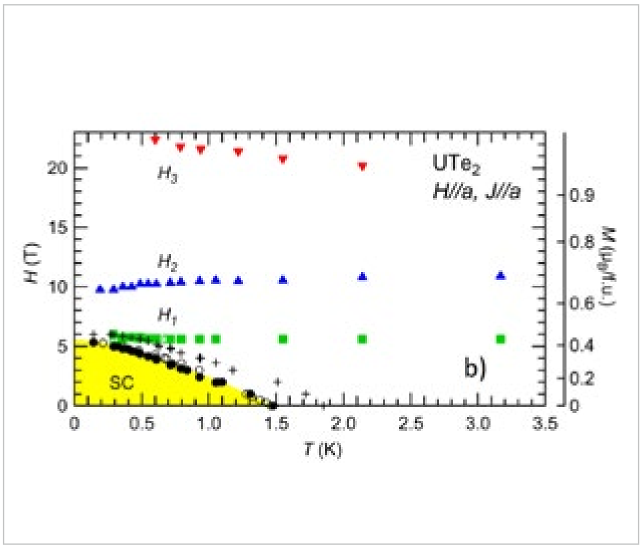
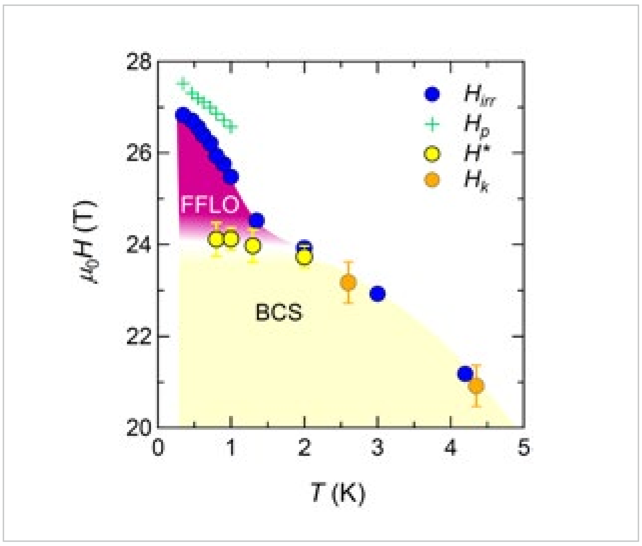
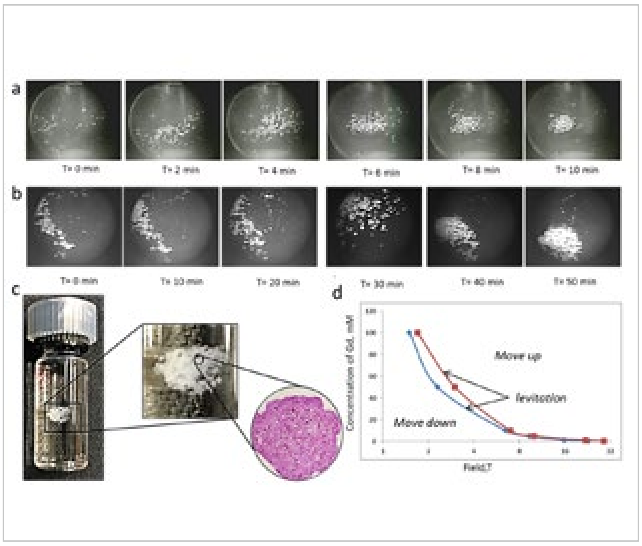
European Magnetic Field Laboratory

EMFLNEWS

N°1 2020







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DEAR READER

This EMFL News comes to you at an extraordinary time: All EMFL facilities have stopped their user operation, all scheduled user experiments are canceled, and most of the EMFL staff is confined at home, but fortunately we have no coronavirus victims. We hope that all of you and your families and friends will also get through this ordeal unscathed.

For the moment, we have no clear idea when normal user operation of the EMFL facilities will resume. We will launch the usual bi-annual call for proposals, but because of the backlog of proposals from the previous two calls, the pressure on the available magnet time will be high.

