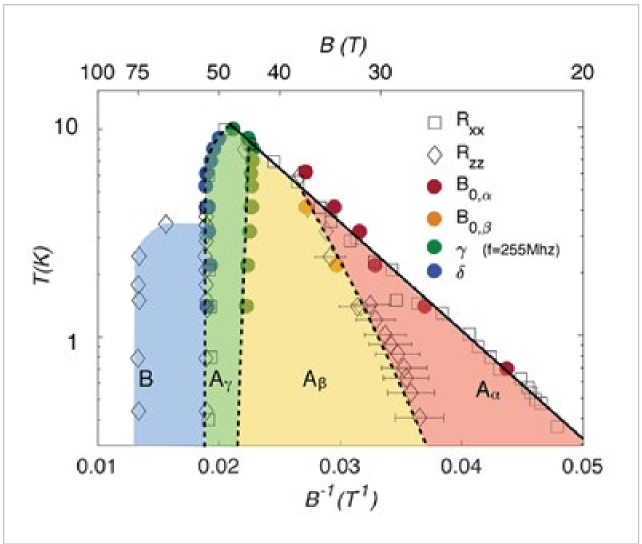
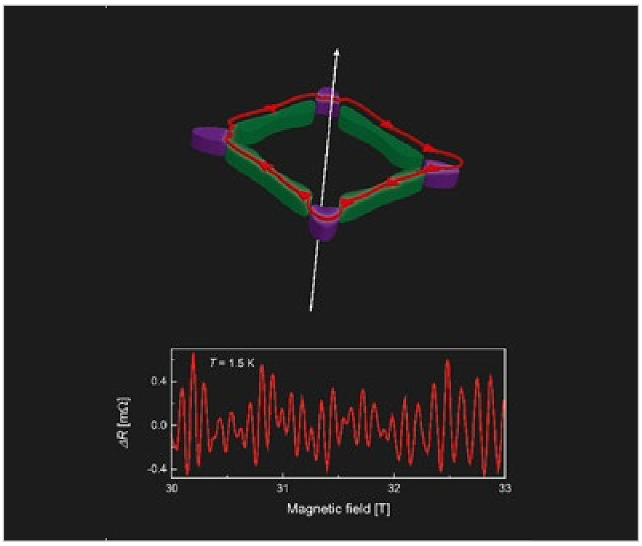
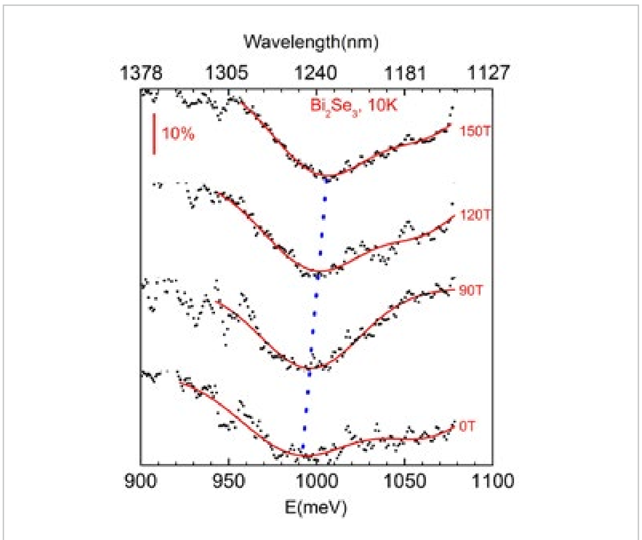
European Magnetic Field Laboratory

