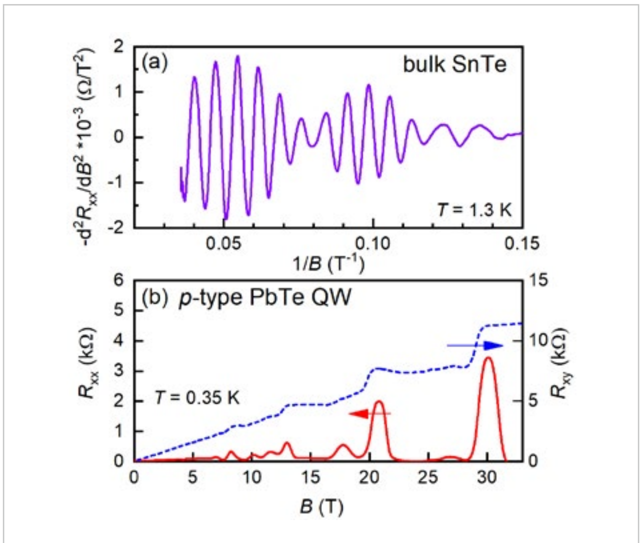
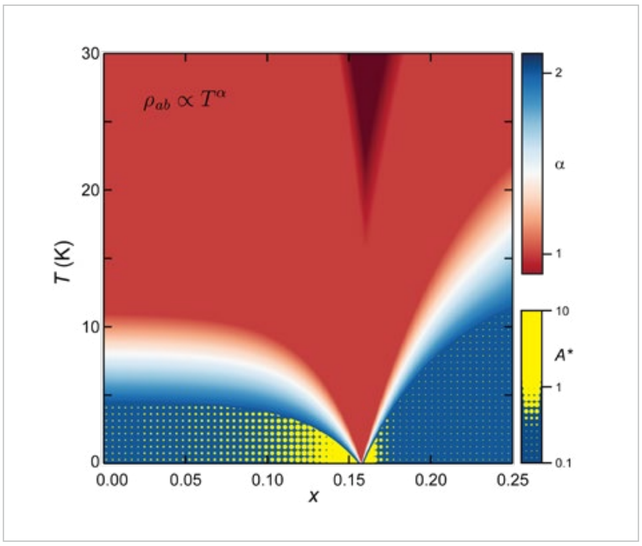
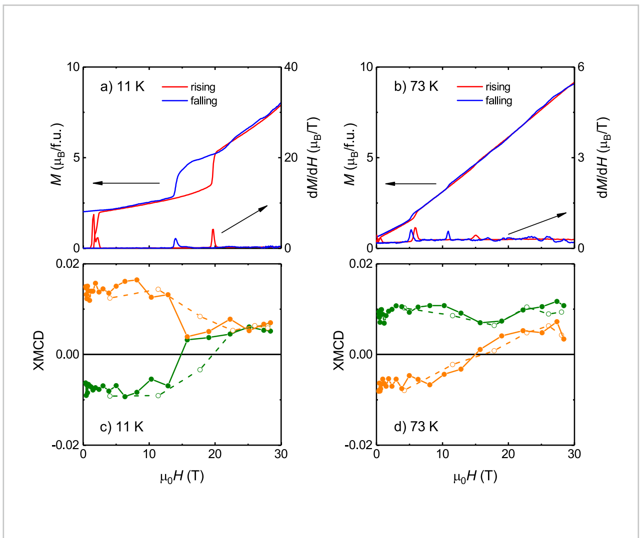
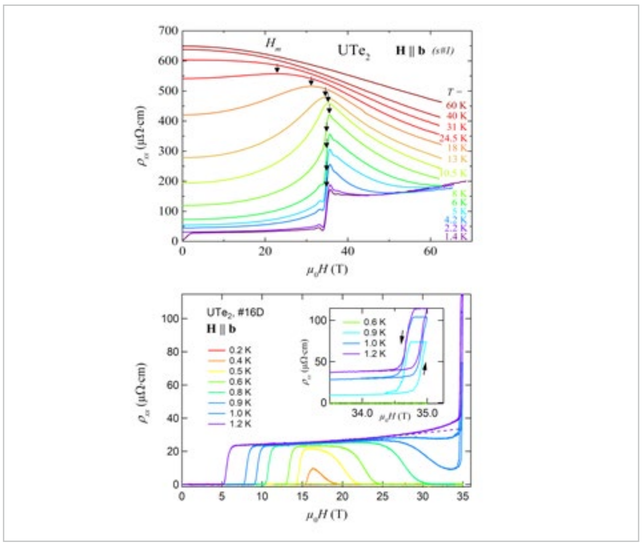
EMFLNEWS

N°2 2019









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DEAR READER

To mark the Polish EMFL membership, which has started this year, the 2019 EMFL User Meeting was held at the University of Warsaw, organized by Adam Babiński. It turned out a big success, with plenty of interesting presentations of users and staff, lively discussions and, of course, the EMFL prize attribution, which this year went to Ashish Arora (University of Münster) for his outstanding work on the magneto-spectroscopy of transition-metal chalcogenides. The next User Meeting will be organized by the HLD in Dresden in the second half of June 2020.