For the same reason, we have decided to cancel the annual User Meeting and the Hands-on Workshop, planned in Dresden during 16 - 18 of June. We hope to see you all at the next User Meeting (and first Hands-on Workshop), scheduled for June 2021 in Dresden.

However, all is not bad; we were very successful with our European projects. The H2020-ISABEL project, focused on improving the long-term sustainability of the EMFL, and the H2020-SuperEMFL project, on the development of high-Tc superconducting user magnets, were both accepted by the European Union. Both projects, with 18 and 11 partners, respectively, from academia and industry, and a total budget of about 8 M€, will greatly contribute to reinforcing the EMFL, to the greater benefit of all our users, and we are looking forward to working with you all on realizing this potential.

Take good care of yourselves and your family and friends, and we hope to see you again in one of the EMFL facilities when the pandemic is mastered.

Geert Rikken, Director LNCMI, Chairman EMFL

MEET OUR PEOPLE

Anne Missiaen, LNCMI Grenoble

I am currently in my first year of PhD at LNCMI in Grenoble under the supervision of David Le Bœuf and Marc-Henri Julien. I passed a master's degree in fundamental physics at Ecole Normale Supérieure in Lyon. During the first year of my master's degree, I did an internship in Amalia Coldea's group at Oxford University, where I really discovered my interest in solid-state physics. Since then, I have been looking for a PhD position in this area.

In my PhD work, I study superconducting cuprates in high magnetic fields (both static in Grenoble and pulsed in Toulouse) using both NMR and ultrasound measurements. These two techniques are complementary probes to investigate the highly complex phase diagram of the cuprates and especially hidden magnetic phases.

Working at the LNCMI is a great opportunity for me. Indeed, I am acquiring great knowledge on various experimental techniques from the preparation of samples to the operation of pulsed-field magnets. Furthermore, it is enriching to work in a high-field laboratory alongside people with a huge diversity of backgrounds: researchers, engineers, technicians, and students from everywhere in the world.

Anne Missiaen, LNCMI Grenoble

FERMI-SURFACE INSTABILITIES IN THE HEAVY-FERMION SUPERCONDUCTOR UTe_2

Alexandre Pourret, CEA Grenoble and Gabriel Seyfarth, LNCMI-Grenoble

The recently discovered heavy-fermion superconductor UTe_2 with superconducting transition temperature of 1.6 K is one of the rare examples of a heavy-fermion material with superconductivity appearing above 1 K. In contrast to the ferromagnetic heavy-fermion superconductors UCoGe and URhGe, UTe_2 is paramagnetic. Nevertheless, it exhibits re-entrant superconductivity up to unrivalled magnetic field strengths (65 T) among this class of materials. For magnetic fields applied along the crystallographic b direction, the upper critical field is strongly enhanced and equals the first-order metamagnetic transition occurring at H_m = 35 T at low temperatures, strongly exceeding the Pauli limit. Recent studies on the U-based ferromagnetic superconductors have highlighted the importance of the interplay between magnetic fluctuations and Fermi-surface instabilities when crossing the ferro- to paramagnetic quantum phase transition, which raises the question of the precise role of these instabilities in the reinforcement of superconductivity.

Here, we present transport measurements up to 29 T with magnetic field applied along the easy magnetization axis which is the crystallographic a axis of the body-centered orthorhombic structure for which the upper critical field is 6 T. As a function of field, the thermopower exhibits successive anomalies (Figure [a]) at low temperatures, signaling Fermi-surface instabilities. One of them (H_1, green squares in Figure [b]) could clearly be identified as a Lifshitz transition. Such a behavior is reminiscent of what we have already observed in UCoGe, i.e., the appearance of Fermi-surface instabilities for fields parallel to the easy magnetization axis (direction with a high magnetic susceptibility). Another striking feature is that the instability at H_1 occurs at exactly the same critical value of magnetization ($0.4\mu_B$) than H_m = 35 T for fields aligned along b. Finally, recent measurements under pressure for fields along the a direction reveal a peculiar feature in the upper critical field around H_1.