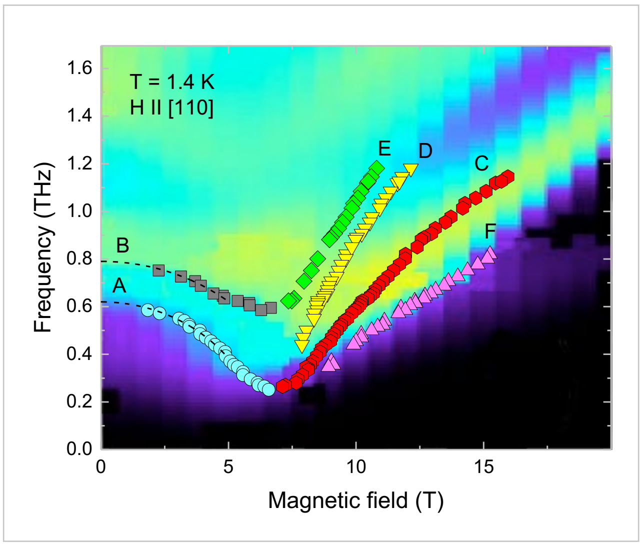
EMFLNEWS

N°4 2017









CONTENTS

DEAR READER

I hope you all had a great start in 2018. All the best on behalf of the whole EMFL staff with lots of excellent scientific results to come. Indeed, during the last year our users were highly productive with many high-level publications reporting on the extraordinary science they did in our EMFL facilities. Some highlight examples of this science you will find, as usual, on the following pages.

The last call for magnet time in 2017 closed with a record number of proposals showing the ever increasing demand for high-magnetic-field experiments using our facilities. We will do our best to satisfy your requests and will provide you with the expert support from our local contacts you are used to. But of course there is always room for improvement and for that we need the feedback from our users. A good chance to interact directly with the EMFL staff and management as well as with other users and the User Committee will be the yearly EMFL user meeting hosted this year in the High Field Magnet Laboratory, Nijmegen, on Thursday, June 21, 2018 (see the announcement in this issue). I hope to see many of you during this event in Nijmegen.

Have a stimulating reading,
Jochen Wosnitza
Director HLD
Chairman EMFL

MEET OUR PEOPLE

Dr. Tino Gottschall, HLD Dresden

› Dr. Tino Gottschall

"In the last years, I came to the Dresden High Magnetic Field Lab a couple of times as a user by myself. Since May 2017, I am now a local contact for pulsed-field experiments assisting other users in their research. What a surprising development!"

Dr. Tino Gottschall studied physics at the TU Dresden and went for his PhD to the Technical University of Darmstadt. After his scientific stay at the University of Barcelona, Gottschall became a postdoctoral researcher and local contact at the Dresden High Magnetic Field Laboratory. He supervises external users in pulsed-field measurements of magnetization and magnetocaloric effects.

"The experimental determination of the adiabatic temperature change of magnetocaloric materials in pulsed magnetic fields is actually a pretty challenging task. It took us about two years of testing, dating back to 2014, in order to develop this technique. However, our efforts paid off and now we have a fantastic tool not only to study magnetocaloric effects with highest sensitivity. It is also possible to investigate the kinetics of first-order transitions. Together with our collaborators at TU Darmstadt and University of Duisburg-Essen, we are able to cover field-sweeping rates over five orders of magnitude from 0.1 to more than 1000 Ts-1 which is unique in this form worldwide."

Besides the user support, Dr. Gottschall is working on calorimetric techniques in static fields as well. Currently, he builds up a versatile calorimeter for the fast and reliable determination of the specific heat in magnetic fields up to 16 T. But also the further development of the experimental setups for pulsed fields is an issue.

"Using standard thermocouples limits the operational range of the measurements. Below 40 K, the sensitivity is simply too poor. At the moment, we are aiming to extend our measurement range towards lower temperatures. This is of particular interest because there are many different kinds of phase transitions in strongly correlated electron systems showing magnetocaloric effects at low temperatures. Having the possibility to observe these effects directly is an exciting goal for the future."

ULTRASOUND MEASUREMENTS IN THE QUANTUM LIMIT OF GRAPHITE

D. LeBoeuf, Gabriel Seyfarth M. Frachet, W. Tabis LNCMI, B. Fauqué ESPCI

In presence of a magnetic field, the charge carriers of a Fermi sea group into Landau levels. At high enough magnetic field, the so-called quantum limit is reached when the carriers are confined into the lowest Landau level. In such limit, electronic correlations are at work to generate new electronic states, such as composite fermions and topological states in the fractional quantum Hall effect in two-dimensional systems. In three dimensions, this limit is still largely unexplored but exotic states of matter have been predicted to emerge. The exploration of this limit in the semimetal graphite started more than three decades ago. Renewed interest arose recently with magnetoresistance measurements that revealed unexpected transitions [B. Fauqué et al., Phys. Rev. Lett. **110**, 266601 (2013)]. Mostly studied with transport measurement so far, the exact nature of those phases and the mechanism responsible for their appearance remain elusive.