And EMFL continues to grow; the EMFL Council has recently approved the membership application of the French Commissariat à l'énergie atomique et aux énergies alternatives (CEA), which wants to join forces with the EMFL facilities on the development of high-Tc superconductor magnets. I am looking forward to the new experimental opportunities that this collaboration will ultimately provide for our users.

Geert Rikken, Director LNCMI, Chairman EMFL

MEET OUR PEOPLE

*Rubi, **Postdoc** - HFML Nijmegen*

During my two-year post-doctoral stay at the HFML, I will continue my research that I started at the high magnetic field lab LNCMI in Toulouse. There, I studied novel aperiodic quantum oscillations in the two-dimensional electron gas that exists at the interface between two insulating oxides. To observe these oscillations, I cooled down the materials to less than -271 degrees Celsius, and put them in very high magnetic fields. The behavior I found was something completely new and is not fully understood yet. At the HFML, I continue my research on these oscillations on different materials with comparable properties and at lower temperatures. This way, I hope to find some explanations.

One big advantage of working at the HFML is that the lab has static high magnetic fields, as opposed to the pulsed fields available at LNCMI-Toulouse. The static magnetic field allows me to apply a smaller excitation current and, therefore, causes less heating in the material, which enables to measure at even lower temperature. Because of this, I will be able to see the oscillations we are looking for even clearer in our measurements here. Just like LNCMI, HFML is a user facility, which again is an advantage. The knowledge that I gain from working together with international researchers that come and use the magnets at the HFML strengthens my own research.

I am originally from India and completed my PhD degree at National University of Singapore. During my PhD, I researched magnetic oxide materials that could possibly be used to make magnetic refrigerators suitable for ultra-low temperatures. At the same time, I got interested in how the behavior of electrons change in a material when a magnetic field is applied. The results I obtained were very complex to understand, which motivated me to learn more about the topic and to dig deeper into this type of research.

› Rubi, PhD student - HFML Nijmegen

BRAZILIAN PHD INTERNSHIPS AT HFML: SUCCESSFUL COLLABORATION

Steffen Wiedmann, HFML Nijmegen

In 2017 and 2018, two PhD students from Brazil came to Nijmegen to do a part of their post-graduate program at the EMFL facility in Nijmegen. They obtained a one-year PhD fellowship from the Federal Agency for Support and Evaluation of Graduate Education (CAPES). Thanks to a collaboration between researchers from Brazil and Steffen Wiedmann from the HFML, they had the opportunity to perform experiments in high magnetic fields and explore new territory as part of their PhD research.

Anderson Okazaki from the Brazilian Institute for Space Research (São José dos Campos) started his measurements in April 2017 on $Pb_{1-x}Sn_xTe$ epitaxially grown films. Such narrow-gap semiconductors have been widely studied due to their potential application in infrared optical devices and thermoelectric generators. Recently, $Pb_{1-x}Sn_xTe$ has been identified as a topological crystalline insulator. The main goal of Okazaki was to unravel their fundamental properties by means of magneto-transport experiments. In one of his high-field experiments, he performed a magnetic-quantum-oscillation study on SnTe (Figure, panel (a)) to probe the topology of the Fermi surface. With angle- and temperature-dependent measurements, he demonstrated that quantum oscillations in SnTe originate from the bulk band structure due to Rashba splitting of the longitudinal valley.

In September 2018, Fernando Pena from the University of Itajubá joined the group. His project was dedicated to investigate the integer quantum Hall effect (QHE) in a series of p-type PbTe/PbEuTe quantum-well structures at low temperatures. He observed the integer QHE (Figure, panel (b)) in quantum wells with different well widths indicating the high quality of the two-dimensional systems under study.

Shubnikov–de Haas oscillations in topological crystalline insulator SnTe(111) epitaxial films, A. K. Okazaki, S. Wiedmann, S. Pezzini, M.L. Peres, P. H. O. Rappl, and E. Abramof, Phys. Rev. B **98**, 195136 (2018).