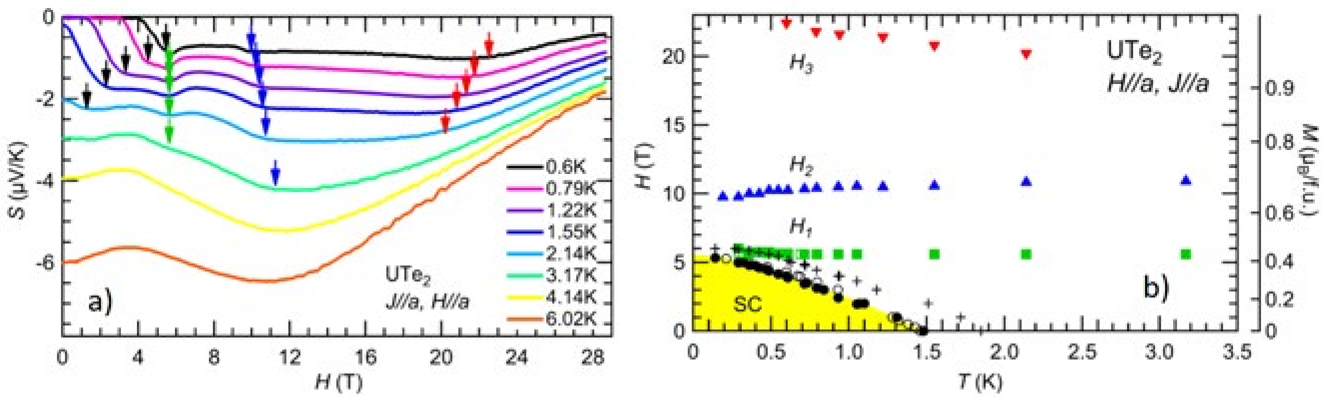

Figure: (a) Field-dependence of the thermopower at different temperatures exhibiting anomalies at the superconducting transition (black arrows) and at 3 successive electronic instabilities (critical fields) for H II a. (b) Magnetic field-temperature phase diagram with the superconducting phase and critical fields, which correspond to specific values of the magnetization.

Fermi-Surface Instability in the Heavy-Fermion Superconductor UTe_2, Q. Niu, G. Knebel, D. Braithwaite, D. Aoki, G. Lapertot, G. Seyfarth, J.-P. Brison, J. Flouquet, and A. Pourret, Phys. Rev. Lett. **124**, 086601 (2020);
Anisotropy of the Upper Critical Field in the Heavy-Fermion Superconductor UTe_2 under Pressure, G. Knebel, M. Kimata, M. Vališka, F. Honda, D. Li, D. Braithwaite, G. Lapertot, W. Knafo, A. Pourret, Y. J. Sato, Y. Shimizu, T. Kihara, J.-P. Brison, J. Flouquet, D. and Aoki, arXiv:2003.08728 (2020).

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SCAFFOLD-FREE AND LABEL-FREE BIOFABRICATION TECHNOLOGY USING LEVITATIONAL ASSEMBLY IN HIGH MAGNETIC FIELD

Hans Engelkamp and Peter Christianen, HFML Nijmegen

This research shows that magnetic levitational bioassembly with a non-toxic, low concentration of a paramagnetic medium in high magnetic field is technologically feasible. Moreover, the experimental results confirm that it can be used as a cost-effective alternative to microgravity research at the International Space Station ISS.

For the experiments, a gadolinium(III)-chelate contrast agent was selected, which is known to have the lowest possible toxicity. However, at high concentrations, it is still potentially toxic for cells and tissue spheroids, because of the osmotic pressure imbalance due to excessive use of ions in the paramagnetic medium. An obvious dilemma - high concentration of gadolinium enables magnetic levitation but is relatively toxic, whereas a low, non-toxic concentration of gadolinium does not allow magnetic levitation with permanent magnets. The solution is to perform the levitation at a low concentration of gadolinium but taking advantage of very high magnetic fields.

Using a magnetic field of up to 31 T, researchers from Moscow, Maastricht, and Nijmegen performed magnetic levitational assembly of tissue constructs from living spheroids. The construct from tissue spheroids partially fused after 3 hours of levitation. The analysis of viability after prolonged exposure to the magnetic field showed the absence of significant cytotoxicity or morphology changes in the tissue spheroids. This means that the high magnetic field acts as a non-toxic, temporal, and removable support. The researchers demonstrate that formative biofabrication of tissue-engineered constructs from tissue spheroids in high magnetic fields is a promising research direction.