We report the first study of the elastic constant and ultrasound attenuation of graphite in DC and pulsed magnetic fields. With the ultrasound technique, we were able to provide the first thermodynamic evidence for the existence of a series of phase transitions in the quantum limit of graphite. By performing a thermodynamic analysis of the sound-velocity anomaly, we conclude this electronic phase is likely to have a significant coupling to the lattice. In addition, we performed magnetostriction measurements in collaboration with the HFML Nijmegen (M. Berben and S. Wiedmann) and resistivity measurements. The combination of those techniques made it possible to build the phase diagram shown in the Figure. This diagram highlights the surprising richness of graphite. The role of the lattice in the formation of those states has so far been overlooked theoretically. Our results have profound implications for the understanding of quantum-limited electron fluids.

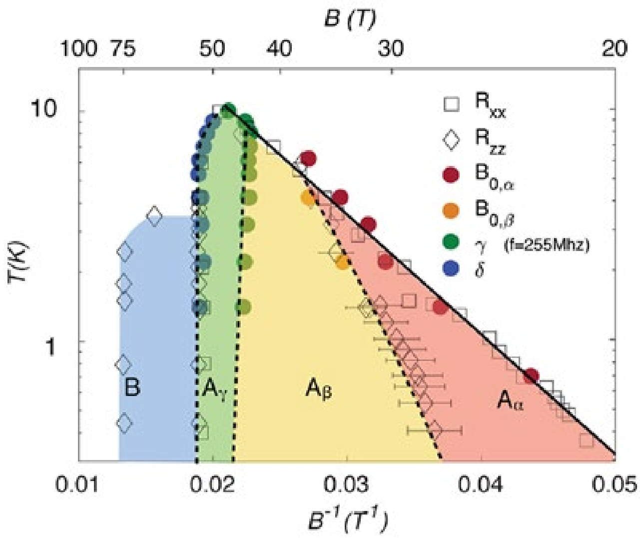


Figure: Phase diagram beyond the quantum limit of graphite, extracted from ultrasound (colored circles) and magnetoresistance measurements (open symbols). In this work we focused on the phases A_α, A_β and A_γ

Thermodynamic signatures of the field-induced states of graphite, D. LeBoeuf, C. W. Rischau, G. Seyfarth, R. Küchler, M. Berben, S. Wiedmann, W. Tabis, M. Frachet, K. Behnia, and B. Fauqué, Nat. Comm. **8**, 1337 (2017).

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ORBITING THE DIRAC NODAL LINE: UNCONVENTIONAL QUANTUM OSCILLATIONS IN ZrSiS

Sergio Pezzini, Maarten R. van Delft, Nigel E. Hussey, Steffen Wiedmann, HFML Nijmegen

Semimetals hosting band-touching points in reciprocal space are classified as Weyl, Dirac, and nodal-line, depending in which form this touching occurs. In ZrSiS, a tetragonal crystal with Si square-net planes, linearly-dispersing bands touch each other along a three-dimensional loop. ZrSiS, compared to many other topological semimetals, has an ideal band structure to investigate the physics of Dirac quasiparticles, since all the energy bands at the Fermi level possess a linear dispersion in a large range up to 2 eV.

Magnetotransport experiments up to 33 T were performed at HFML Nijmegen on high-quality ZrSiS crystals, grown at Max Planck Institute for Solid State Research in Stuttgart. When applying a high magnetic field parallel to the c axis, the charge carries, rather than following conventional orbits tied to individual pockets of the Fermi surface (green and violet elements in the upper panel of the Figure - DFT calculations from Bristol University), perform complete revolutions along the Dirac line, the so-called breakdown orbits, which manifest themselves in fast oscillations in the resistance of the material, with characteristic frequencies in the range 8 to 11 kT (lower panel of the Figure). Measurements of the resistance as a function of the magnetic field at different temperatures and field intervals, have demonstrated an unconventional evolution of the oscillations' amplitude, revealing an enhancement in the mass of the quasiparticles which is commensurate with electron-electron interactions. Moreover, the breakdown orbits can selectively enclose the vertexes of the loop, which results in different number of windings around singularities of the Berry curvature, providing a new "diagnostic tool" for the topological character of the electronic states. These experimental observations, corroborated by theoretical support from the Condensed Matter Theory group at IMM – Radboud University, are a milestone for the realization of collective quantum states in topological semimetals.