Using the high-field facility in collaboration with staff at the HFML, Okazaki and Pena achieved all their research goals stated in the grant proposals. Currently, they are finishing their PhD programs at their universities and further publications are in preparation. Besides that, they could also expand their experimental skills and knowledge taking a close look at the science done in high magnetic fields.

Steffen Wiedmann: “This was the first time that I organized these internships together with my collaborators from Brazil. Anderson and Fernando did a fantastic job. It was not only scientifically rewarding, they also had a pleasant time here in the Netherlands working together with our team members and learning new skills. I am proud that I could act as supervisor and thank Eduardo Abramof, Marcelos Peres, Sergio Pezzini, and Paulo Rappl for this great collaboration.”

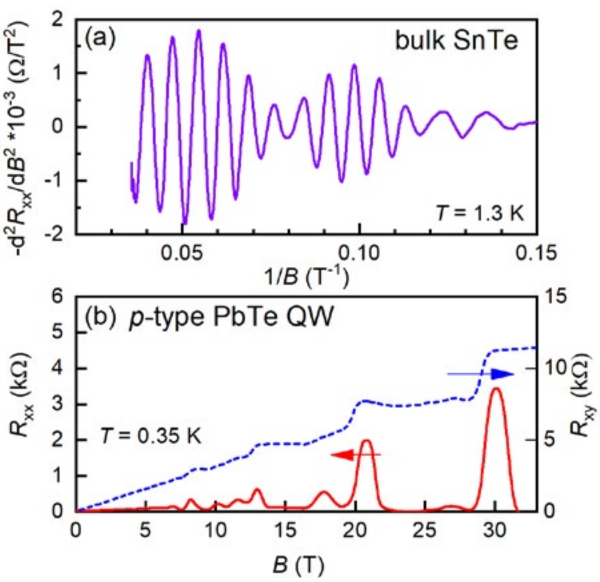


Figure: (a) Second derivative of the longitudinal resistance R_{xx} as a function of 1/B measured on SnTe epitaxial films at 4.2 K and up to 30 T. (b) Quantum Hall effect in a PbTe/PbEuTe quantum well at 0.35 K and up to 33 T: Hall resistance R_{xy} (blue dashed line) and longitudinal resistance R_{xx} (red line).

Contact: steffen.wiedmann@ru.nl

ELECTRICAL RESISTIVITY ACROSS A NEMATIC QUANTUM CRITICAL POINT

Nigel Hussey, HFML Nijmegen

It is not only elemental or ordinary metals that superconduct. Today, scientists are also fascinated by strange metals that undergo phase transitions (e.g., to a magnetic state) before superconductivity sets in. If they find the right tuning knob, scientists can suppress the temperature at which this transition occurs, driving it to 0 K. When doing so, the electrons start fluctuating quantum mechanically between the magnetic and non-magnetic phases without any thermal agitation. This is the quantum critical point. Accessing this quantum critical point is important for two reasons. Firstly, when the temperature is just above the critical point, the resistivity of the strange metal acts in a way that goes against every conventional theory. Secondly, it is highly likely that these critical fluctuations that cause the strange resistance are also responsible for inducing superconductivity, so if scientists can access this strange metallic state and study its behavior, they might be able to identify the interaction what causes superconductivity in these exotic systems.

Researchers from HFML in Nijmegen, together with Japanese collaborators, thought of a way to make superconductivity disappear and explored the metallic state down to the lowest temperatures possible. In FeSe, the electrons appear to undergo a transition to a purely nematic phase at a temperature close to 100 K. When exactly 1/6 of the Se atoms are substituted with S atoms, the transition temperature to the nematic phase is suppressed to 0 K. The quantum critical point itself is still 'protected' by a veil of superconductivity that must first be removed. In high magnetic fields, however, superconductivity will eventually succumb. Then, the strange metallic state revealed itself, extending all the way down to temperatures just one degree above absolute zero. As the quantum critical point is approached, the electrons become progressively heavier, 'weighed down' by the intensifying fluctuations of the nematic order.

Electrical resistivity across a nematic quantum critical point, S. Licciardello, J. Buhot, J. Lu, J. Ayres, S. Kasahara, Y. Matsuda, T. Shibauchi, and N. E. Hussey, Nature **567**, 213 (2019).