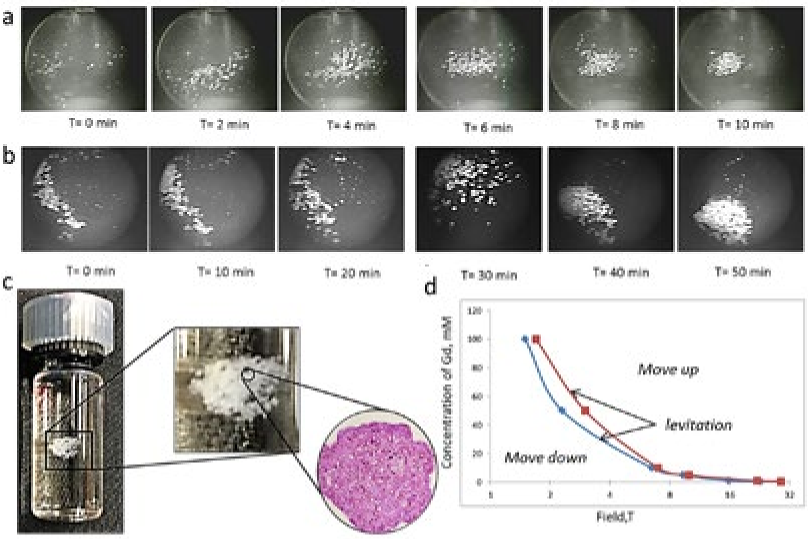

Figure: Construct assembly under high magnetic field levitation. a) Polystyrene beads assembling at 0.5 mM gadobutrol and in a magnetic field of 22 T. b) Tissue spheroids assembling until a stable construct was obtained at 0.8 mM gadobutrol and a magnetic field of 19 T. c) Construct assembled after 3 hours at 19 T (insert circle shows a histological section of the construct). d) Curves of levitation conditions depending on the gadobutrol concentration and magnetic field applied for tissue spheroids (red curve) and polystyrene beads (blue curve).

Scaffold-free and label-free biofabrication technology using levitational assembly in high magnetic field, V. A. Parfenov, V. A. Mironov, K. A. van Kampen, P. A. Karalkin, E. V. Koudan , F. DAS Pereira, S. V. Petrov, E. K. Nezhurina, O. F. Petrov, M. I. Myasnikov, F. X. Walboomers, H. Engelkamp, P. Christianen, Y. D. Khesuani, L. Moroni, and C. Mota, Biofabrication (2020). https://doi: 10.1088/1758-5090/ab7554

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EVIDENCE FOR AN EXOTIC HIGH-FIELD SUPERCONDUCTING STATE IN FeSe

S. Kasahara, Kyoto University, N. Hussey, HFML Nijmegen, and J. Wosnitza, HLD Dresden

Superconductivity is destroyed at high magnetic fields. Usually, the highest field up to which this state can exist is the Pauli paramagnetic limit, when the Zeeman energy of the itinerant electrons becomes larger than the superconducting condensation energy. Superconductivity may, however, survive even beyond the Pauli limit in a spatially modulated order. This so-called FFLO state was already predicted in 1964, independently by Fulde and Ferrell as well as Larkin and Ovchinnikov. Despite tremendous efforts in the search for the FFLO states in the past half century, indications of its experimental realization have been reported in only a few candidate materials.

In a recent work, a team of scientists from Kyoto, Bochum, and the EMFL high-field labs in Nijmegen and Dresden investigated the superconductor FeSe combining the complementary expertise available at two different EMFL labs. The team found compelling evidence of a distinct high-field superconducting phase, which is separated from the low-field phase via a first-order phase transition. This high-field phase is attributed to an FFLO state, in which the Abrikosov flux-line lattice is segmented by periodic nodal planes.