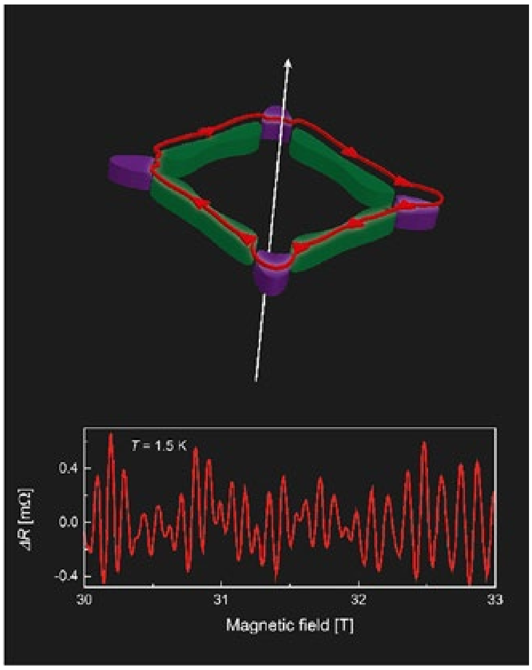

Figure: (Upper panel) Sketch of one of the multiple breakdown orbits detected in ZrSiS. (Lower panel) Oscillatory part of the longitudinal resistance as a function of magnetic field, in the high-field limit.

Unconventional mass enhancement around the Dirac nodal loop in ZrSiS, S. Pezzini, M. R. van Delft, L. M. Schoop, B. V. Lotsch, A. Carrington, M. I. Katsnelson, N. E. Hussey, and S. Wiedmann, Nat. Phys. **14**, 178 (2018).

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WIDE-BAND NEAR-INFRARED SPECTROSCOPY ABOVE 100 TESLA

O. Drachenko, A. Miyata, O. Portugall, P. Plochocka, A. Surrente, LNCMI-Toulouse and R. J. Nicholas, University of Oxford

The Toulouse MegaGauss installation routinely generates magnetic fields well above 100 tesla. The magnetic field is generated in a semi-destructive manner; the coil, producing the magnetic field, disintegrates during every pulse, while the sample space remains intact, making this technique useful for reliable and reproducible scientific experiments. The magnetic field pulse duration is intrinsically limited by the timescale of the mechanical disintegration of the coil, and cannot exceed a few microseconds. This is too fast for standard multichannel detectors, which typically have minimum integration times of tens of microseconds, thereby integrating the spectra over the entire magnetic-field pulse. Only streak cameras provide a spectral resolution on this timescale; however, they are limited to the visible wavelength range.

Recently, we have developed a novel wide-band near-infrared spectroscopy technique covering the spectral range from 1150 up to 1650 nm in a single magnetic-field pulse. In our setup, we use a supercontinuum laser which emits broadband pulses with 20 ns duration at 1 kHz repetition rate, meaning that the magnetic field is essentially constant during a light pulse. The transmitted light pulse and a concomitant reference light pulse are guided to two InGaAs multichannel spectrometers, allowing to compensate fluctuations of the light source and to obtain normalized transmission spectra. As a typical result, we show transmission measurements on Bi_2Se_3, a topological insulator, at 10 K (Figure).

Because of the large spectral coverage of supercontinuum lasers, this technique can be straightforwardly extended to any wavelength range for which (slow) multichannel detectors are available.