The outcome was different from what the team expected. First of all, strange metal behavior had only been seen previously in systems close to a magnetic quantum critical point, never close to a purely nematic one. Indeed, there is currently no theoretical model that predicts this behavior. Secondly, while the critical fluctuations become stronger the nearer the system is to the nematic quantum critical point, the superconductivity itself does not become stronger. It raises new questions and begs for more research. How do electrons interact with nematic fluctuations to cause strange metallic behavior in the first place? Why is superconductivity in this particular system not enhanced near the quantum critical point? Nematic fluctuations are one possible route to high-temperature superconductivity, but not, it seems, in the iron chalcogenides. Nevertheless, understanding what first inhibits the growth of superconductivity can help us understand what makes it grow.

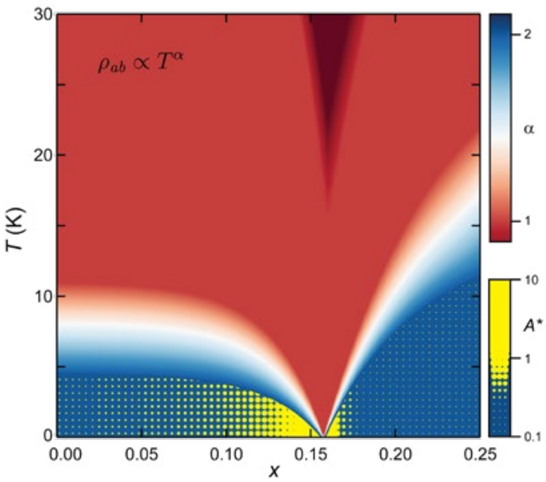


Figure: Low-temperature phase diagram of $FeSe_{1-x}S_x$ described in terms of the exponent of the T-dependent resistivity that is itself defined in the upper color scale. The density of dots inside the T^2 regime indicate the strength of A*, the coefficient of the T^2 resistivity, normalized to a fixed charge-carrier density (and defined in the lower color scale).

Contact: nigel.hussey@ru.nl

MAGNETIC-FIELD-INDUCED METAMAGNETISM AND REENTRANT SUPERCONDUCTIVITY IN THE HEAVY-FERMION SUPERCONDUCTOR UTe_2

William Knafo, Marc Nardone (LNCMI Toulouse), Sanu Mishra (LNCMI Grenoble) and Georg Knebel (CEA-Grenoble)

Following the recent discovery of superconductivity in the heavy-fermion paramagnet UTe_2, which is suspected to lie on the verge of ferromagnetism [S. Ran et al., arXiv:1811.11808v3, D. Aoki et al., J. Phys. Soc. Jpn. 88 (2019) 043702], complementary and almost simultaneous series of magnetoresistivity experiments on UTe_2 were performed in steady fields up to 35 T at LNCMI Grenoble and in pulsed fields up to 70 T at LNCMI Toulouse.

As step one, low-temperature metamagnetism was evidenced in a magnetic field applied along the hard magnetic b axis at μ_0H_m = 35 T (Figure, top). When the temperature is raised, the signature of first-order metamagnetism was observed up to a critical endpoint at 7 K. A sharp maximum in the quadratic Fermi-liquid coefficient of the resistivity found at H_m indicates an enhanced effective mass associated with critical magnetic fluctuations, possibly coupled with a Fermi-surface instability.

As step two, we have discovered that low-temperature superconductivity is reinforced when H_m is approached in a field applied along b, and suddenly disappears above H_m (Figure, bottom). A home-made dilution refrigerator, specially developed for the pulsed-field experiments at LNCMI Toulouse, was used. By studying the angular dependence of the superconducting upper critical field in field directions close to the b axis, the maximum of the reentrant superconducting temperature was found to be rapidly depinned from the metamagnetic field. A key ingredient for the field reinforcement of superconductivity on approaching H_m appears to be an immediate interplay with magnetic fluctuations and a possible Fermi-surface reconstruction. Further studies of the field-induced superconductivity in UTe_2 are planned at LNCMI.

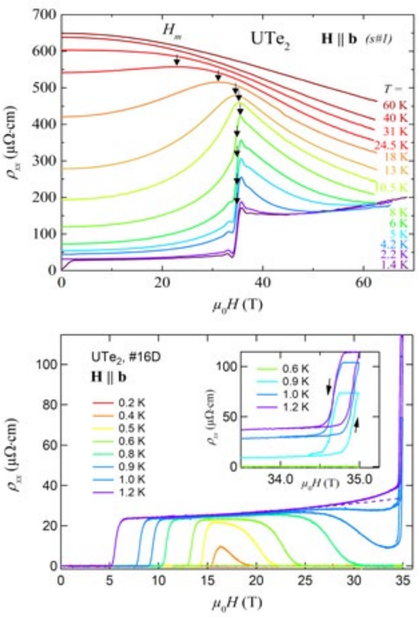


Figure: Signatures of (top) high-temperature metamagnetism and (bottom) low-temperature superconductivity in the electrical resistivity of UTe_2 in a magnetic field applied along the crystallographic b axis.