FeSe is a layered iron-chalcogenide superconductor with a superconducting transition temperature at about 9 K. The material shows exotic superconductivity with various distinct features. The scientists studied high-quality single crystals of FeSe by means of electrical-resistivity and thermal-conductivity measurements in fields up to 35 T applied parallel to the layer. The resistivity data revealed an unusual upturn of the irreversibility field, i.e., of the onset of nonzero resistance, and a peak in resistance at somewhat higher field (Figure). The upturn in the upper critical field, which is expected to be located well above the irreversibility field, suggests the formation of a high-field superconducting phase. The most remarkable feature is that the field-dependent thermal-conductivity data below 2 K exhibit a discontinuous downward jump at about 24 T. Across this field, a large change of the field-dependent slope appears. Thus, these measurements provide strong evidence for a distinct high-field superconducting phase in FeSe, most probably an FFLO phase.

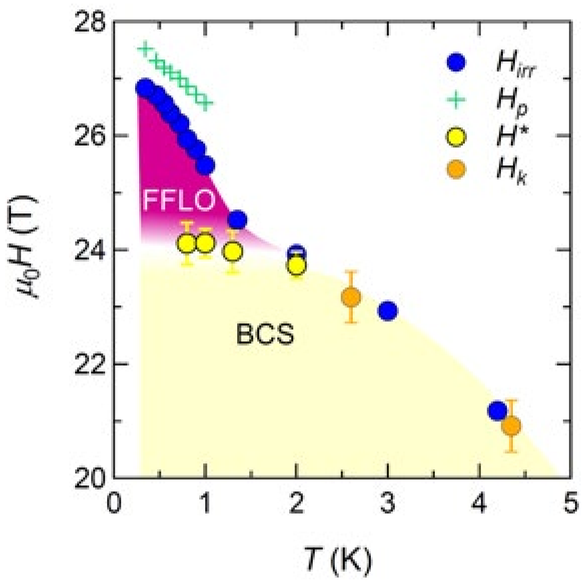

Figure: High-field phase diagram of FeSe for field aligned parallel to the layers. Blue circles and green crosses show the irreversibility field, H_{irr}, and peak field, H_p, determined by resistivity measurements. Orange and yellow circles show the fields H_k and H*, where thermal-conductivity data show either a kink or downward jump, respectively. Above the first-order phase transition field H*, a distinct field-induced superconducting phase emerges at low temperatures.

Evidence for an Fulde-Ferrell-Larkin-Ovchinnikov State with Segmented Vortices in the BCS-BEC-Crossover Superconductor FeSe, S. Kasahara, Y. Sato, S. Licciardello, M. Čulo, S. Arsenijević, T. Ottenbros, T. Tominaga, J. Böker, I. Eremin, T. Shibauchi, J. Wosnitza, N. E. Hussey, and Y. Matsuda, Phys. Rev. Lett. **124**, 107001 (2020).

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ORIGIN OF THE LARGE UPPER CRITICAL FIELD OF A STOICHIOMETRIC IRON-BASED SUPERCONDUCTOR, $CaKFe_4As_4$

Matthew Bristow, Amalia Coldea, University of Oxford and William Knafo, LNCMI-Toulouse

$CaKFe_4As_4$ belongs to a new family of 1144 iron-based superconductors. It is a clean and stoichiometric superconductor with a relatively high critical temperature of 35 K. This system lacks long-range magnetic order or a nematic electronic state at low temperatures. It is an ideal stoichiometric superconductor that is already optimally doped.

Due to the reduced symmetry compared with the 122 family, the Fermi surface of $CaKFe_4As_4$ is predicted to have up to ten different electron and hole sheets in which interband pairing between electron and hole pockets as well as the intraband pairing is possible (Figure 1f). $CaKFe_4As_4$ has an exceptionally large critical current density due to the strong point-like defects caused by local structural site effects as well as surface pinning. In order to understand the multi-band superconducting properties of $CaKFe_4As_4$, we have measured the upper critical fields for two orientations in magnetic fields up to 90 T using electrical-transport measurements (Figures 1a and 1b). These studies provide a complete upper critical field phase diagram of $CaKFe_4As_4$ indicating that it is isotropic at the lowest temperature (Figures 1c and 1d). We use a two-band model to describe the temperature dependence of the upper critical fields for both field orientations. The band coupling parameters indicate the presence of different competing pairing channels. Furthermore, at low temperatures, the in-plane upper critical field does not saturate but shows an upturn, consistent with the emergence of a Fulde-Ferrell-Larkin-Ovchinnikov (FFLO) state that can be stabilized in a clean system with shallow bands and a large Maki parameter (about 4.2) such as $CaKFe_4As_4$ (Figure 1e).