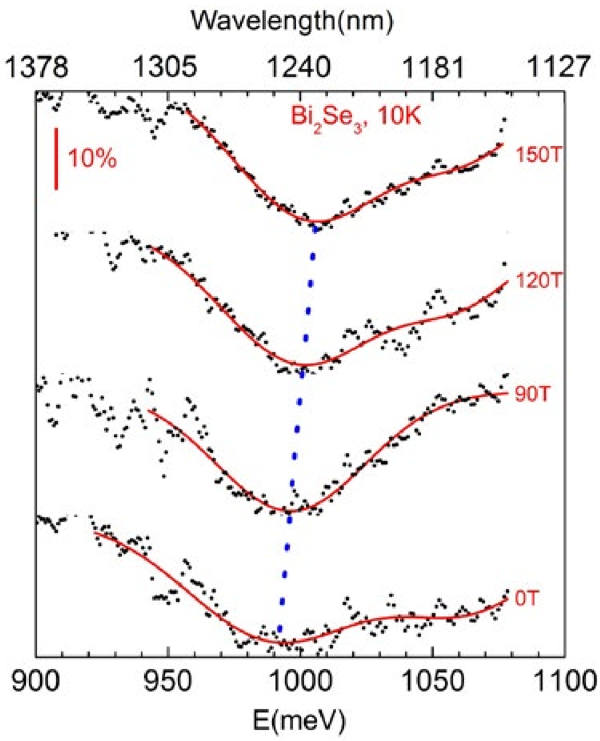

Figure: Transmission spectra of a Bi_2Se_3 topological-insulator crystal measured at 10 K and various magnetic fields up to 150 T. The solid lines are Gaussian fits and the dotted line illustrates the shift of the transmission minimum.

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MAGNETIC EXCITATIONS IN THE HONEYCOMB-LATTICE MATERIAL α-$RuCl_3$

Sergei Zvyagin, HLD Dresden

The Kitaev-Heisenberg model of interacting magnetic spins is one of the few quantum-mechanical models which can be solved exactly. Such spin arrangements may be realized in materials with honeycomb-lattice structures and strong spin-orbit coupling. The magnetic phase diagram for the Kitaev-Heisenberg model as function of interaction parameters is rather complex, encompassing a variety of magnetic ground states, ranging from conventional Néel order to a quantum spin liquid. One of the most important peculiarities of the Kitaev quantum spin liquid is the presence of exotic excitations and fractionalized Majorana fermions, obeying non-Abelian statistics.

α-$RuCl_3$ appears to be a prime candidate to exhibit Kitaev physics. In spite of its almost ideal two-dimensional structure, this material undergoes a transition into an antiferromagnetically ordered zigzag state at 7 K. Remarkably, the ordered state can be suppressed by a magnetic field of around 7 to 8 T, applied along the honeycomb planes and transforming the system into a gapped, magnetically disordered (quantum paramagnetic) phase. The nature of the ground state and the spin dynamics in the field-induced phase have remained open questions.

High-field electron spin resonance (ESR) experiments have been performed at the Dresden High Magnetic Field Laboratory (HLD). A rich excitation spectrum was observed at low temperatures (see Figure). Two antiferromagnetic-resonance modes were detected in the ordered phase. Four ESR modes appear in the field-induced quantum paramagnetic phase. The data obtained in the field-induced phase were compared with results of recent numerical calculations, performed by a group from Frankfurt University (S. Winter et al., arXiv:1707.08144). Very good agreement between the calculated results and the experimental data is found. Most importantly, our studies reveal a very coherent, multiparticle nature of the spin excitations in α-$RuCl_3$. A strong ferromagnetic Kitaev coupling may be the reason for such unusual spin dynamics, facilitating the formation of bound states split from a two-magnon continuum.

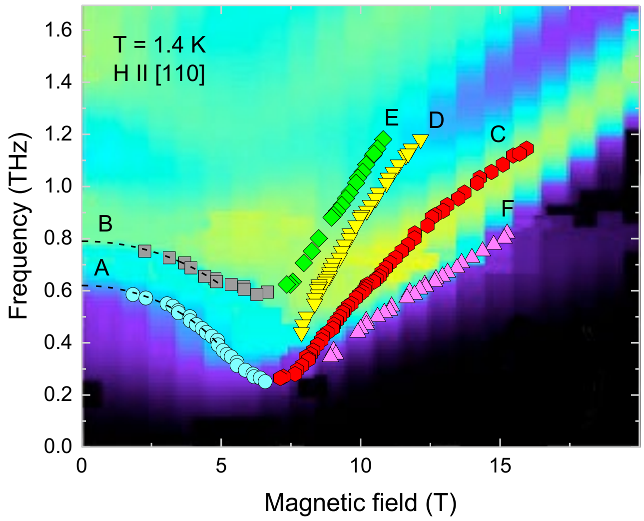

Figure: Frequency-field diagram of ESR excitations in α-$RuCl_3$. The experimental data (symbols) are shown together with the ESR response obtained numerically (color scale).