Magnetic-field-induced phenomena in the paramagnetic superconductor UTe_2, W. Knafo, M. Valiska, D. Braithwaite, G. Lapertot, G. Knebel, A. Pourret, J.-P. Brison, J. Flouquet, and D. Aoki, J. Phys. Soc. Jpn. **88**, 063705 (2019).

Field-reentrant superconductivity close to a metamagnetic transition in the heavy-fermion superconductor UTe_2, G. Knebel, W. Knafo, A. Pourret, Q. Niu, M. Valiska, D. Braithwaite, G. Lapertot, M. Nardone, A. Zitouni, S. Mishra, I. Sheikin, G. Seyfarth, J.-P. Brison, D. Aoki, and J. Flouquet, J. Phys. Soc. Jpn. **88**, 063707 (2019).

Contact: william.knafo@lncmi.cnrs.fr, ilya.sheikin@lncmi.cnrs.fr, georg.knebel@cea.fr

UNCOVERING THE MICROSCOPIC NATURE OF THE FIELD-INDUCED PHASE TRANSITION IN $HoFe_5Al_7$

Denis Gorbunov, HLD Dresden

Intermetallic compounds based on 3d and 4f elements combine high magnetic ordering temperatures, typical of 3d metals, and the large magnetic anisotropy of the magnetic rare-earths elements. The application of external magnetic fields tunes the exchange and anisotropy interactions and frequently leads to field-induced transitions. A detailed understanding of the magnetization process requires a microscopic technique, such as magnetic x-ray scattering, in order to follow the evolution of the magnetic structure in the applied field. Yet, it is exactly the strength of the interactions that makes such a study challenging due to the high magnetic fields needed.

$HoFe_5Al_7$ is a strongly anisotropic ferrimagnet. At 2 K, it displays field-induced phase transitions at 13-20 and 34-38 T. We performed x-ray magnetic circular dichroism (XMCD) experiments in pulsed magnetic fields up to 30 T to follow the rotations of the individual sublattice magnetizations. Panels (a) and (b) of the figure show the bulk magnetization and its field derivative for a field applied along the easy magnetization direction above and below the compensation temperature of 65 K. At 11 K, a first-order phase transition is observed between 14 and 19.5 T. At 73 K, two weak transitions can be resolved between 5.5 and 6 T and between 11 and 15 T. The field-dependent Fe- and Ho-sublattice magnetizations inferred from the XMCD data both rotate at the phase transition at 11 K, whereby the Fe magnetization reverses its sign (panel c). Above the compensation temperature, the Ho moment starts to increase continuously above 6 T, reversing sign at about 16 T. For the Fe moment, two small hysteresis loops open at around 10 and 27.5 T, concomitant with the beginning and the end of the reversal of the Ho magnetization.

Modeling of the individual sublattice magnetizations allowed us to determine the in-plane anisotropy constant, $K \approx 0.5$ MJ/m^3, close to the ground state. The additional field-induced transition observed above the compensation temperature can be explained by the fact that the Ho-sublattice magnetization is no longer rigid, as the applied field acts against the Ho-Fe molecular field in this temperature range. This study provides the first microscopic insight into the magnetization process of a strongly anisotropic ferrimagnet in pulsed magnetic fields.

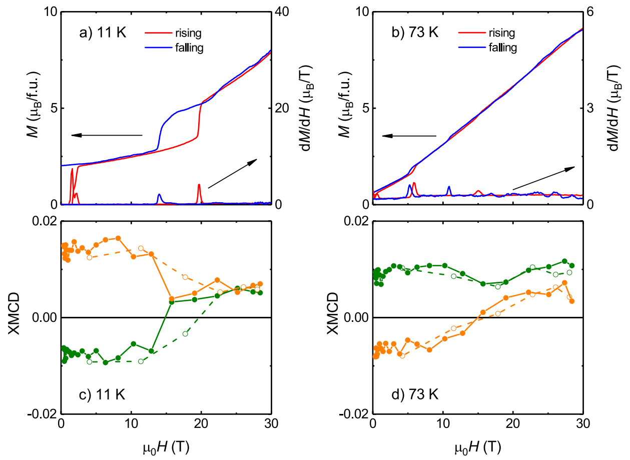


Figure: Bulk magnetization and field derivative of (a), (b) the magnetization of $HoFe_5Al_7$ and (c), (d) field dependences of the amplitudes of the Fe-like (green) and Ho-like (orange) components below and above the compensation temperature. Open symbols and dashed lines, rising field; full symbols and lines, decreasing field.