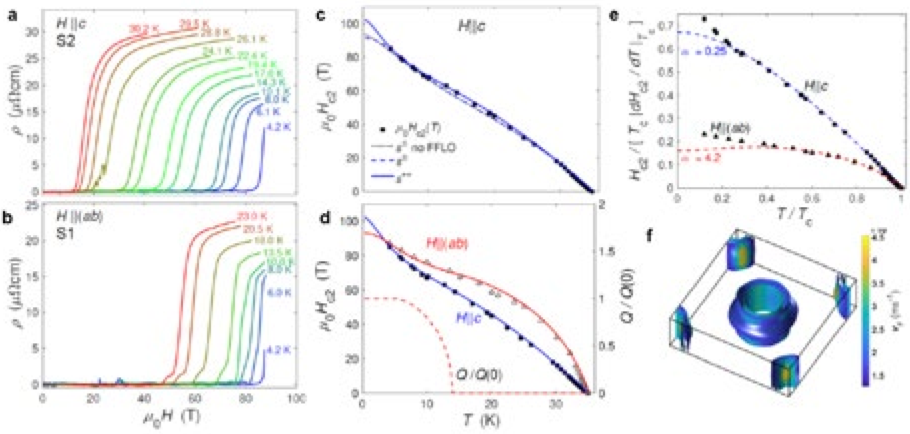

Figure 1: Resistivity versus magnetic field at constant temperatures measured in pulsed fields up 90 T, for (a) H || c (S2) and (b) H || (ab) (S1). The two-band model describes the temperature dependence of the upper critical field for the two different pairing symmetries for H || c in (c) and including the emergence of the FFLO state in (d). (e) Upper critical fields for the two field orientations scaled by the superconducting transition temperature, T_c, and the slope near T_c from the WHH model against the reduced temperature T/T_c. (f) Fermi surface of $CaKFe_4As_4$.

Competing pairing interactions responsible for the large upper critical field in a stoichiometric iron-based superconductor $CaKFe_4As_4$, M. Bristow, W. Knafo, P. Reiss, W. Meier, P. C. Canfield, S. J. Blundell, and A. I. Coldea, Phys. Rev. B **101**, 134502 (2020).

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OPENING OF THE CALL FOR ACCESS NO. 23

In the wake of the COVID-19 crisis, user operation in the EMFL facilities has stopped. We sincerely hope that our labs soon will be available again for user access. Keeping in mind the considerable backlog of granted proposals that could not be carried out at our facilities due to the ongoing crisis, we would like to ask you, this time, to indicate special urgencies for performing your proposed experiment.

The 23rd call for proposals has been launched on April 15, 2020, inviting researchers worldwide to apply for access to one of the large installations for high magnetic fields collaborating within EMFL.

The four facilities

> LNCMI - Grenoble - France: Static magnetic fields up to 36 T
> HFML - Nijmegen - the Netherlands: Static magnetic fields up to 37,5 T
> HLD - Dresden - Germany: Pulsed magnetic fields to beyond 90 T
> LNCMI - Toulouse - France: Pulsed magnetic fields of long duration to beyond 99 T and on the microsecond scale to beyond 200 T

run a joint proposal program, which allows full access to their installations and all accompanying scientific infrastructure to qualified external users, together with the necessary support from their scientific and technical staff.

Users may submit proposals for access to any of these installations by a unified procedure. The online form for these proposals can be found on the EMFL website.
www.emfl.eu/user

Please note that each experiment carried out on our high magnetic field installations must be followed up by a progress report and your publication record filled out online on the EMFL website. Please be aware that this information will also be made available to the Selection Committee.

To further improve our user program, your feedback to the user committee is highly appreciated.
Please find the form on the EMFL website.
https://emfl.eu/SelCom/UserCommittee/feedbackform.php

The deadline for proposals for magnet time is May 15, 2020. Accepted proposals of calls 119 and 219 that could not be performed due to the COVID-19 crisis, remain valid.