Unconventional spin dynamics in the honeycomb-lattice material α−$RuCl_3$: High-field electron spin resonance studies, A. N. Ponomaryov, E. Schulze, J. Wosnitza, P. Lampen-Kelley, A. Banerjee, J.-Q. Yan, C. A. Bridges, D. G. Mandrus, S. E. Nagler, A. K. Kolezhuk, and S. A. Zvyagin, Phys. Rev. B **96**, 241107(R) (2017).

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RESULTS OF THE EIGHTEENTH CALL FOR ACCESS

On November 15th, 2017, the 18th call for access ended inviting proposals for research requiring access to our large-scale installations for high magnetic fields collaborating within EMFL.

The four facilities

> LNCMI - Grenoble - France: Static magnetic fields to 36 T
> HFML - Nijmegen - the Netherlands: Static magnetic fields to 37.5 T
> HLD - Dresden - Germany: Pulsed magnetic fields to beyond 95 T
> LNCMI - Toulouse - France: Pulsed magnetic fields of long duration, to over 90 T, and on the microsecond scale to beyond 180 T

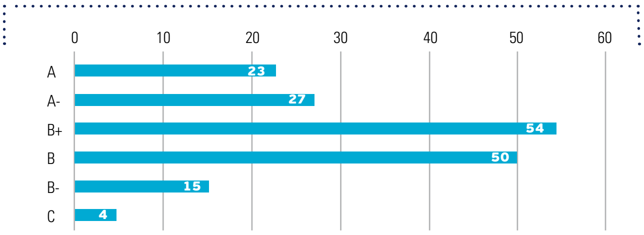
are open to users worldwide. EMFL operates a joint transnational access program, which gives full access to these installations and all associated scientific infrastructure to qualified external users, together with the necessary support from the scientific and technical staff.

For this 18th call 173 applications from 21 different countries were received which have been evaluated by the EMFL selection committee until December 15th, 2017. The Selection Committee consists of 18 specialists covering the following five types of scientific topics

> Metals and Superconductors (57 applications),
> Magnetism (70 applications),
> Semiconductors (34 applications),
> Soft Matter and Magnetoscience (7 applications),
> Applied Superconductivity (5 applications).

Besides of ranking the proposals the committee decides on the number of accepted magnet hours or number of pulses.

NEXT CALL :
Launch: April 15, 2018
Deadline: May 15, 2018



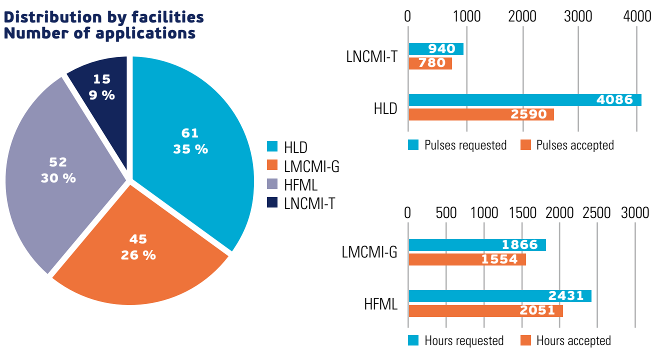
Evaluation of applications

Projects are classified in three classes:

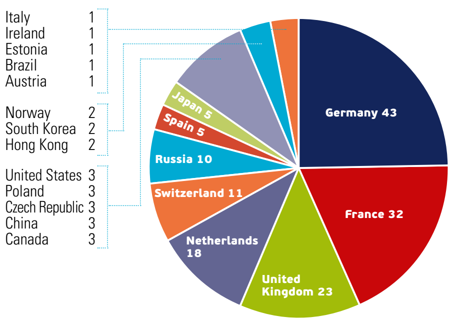
A (excellent proposal to be carried out),
B (should be performed but each facility has some freedom considering other constraints),
C (poor proposal or one that does not need any of the four unique high magnetic field laboratories).