Microscopic Nature of the First-Order Field-Induced Phase Transition in the Strongly Anisotropic Ferrimagnet $HoFe_5Al_7$, D. I. Gorbunov, C. Strohm, M. S. Henriques, P. van der Linden, B. Pedersen, N. V. Mushnikov, E. V. Rosenfeld, V. Petříček, O. Mathon, J. Wosnitza, and A. V. Andreev, Phys. Rev. Lett. **122**, 127205 (2019).

Contact: D.Gorbunov@hzdr.de

RESULTS OF THE TWENTYFIRST CALL FOR ACCESS

On May 16th, 2019, the 21st call for access ended inviting proposals for research requiring access to the large installations for high magnetic fields collaborating within EMFL.

Our four facilities

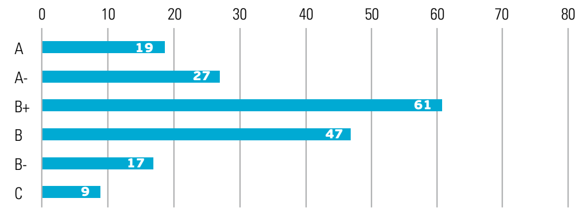
- LNCMI - Grenoble - France: Static magnetic fields to 36 T
- HFML - Nijmegen - the Netherlands: Static magnetic fields to 37.5 T
- HLD - Dresden - Germany: Pulsed magnetic fields to beyond 95 T
- LNCMI - Toulouse - France: Pulsed magnetic fields of long duration, to over 90 T and on the microsecond 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 21st call 180 applications from 23 different countries were received which have been evaluated by the EMFL selection committee until June 24th, 2019. The Selection Committee consists of 18 specialists covering the following five types of scientific topics

- Metals and Superconductors (48 applications),
- Magnetism (78 applications),
- Semiconductors (37 applications),
- Soft Matter and Magnetoscience (10 applications),
- Applied Superconductivity (7 applications).

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



Evaluation of applications

Projects are classified in three classes:

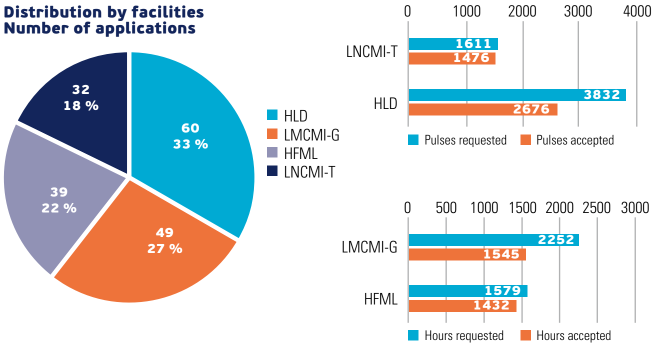
A (excellent proposal to be carried out),

B (should be performed but each facility has some freedom considering other constraints),

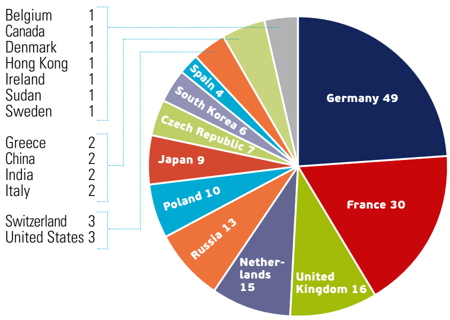
C (poor proposal or one that does not need any of the four unique high-magnetic-field laboratories).

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



NEXT CALL :

Launch: October 15, 2019

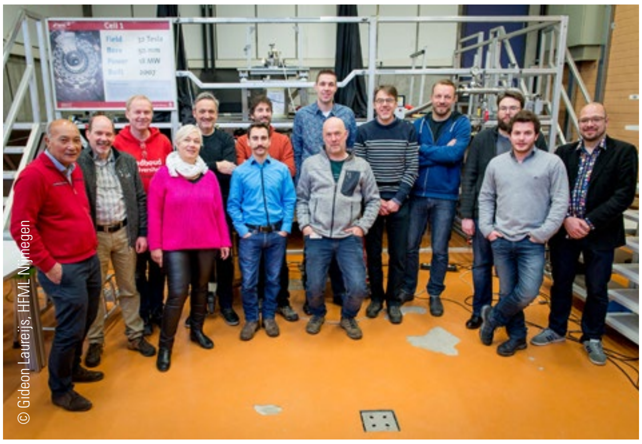
Deadline: November 15, 2019

EMFL INSTRUMENTATION EXCHANGE VISITS BETWEEN GRENOBLE AND NIJMEGEN

Whereas most of the scientists already know the different EMFL facilities and their activities from visits, conferences and workshops, there is less contact between technical teams. In order to further expand the collaboration between the EMFL laboratories at this level, an initiative for exchange was launched that finally picked up speed: In September 2018, three members of the instrumentation team from HFML Nijmegen visited LNCMI Grenoble and in January 2019 a return visit of seven members of the Grenoble instrumentation team took place.