The proposals will be evaluated by a Selection Committee. Selection criteria are scientific quality (originality and soundness), justification of the need for high fields (are there good reasons to expect new results) and feasibility of the project (is it technically possible and are the necessary preparations done). It is strongly recommended to contact the local staff at the facilities to prepare a sound proposal and ideally indicate a local contact.

Please do acknowledge any support under this scheme in all resulting publications with „We acknowledge the support of the HFML-RU (or HLD-HZDR or LNCMI-CNRS), member of the European Magnetic Field Laboratory (EMFL)." UK users should, in addition, add "A portion of this work was supported by the Engineering and Physical Sciences Research Council (grant no. EP/K016709/1)."

> You may find more information on the available infrastructures for user experiments on the facility websites.

www.hzdr.de/hld
www.lncmi.cnrs.fr
www.ru.nl/hfml

EMFL
European Magnetic Field Laboratory

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

"SUPEREMFL" AND "ISABEL": EMFL CONSORTIUM RECEIVES 7,8 MILLION EUROS EU FUNDING

Together with partners the three European Magnetic Field Laboratories, joined in EMFL, have been awarded two EU Horizon 2020 grants: one to develop all-superconducting user magnets beyond 40 Tesla (2.9 M€), and one to expand EMFL's industrial and user community (4.9 M€). With these grants, EMFL will strengthen its long-term sustainability and invest in the design of beyond-state-of-the-art magnets.

Some recent advances open the way for the implementation of fully superconducting magnets, combining low- and high-temperature superconductor (HTS) technology for the magnets at the EMFL facilities. These magnets will partly replace current high-field resistive magnets in the future, leading to a significantly lower energy consumption and new scientific possibilities. It creates new market opportunities in areas such as materials characterization, materials processing, chemistry, and biology. It also enhances the competitiveness of industrial partners, and has the potential to create spin-offs in sectors such as medical imaging, materials processing, energy transport and storage.

EMFL aims to ensure its long-term sustainability by optimizing its structure, bridging the gap with industry (offer a better service for industrial users and active transfer of EMFL technology), and strengthening the role of high-magnetic-field research in Europe and worldwide. Important goals are the enlargement of EMFL membership and the improvement of several organizational aspects, such as data management, outreach, and access procedures.

EU H2020 INFRADEV

The EU Horizon 2020 INFRADEV program aims to support the development of world-class research infrastructures which will help Europe to respond to grand challenges in science, industry, and society. It facilitates and supports the implementation and long-term sustainability of the research infrastructures identified by the European Strategy Forum on Research Infrastructures (ESFRI) and of other world-class research infrastructures. There are several INFRADEV programs. The Design Study (INFRADEV-01 - "SuperEMFL") program offered the financial support to develop all-superconducting user magnets above 40 Tesla. The expansion of the industrial and user community falls under 'Individual support to ESFRI and other world-class research infrastructures' (INFRADEV-03 - "ISABEL"). Both projects have a duration of 4 years.

PROF. SEBASTIAN M. SCHMIDT TAKES OVER AS HZDR'S SCIENTIFIC DIRECTOR AND MEMBER OF THE EMFL COUNCIL

Prof. Sebastian M. Schmidt took the reigns as scientific director of the Helmholtz-Zentrum Dresden-Rossendorf (HZDR) on April 1, 2020. He came from the Forschungszentrum Jülich, where he was a member of the Executive Board and has been responsible since November 2007 for the research areas „Matter" and „Key Technologies / Information". After fourteen years of service to the HZDR, Prof. Roland Sauerbrey is retiring as scientific director and member of the EMFL Council.

From one of the largest research centers in western Germany to one of the largest research centers in eastern Germany: Prof. Sebastian M. Schmidt remains loyal to the Helmholtz Association. His path leads from Jülich to Dresden, where the physicist will lead as scientific director of the HZDR from April 1st. Prof. Roland Sauerbrey, as planned, officially renounced his position on March 31st.

Above all good reasons, it is the large-scale facilities in Rossendorf and the broad research spectrum that attracted Schmidt to the Saxonian capital. "In the area of materials research, the HZDR is ideally positioned with its unique infrastructures. The ELBE Center for High-Power Radiation Sources, the High Magnetic Field Laboratory, and the Ion Beam Center are in demand by users around the world. With the European platform for dynamo experiments (DRESDYN) and the Helmholtz International Beamline for Extreme Fields (HIBEF), additional exciting facilities are being created that will attract national and international attention to the center."