In the B category, the ranking + or - serves as a recommendation to the facility. This freedom within the B category is necessary to allow the facilities to consider other aspects such as, for instance, available capacity and equipment necessary for a successful project.

Distribution by facilities
Number of applications



Distribution by countries
Number of applicants



THE HIGHEST STATIC MAGNETIC FIELD FOR NEUTRON STUDIES NOW AVAILABLE FOR USERS: A CASE STUDY OF Rh-DOPED URu_2Si_2

K. Prokes, Helmholtz-Zentrum Berlin

Neutron diffraction proved to be an indispensable microscopic tool for the determination of magnetic structures. This structure is typically determined via fitting of observed (magnetic) Bragg reflection intensities to intensities calculated from a model. As the magnetic state of a solid depends in many cases on external variables (such as temperature, pressure, and magnetic field) one aims to be able to perform diffraction experiments by accurately controlling these parameters.

Although being the subject of numerous studies for three decades, the nature of the order in the heavy-fermion system URu_2Si_2 is still a mystery, which neutron (and all other) techniques could not solve. Unfortunately, the field necessary to create new phases in the pure system is high (35-38 T), preventing to date highly desirable neutron diffraction studies in static fields. Light doping, pressure and/or magnetic field, on the other hand, destroys this so-called hidden order and leads to new magnetic phases that then are observable with neutrons.

In our study, we were able to determine the details of the first field-induced magnetic phase in an 8 % Rh-doped URu_2Si_2 single crystal in magnetic fields up to 24 T. This has been possible thanks to the recently completed HFM-EXED facility installed at HZB Berlin which offers the highest static magnetic fields worldwide for neutron scattering, as described in our article that has been published in Physical Review B as a rapid communication. The horizontal tapered-cone hybrid magnet (13 T, 4 MW resistive insert plus a 13 T superconducting outsert) was produced in close cooperation with the NHMFL in Tallahassee.

Magnetic structure in $U(Ru_{0.92}Rh_{0.08})_2Si_2$ single crystal studied by neutron diffraction in static magnetic fields up to 24 T,
K. Prokes, M. Bartkowiak, O. Rivin, O. Prokhnenko, T. Förster, S. Gerischer, R. Wahle, Y.-K. Huang, and J. A. Mydosh,
Phys. Rev. B **96**, 121117(R) (2017).

The first field-induced magnetic phase in our sample that exists between 21.6 and 38 T is commensurate with the crystal lattice leading to new superstructure magnetic Bragg reflections indexable by a propagation vector q = (2/3 0 0) as documented in the Figure. The magnetic structure consists of an up-up-down sequence of 1.45 μ_B U moments propagating along the a axis and oriented along the c axis. Since in zero and low fields only short-range order is present, our system can be classified as an itinerant 5f-electron metamagnet, in which the combined influence of Rh doping for Ru along with the magnetic field modify the Fermi surface and lead to a long-range magnetic order of a different type.

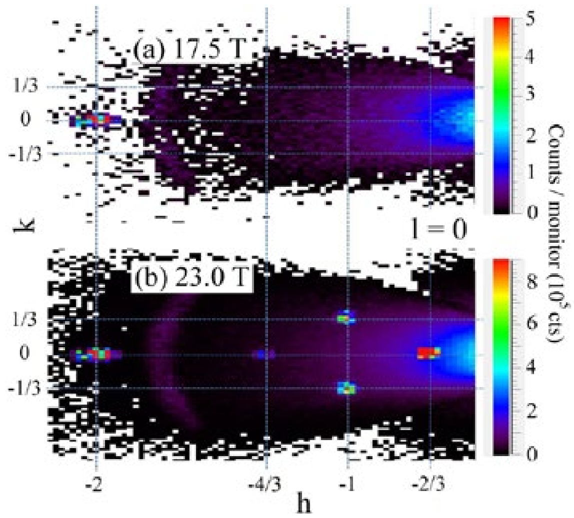


Figure: (a) Portion of the reciprocal space (l = 0 plane) produced by the 8 % Rh-doped URu_2Si_2 single crystal with field applied along the c axis in the forward direction, showing the color-coded intensity of diffracted neutrons at 17.5 T, and (b) at 23 T, both at 1.4 K.