Both hosts organized a tailored program combining visits of the facilities and their instrumentation infrastructure with ample time for exchange in small groups and on a specialist level. By easily overcoming the language barrier all the participants quickly engaged themselves in interesting and fruitful discussions on the very large field of instrumentation in high magnetic fields. The topics of discussion covered the choice of materials and fabrication techniques, the development and operation of cryogenic devices, the various methods for calibration of magnetic field and temperature, the software user interfaces running the magnet and the scientific experiments, issues of user support as well as original developments of recent experimental set-ups operating in this challenging environment. During the visits all participants realized that fruitful exchange on instrumentation strongly profits from personally knowing the colleague in the other laboratory, staying there on the site, and putting hands on the objects.

After respectively three days of visit the instrumentation teams of both laboratories got many inspirations for future collaborations as well as for their daily work at home. They would like to thank the administration teams at HFML Nijmegen and LNCMI Grenoble for their help and both directors for financial support. All the participants are already looking forward to further visits and an enlargement of the exchange to the EMFL sites in Dresden and Toulouse in the near future.



HFML and LNCMI instrumentation teams during the exchange visits at LNCMI Grenoble (left) and HFML Nijmegen (right).

REPORT FROM THE EMFL USER MEETING - WARSAW JUNE 25TH, 2019

The eleventh EMFL User Meeting was held at the University of Warsaw on 25th of June 2019. This was the second time that the User Meeting took place outside one of the EMFL high-field facilities. With over 50 participants, it was very well attended. Warsaw was chosen as venue to particularly promote the exchange of ideas and wishes with our (future) Polish users. Since this year, Poland is the newest member of the EMFL. This was possible through a grant from the Polish ministry of Education to a consortium of Polish high-magnetic-field users, that is being coordinated by Prof. Adam Babiński (University of Warsaw), who also hosted the meeting. The User Meeting included two scientific and one technical session, to showcase some of the most recent scientific highlights as well as new technical and instrumentational developments at the high-field facilities.

The technical session focussed on recent progress and developments in magnet technology particularly on the superconducting technology for which Xavier Chaud showed outstanding new results using high-Tc coils in Grenoble. Jerome Beard presented the planned upgrade of the Toulouse capacitor bank, allowing to store more energy and an even more reliable use of the installation. Jake Ayres' work focused on high-pressure experimental results that were obtained in Nijmegen and, finally, Toni Helm showed the possibilities of focussed ion beams to microstructure samples for experimental investigations under extreme conditions. The scientific highlights were of a very high quality and covered many areas of topical interest including 2D materials, transition-metal dichalcogenides (TMDCs), perovskites, strange metals, correlated systems, and superconductors. The talks illustrated the wide variety of research topics that can be investigated using intense magnetic fields.

The User Committee meeting was chaired by Raivo Stern (NICPB, Tallinn, Estonia) who reported the outcome of the meeting and the suggestions of the Committee back to the Board of Directors at the end of the meeting. A brief summary of the User Committee meeting can be found on the next page in this issue.

We would like to thank all the staff at the University of Warsaw, and especially Prof. Adam Babiński, for their excellent organization and for the diverse and inspiring meeting. The next EMFL meeting will be held at the HLD in Dresden, Germany, in June 2020.

Participants of the EMFL User Meeting 2019 in front of the Faculty of Physics building of the University of Warsaw.

USER COMMITTEE MEETING IN WARSAW

During the EMFL User Meeting, the EMFL User Committee meeting was held on the 25th of June 2019 at the Physics Faculty of Warsaw University as well. Five of the nine members of the User Committee (R. Stern, M. Doerr, A. Arora, S. Tozer, V. Skumryev) and a number of users attended the meeting, with Prof. Stern chairing the committee. The meeting was followed by a discussion meeting with the Board of Directors of the EMFL and the user community. Several matters were discussed and recommendations made to the Board of Directors, that will be outlined in a later issue of the EMFL News.