With Roland Sauerbrey retiring, Sebastian M. Schmidt is also his successor in the EMFL Council, the highest governing body of the consortium.

Since April 1, 2020, Prof. Sebastian M. Schmidt (right) is Scientific Director of the HZDR. His predecessor, Prof. Roland Sauerbrey (left), is retiring.

GREETINGS FROM WUHAN IN TIMES OF CORONA: TOGETHER WE FIGHT

© Tao Peng, Wuhan National High Magnetic Field Center

Wuhan, capital city of Hubei province in the People's Republic of China, was the first urban center worldwide to get hit hard by the Corona pandemic. Now, months later, the situation on site is slowly getting back to normal. On April 8, 2020, the Wuhan lockdown officially ended. Meanwhile, the focus of attention in the fight against the new coronavirus SARS-CoV-2 is shifting to other parts of the world, noticed by Wuhan's population with genuine concern. Trying to alleviate the impact of the Corona pandemic in other parts of the world, especially in the segment where it has close ties to, the Wuhan National High Magnetic Field Center donated batches of protective masks to their colleagues of the High Magnetic Field Community worldwide, shipping them to Tallahassee (USA), Dresden (Germany), Toulouse (France), Nijmegen (The Netherlands) and Sendai (Japan).

At this occasion, the EMFL would like to express the gratitude of its members for this very special gesture of solidarity and friendship within the High Magnetic Field Forum.

COVID-19: THIS YEAR'S EMFL USER MEETING AND HANDS-ON WORKSHOP POSTPONED UNTIL NEXT YEAR

Thank you to everyone who registered for participation. Your level of commitment left us very encouraged, specifically in the case of the hands-on workshop, for which we experienced a pleasingly large number of applications. We are deeply sorry, but the current situation due to the Corona pandemic left us with no option other than to postpone the events until next year. The venue will be the same as planned for this year, the HLD in Dresden in the middle of June, 2021. The exact date will be disclosed as soon as possible. We truly regret any inconvenience these changes may cause.

Most sincerely,
EMFL User Meeting and Hands-on Workshop Organizing Committee

UPCOMING EVENTS

Due to the dynamics of the current situation, some of these conferences might get canceled in due course.

1. International Conference on the Physics of Semiconductors (ICPS), Sydney, Australia, August 9-14, 2020. **https://www.icps2020.org/** CANCELED

2. 29th International Conference on Low Temperature Physics (LT29), Sapporo, Japan, August 15-22, 2020. **http://www.lt29.jp** CANCELED

3. 24th International Conference on High Magnetic Fields in Semiconductor Physics (HMF), Hong Kong, China, August 16-21, 2020. **https://hmf24.ust.hk/** CANCELED

4. International Conference on Strongly Correlated Electron Systems (SCES 2020), Guarujá, Brazil, September 20-25, 2020. **https://sces2020.org/**

5. 65th Annual Conference on Magnetism and Magnetic Materials, Palm Beach, USA, November 2-6, 2020. **https://magnetism.org/**

6. IRMMW-THz 2020, 45th International Conference on Infrared, Millimeter, and Terahertz Waves, Buffalo, USA, November 8-13, 2020. **https://irmmw-thz.org/current-conference/home**

7. Symposium „Materials for Extreme Conditions", 2020 MRS Fall Meeting & Exhibit, Boston, USA, November 29 – December 4, 2020. **https://www.mrs.org/meetings-events/fall-meetings-exhibits/2020-mrs-fall-meeting/call-for-papers/call-for-papers-detail?code=SF01**

8. Joint European Magnetic Symposia (JEMS), Lisbon, Portugal, December 7-11, 2020. **https://www.jems2020.com/**

9. International Conference on Magnetism (ICM), Shanghai, China, July 4-9, 2021. **http://www.icm2021.com/**

10. MT27, International Conference on Magnet Technology, Fukuoka, Japan, November 15-19, 2021. **http://csj.or.jp/conference/MT27/**

Wind rose on the pavement in front of the Monument of the Discoveries, Lisbon, Portugal.

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