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23RD INTERNATIONAL CONFERENCE ON HIGH MAGNETIC FIELDS IN SEMICONDUCTOR PHYSICS | 22 – 27 JULY 2018, TOULOUSE, FRANCE

The 23rd International Conference on High Magnetic Fields in Semiconductor Physics (HMF-23) will be held in Toulouse, France, from 22 to 27 July 2018 as a satellite conference to the International Conference on the Physics of Semiconductors (ICPS-2018, Montpellier, France).

The program will consist of invited and contributed lectures and posters in single sessions with sufficient time allocated to stimulate discussions and interactions between the participants. Participation of students is explicitly encouraged.

The scope of this conference covers traditional and new topics on fundamental and applied semiconductor physics and related subject areas where high magnetic fields play a crucial role. Note, however, that HMF does not exclude, but rather welcomes related topics on physics at zero magnetic field (such as quantum spin Hall effect and quantum anomalous Hall effect.)

Topics

> Quantum Hall effects
> Quantum wells, quantum wires and quantum dots
> Bulk semiconductors and semimetals
> Organic conductors
> Spin-related phenomena
> 2D materials (Graphene, TMDCs and others)
> Topological matter
> Dirac- and Weyl materials
> Electron correlations and magnetic-field driven phases
> New techniques in high magnetic fields

Important dates (tentative):

> 1st Announcement / Call for abstracts: December 2017
> Abstract deadline: 08 March 2018
> Abstract acceptance: 31 March 2018
> Early-registration: 31 May 2018

Contact details:

HMF-23 (2018)
HFML Secretariat
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www.hfml.science.ru.nl/HMF23

EMFL USER MEETING 2018

The yearly user meeting of the European high-magnetic-field facilities for

> continuous fields (LNCMI Grenoble and HFML Nijmegen) and
> pulsed magnetic fields (HLD Dresden and LNCMI Toulouse)

will be hosted by Prof. Nigel Hussey (HFML) and will take place in the High Field Magnet Laboratory, Nijmegen, The Netherlands on Thursday, 21st of June 2018.

The aim of this one-day meeting is to update our users on recent developments in the EMFL facilities, exchange ideas and experiences, present scientific results, and discuss possibilities for joint research programs and improving the facilities attractiveness.

During the meeting several talks will be given by the users and the directors of the EMFL to inform the user community about recent scientific and technical developments in high magnetic fields. Users are also invited to present their scientific work on posters.

Registration is free of charge.

We would like to involve you, our users, in the process of defining the meeting's agenda; please inform us of the specific needs in terms of new equipment or facility developments you have today or may have in the future, so that we can provide you with the corresponding information during the meeting. Do not hesitate to suggest themes that you would like to discuss during the meeting.

The User Committee has an online feedback form for all users:
www.emfl.eu/user/user-committee.html
In addition, users can contact the User Committee directly via e-mail:
UserCommittee@gmail.com

The User Committee will meet and interact with the users during a dedicated session. Chair of the User Committee is Prof. Raivo Stern (National Institute of Chemical Physics & Biophysics, Tallinn, Estonia).

EUROPEAN MAGNETIC FIELD LABORATORY SUMMER SCHOOL SCIENCE IN HIGH MAGNETIC FIELDS

26 - 30 September 2018—Arles, France

This school is dedicated to recent advances in science in high magnetic fields. Renowned scientists will give tutorial lectures on different areas such as semiconductor physics, low-dimensional materials and nano-scaled objects, strongly correlated electron systems, magnetism, superconductivity, molecular systems, high magnetic field technology and new high-field experimental techniques.

Participants will be selected among young scientist based on their motivation, curriculum vitae and abstract submission. They will have the possibility to present their work as an oral contribution or a poster. The EMFL will provide substantial financial support for accommodation.

High magnetic fields are an indispensable tool to access the fundamental properties of matter. In the 20th century they enabled significant breakthroughs witnessed by several Nobel prizes, and, undoubtedly, high magnetic fields will continue to play a decisive role in shaping the European landscape in the future.

Important dates:

> October 2017: 1st announcement
> February 2018: 2nd announcement with list of subjects and invited speakers
> June 2018: Application and abstract submission deadline
> July 2018: Notification of acceptance
> 26-30 September 2018: EMFL Summer School

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