Rev. B **92,** 161114(R) (2015)

TT 52.6 Thu 10:45 H7

**Quantum Monte Carlo study of the SU($N$) Kondo Lattice Model** — •Marcin Raczkowski and Fakher Assaad — Institut für Theoretische Physik und Astrophysik, Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany

The two-dimensional half-filled Kondo lattice model with exchange $J$ features a quantum phase transition which stems from the competition between the Ruderman-Kittel-Kasuya-Yoshida (RKKY) interaction and the Kondo screening. Quantum Monte Carlo (QMC) simulations predict that below the magnetic energy scale $T_{\mathrm{RKKY}}$, the single-particle gap scales as $J$. This contrasts with an exponentially small gap in paramagnetic large-$N$ and dynamical mean-field theories which omit spatial fluctuations. Here, we perform zero-temperature QMC simulations of the SU(N) symmetric Kondo lattice model and elucidate necessary conditions for recovering the large-$N$ limit.

TT 52.7 Thu 11:00 H7

**Heavy quasiparticle bands in the underscreened quasiquartet Kondo lattice** — •Alireza Akbari[1] and Peter Thalmeier[2] — [1]Asia Pacific Center for Theoretical Physics, POSTECH, Pohang, Korea — [2]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany

We study the quasiparticle spectrum in an underscreened Kondo-lattice (KL) model that involves a single spin degenerate conduction band and two crystalline-electric-field (CEF) split Kramers doublets coupled by both orbital-diagonal and non-diagonal exchange interactions. We find the three quasiparticle bands of the model using a constrained fermionic mean field approach. While two bands are similar to the one-orbital model a new genuinely heavy band inside the main hybridization gap appears in the quasiquartet model. Its dispersion is due to effective hybridization with conduction states but the bandwidth is controled by the size of the CEF splitting. Furthermore several new indirect and direct hybridztion gaps may be identified. By solving the selfconsistency equation we calculate the CEF-splitting and exchange dependence of effective Kondo low energy scale, hybridiza-

tion gaps and band widths. We also derive the quasiparticle spectral densities and their partial orbital contributions. We suggest that the two-orbital KL model can exhibit mixed CEF/Kondo excitonic magnetism.
[1] Phys. Rev. B 98, 155121 (2018)

**15 min. break.**

TT 52.8 Thu 11:30 H7

**Many-body approach to Luttinger's theorem of the Kondo lattice** — •Steffen Sykora[1] and Klaus W. Becker[2] — [1]IFW Dresden, 01069 Dresden, Germany — [2]Institut für Theoretische Physik, TU Dresden, 01062 Dresden, Germany

A numerical verification of Luttinger's theorem, based on a recently developed many-body approach, is given for the Kondo-lattice model. For a two-dimensional lattice the completely localized spins ($S = 1/2$) are found to contribute to the Fermi sea volume as if they were electrons, which is in agreement with Oshikawa's topological proof of Luttinger's theorem. Underpinning this result we show results of the momentum-resolved one-particle spectral function where nearly dispersionless excitations appear clearly below the Fermi level for different values of the conduction electron filling. Numerical integration over momentum and energy always leads to the correct particle number of the localized spins according to the well-accepted picture of a large Fermi surface. To our knowledge, the present study is the first many-body approach, which is able to reproduce the correct value of Luttinger's theorem for this model.

TT 52.9 Thu 11:45 H7

**Mutual information in a frustrated Kondo lattice model** — •Toshihiro Sato, Francesco Parisen Toldin, and Fakher F. Assaad — Institut für Theoretische Physik und Astrophysik, Universität Würzburg, Germany

A key notion in heavy fermion systems is the entanglement between conduction electrons and localized spin degrees of freedom. To study these systems from this point of view, we investigate the mutual information in a half-filled Kondo lattice model with geometrical frustration. In addition to the conventional Kondo insulating and antiferromagnetic phases, frustration leads to a so called partial Kondo screened phase [T. Sato, F. F. Assaad, T. Grover, Phys. Rev. Lett. 120, 107201 (2018)]. Using a negative-sign-free auxiliary field quantum Monte Carlo approach, we demonstrate that the area law coefficient of the mutual information shows sharp crossovers (on our finite lattices) at quantum phase transitions. Furthermore, and deep in the respective phases, it can be understood in terms of a product wave function [1].
[1] F. Parisen Toldin, T. Sato, F. F. Assaad, arXiv:1811.11194 (2018)