The User Committee acknowledged Prof. Adam Babiński from Warsaw University and the Board of Directors for arranging an excellent user workshop, where both users and representatives of the EMFL reported on recent developments of high-magnetic-field infrastructures and equipment, 2D materials in high magnetic fields, magnetocaloric materials in pulsed magnets, research in topical areas, and novel material systems of fundamental and technological interest. The user community received this rich program very well.

EMFL PRIZE WINNER 2019: ASHISH ARORA

During the EMFL User Meeting in Nijmegen, the yearly EMFL prize was awarded. This time, Dr. Ashish Arora, postdoctoral researcher at the University of Munster, had the honor to receive the prize. Jochen Wosnitza, Director of the Dresden High Magnetic Field Laboratory handed over the award. Dr. Ashish Arora received the award for his groundbreaking discoveries using the excellent infrastructure at the EMFL facilities. He is working on optical properties of transition-metal dichalcogenides, particularly on the control of the spin and valley degrees of freedom using high magnetic fields. Since 2009, the EMFL members award annually the EMFL prize for exceptional achievements in science done in high magnetic fields.

Jochen Wosnitza congratulates the EMFL prize winner, Ashish Arora.

UPCOMING EVENTS

1. Joint European Magnetic Symposia (JEMS) 2019, Uppsala, Sweden, August 26-30, 2019.
https://jems2019.se/

2. IRMMW-THz 2019, 44th International Conference on Infrared, Millimeter, and Terahertz Waves, Paris, France, September 1-6, 2019.
https://irmmw-thz2019.org/

3. EASTMAG-2019, VII Euro-Asian Symposium "Trends in Magnetism", Ekaterinenburg, Russia, September 8-13, 2019.
http://eastmag2019.imp.uran.ru/

4. MT26, International Conference on Magnet Technology, Vancouver, Canada, September 22-27, 2019.
http://mt26.triumf.ca/

5. SCES 2019, International Conference of Strongly Correlated Electron Systems, Okayama, Japan, September 23-28, 2019.
http://sces2019.org

6. Les Houches Heraeus School – "Fermi Surface and Novel Phases in strongly correlated electron systems" - Fermi SCES, Les Houches, France, October 13–18, 2019.
http://fermi-sces.grenoble.cnrs.fr/

7. Flatlands beyond Graphene 2019, Toulouse, France, September 2–6, 2019.
https://www.hfml.ru.nl/flatlands2019/

8. 14th European Conference on Applied Superconductivity, SEC, Glasgow, United Kingdom, September 1-5, 2019.
https://www.eucas2019.org/

9. Cutting-Edge Topics in Quantum Materials, Paris, France, September 25-28, 2019.
https://parisedge2019.espci.fr/spip.php?rubrique1

10. 2019 Annual Conference on Magnetism and Magnetic Materials, Las Vegas, USA, November 4-8, 2019.
https://magnetism.org/

11. APS March Meeting, Denver, USA, March 2-6, 2020.
https://www.aps.org/meetings/march/

HFML
Radboud Universiteit Nijmegen
Toernooiveld 7
6525 ED Nijmegen
The Netherlands
www.ru.nl/hfml

CNRS – Centre National de la Recherche Scientifique
3, rue Michel-Ange
75794 Paris cedex 16
France
www.lncmi.cnrs.fr

LNCMI Toulouse
143 avenue de Rangueil
31400 Toulouse
France

LNCMI Grenoble
25 rue des Martyrs, B.P. 166
38042 Grenoble cedex 9
France

Helmholtz-Zentrum Dresden-Rossendorf (HZDR)
Dresden High Magnetic Field Laboratory
Bautzner Landstrasse 400
01328 Dresden
Germany
www.hzdr.de/hld

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Publisher / Contact:
Helmholtz-Zentrum Dresden-Rossendorf
Bernd Schröder
Phone: +49 351 260-2515
Email: b.schroeder@hzdr.de
contact@emfl.eu

Editorial Staff:
EMFL Board of Directors, Christine Bohnet, Martin van Breukelen, Benjamin Piot, Bernd Schröder, Larysa Zviagina

Responsible for the content:
Peter Christianen (peter.christianen@ru.nl), Geert Rikken (geert.rikken@lncmi.cnrs.fr), Joachim Wosnitza (j.wosnitza@hzdr.de)

The EMFL develops and operates world class high magnetic field facilities, to use them for excellent research by in-house and external users.

Printing:
reprogress GmbH

Layout:
Pfefferkorn & Friends, www.pfefferkornundfriends.de

EMFL News, the newsletter of the European Magnetic Field Laboratory, is published quarterly.
printed on FSC-certified paper

ISSN 2196-0909
2/2019
www.emfl.eu