TT 52.10 Thu 12:00 H7

**M-edge RIXS as a probe of coherent dynamics in strongly hybridized Kondo systems** — •Marein Rahn[1], Eric Bauer[1], Jon Lawrence[2], Filip Ronning[1], and Marc Janoschek[3] — [1]Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA — [2]Department of Physics and Astronomy, University of California, Irvine, CA 92697, USA — [3]Laboratory for Neutron Scattering, ETH Zürich and Paul Scherrer Institute, CH-5232 Villigen, Switzerland

In rare earth intermetallics with a Kondo energy scale that is much larger than magnetic interactions or crystal field splittings, the screening of local moments leads to a non-magnetic Fermi liquid ground state. The corresponding electronic fluctuations between magnetic and non-magnetic valence configurations renormalize the charge and spin excitations. Due to recent instrumental advances in high-resolution soft resonant inelastic x-ray scattering (RIXS), Kondo phenomena on the order of 30 meV have become accessible to this new spectroscopic technique. The observation of a pronounced momentum-space dependence of the corresponding $f$-$f$ inter-band transitions points to the fact that, at low temperature, the lattice character of the dense Kondo system is imprinted onto the local screening process. This aspect goes beyond traditional impurity-based theoretical approaches, and would instead require a computation of the RIXS response on the basis of a strongly hybridized electronic band structure (as achieved by LDA+DMFT). With the interest to work towards a universal quantitative model of these three spectroscopies, we present our recent insights from RIXS, photoemission and inelastic neutron scattering.

TT 52.11 Thu 12:15 H7

**Residual Conduction in Kondo Insulators** — •Emanuele Maggio, Matthias Pickem, and Jan Tomczak — Institute of Solid State Physics, TU Wien, A-1040 Vienna, Austria

Correlated narrow-gap semiconductors [1] display a pronounced tendency towards resistivity saturation at low temperatures. Especially in heavy-fermion Kondo insulators, the persistence of residual conduction is a long-standing puzzle. Theories of conventional semi-conductors hint at extrinsic impurity-states. Complementarily, it has recently been suggested that certain Kondo insulators may harbour surface states that are protected by topological properties of their bulk electronic structure [2]. Experimentally, there is contrasting evidence (e.g., [3]), insinuating that the nature of conducting states in Kondo insulators may be non-universal. In this contribution, we put forward a new interpretation: we attribute the deviation from activated behaviour in the resistivity to short-comings of the relaxation-time approximation in the calculation of transport properties for correlated materials. Based on a dynamical mean-field theory description and a new linear-response transport scheme, we investigate Ce-based Kondo insulators*such as the prototypical $Ce_3Bi_4Pt_3$. Finding overall good agreement with experiment, we characterise the resistivity in terms of a crossover temperature T* marking the onset of saturation. Studying its control parameters, we delineate the applicability of our scenario to other systems.
[1] J. M. Tomczak, J. Phys.: Condens Mat 30, 183001 (2018)
[2] M. Dzero et al., Phys. Rev. Lett. 104, 106408 (2010)
[3] N. Wakeham et al., Phys. Rev. B 94, 035127 (2016)

TT 52.12 Thu 12:30 H7

**Possible topological effects seen by ESR in the Kondo insulator $SmB_6$ doped by Gd.** — Jean Carlo Souza[1,2], P.F.S. Rosa[3], •Jörg Sichelschmidt[1], S. Wirth[1], Z. Fisk[4], and P.G. Pagliuso[1] — [1]MPI for Chemical Physics of Solids, Dresden — [2]Instituto de Física "Gleb Wataghin", UNICAMP, Campinas, SP, Brazil — [3]Los Alamos National Laboratory, New Mexico 87545, USA — [4]Department of Physics and Astronomy, University of California, Irvine, USA

We utilized Electron spin resonance (ESR) as a microscopic technique to explore the spin dynamics of $Gd^{3+}$ substituted in the Kondo insulator $SmB_6$. For Gd concentrations larger than 400 ppm the ESR spectra at $T < 30$ K acquire a typical metallic line shape while the resistivity shows a Kondo-insulating bulk material. This demonstrates that the hybridization gap is closing locally around the Gd-site. For highly diluted Gd (200 ppm) the spectral shapes are affected by the diffusive transport of spins near the surface. The dependence on temperature, magnetic field, and microwave power provides a link between this diffusive ESR line shape to the presence of topological surface states. A similar result was reported for anomalous diffusive ESR effects for $Nd^{3+}$ in the semimetal YBiPt [1]. Moreover, the temperature dependence of these diffusive ESR effects is similarly seen in the surface response of scanning tunneling spectroscopy [2].
[1] G. G. Lesseux et al., J. Phys. Condens. Matter 28, 125601 (2016)
[2] L. Jiao et al., Nat. Commun. 7, 13762 (2016)