EMFL Annual Report 2020

EMFL

European Magnetic Field Laboratory

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Science in High Magnetic Fields

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European Magnetic Field Laboratory

Annual report 2020

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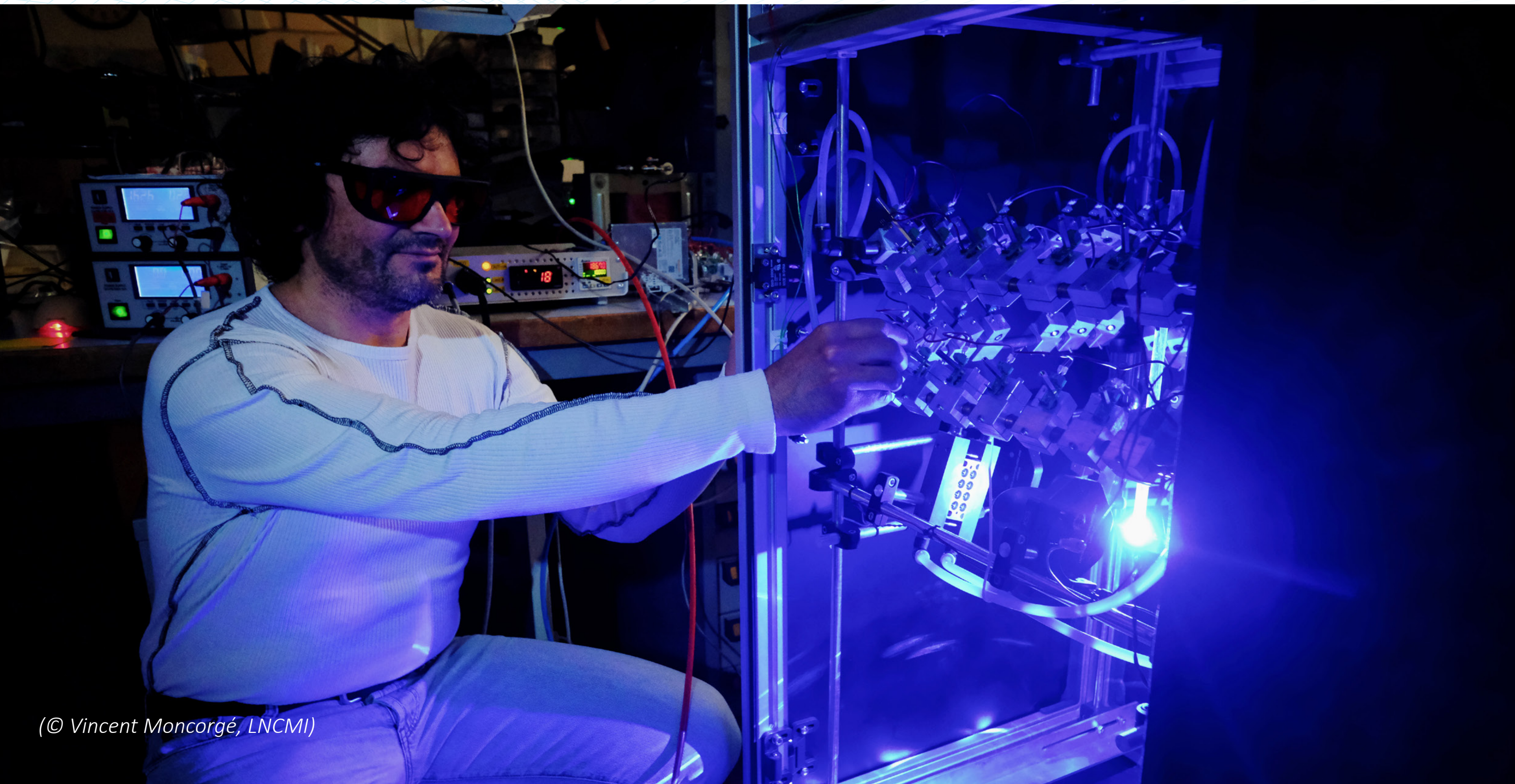
Contents



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Foreword

Dear Reader,

It is a great pleasure to present to you the sixth annual report of the European Magnetic Field Laboratory. 2020 was a year that was dominated by the effects of the world-wide Covid-19 pandemic. The EMFL facilities had to close for a short period of time and after reopening restrictions for lab occupation and traveling seriously hampered their operations. Therefore, we are extremely happy that, despite these most difficult circumstances, we are able to report a large number of scientific highlights, important developments and new high field initiatives.

One of these initiatives is the start of the H2020-ISABEL project, which aims to improve the long-term sustainability of the EMFL, together with many partners, both from academia and industry. We are also looking forward to the start of the H2020-SuperEMFL project, in the beginning of 2021, which will focus on the development of high-Tc superconducting user magnets.

At the end of the year Geert Rikken stepped down as director of LNCMI and as chair of the EMFL Board of Directors. We thank Geert; not only for his excellent chairmanship during the last two years, but also for his great work, during a large number of years, constructing the network of the high magnetic field facilities and being one of the founders of the EMFL. We wish Charles Simon all the best as the new director of LNCMI and we welcome him in the Board of Directors.

Finally, I would like to use this opportunity to thank all the staff and users of the EMFL facilities for their hard work, resilience and flexibility, to make 2020 such a successful year.

Peter Christianen

Chairman EMFL
Director HFML

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Mission

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

High magnetic fields are one of the most powerful tools available to scientists for the study, the modification and the control of the state of matter.

The European Magnetic Field Laboratory (EMFL) was founded in 2015 and awarded the Landmark status in March 2016 during the ESFRI Roadmap presentation in Amsterdam. EMFL provides the highest possible fields (both continuous and pulsed) for its researchers. The EMFL is dedicated to unite, coordinate and reinforce the four existing European high magnetic field facilities – the Dresden High Magnetic Field Laboratory (Germany), the Laboratoire National des Champs Magnétiques Intenses in Grenoble and Toulouse (France), and the High Field Magnet Laboratory in Nijmegen (The Netherlands) – within a single body as a world-leading infrastructure.

The missions of the EMFL are:

- to develop, construct and operate world-class high-field magnets
- to perform excellent research in very high magnetic fields
- to act as a European user facility for the scientists of the participating countries and for other scientists
- to act as the European centre of excellence for different magnetic-field-based material characterisation techniques in very high fields

(High pressure pump © Gideon Laureijs, Radboud University)

Developments 2020

COVID-19

EMFL, like all other large scale research infrastructures, has suffered from the impact of the Covid-19 pandemic. The impact affects different parts of our activities and particularly our international guest programme.

Due to the pandemic, some of the EMFL facility were entirely closed for a short period of time in March-May. After reopening of the facilities, national and local regulations still made it difficult for users from abroad to travel to one of the EMFL sites. Governmental rules, local policies, travel restrictions and insurances made that visits from abroad were very limited from the start of the pandemic. The awarded user projects that could not take place have been postponed and have been rescheduled, whenever possible, in mutual agreement with the respective user group. Consequently, the pandemic has caused a backlog of mainly external projects. Effort was made to offer mail-in and/or remote access enabling to perform external projects. In some cases this was indeed possible, but for a large number of the projects the external experimentalist is required on site.

Next to these also our technical development programmes such as the assembly of the hybrid magnets in Grenoble and Nijmegen are hampered by the covid-19 pandemic. Also here external suppliers and travel restriction have suffered from the pandemic resulting in delays in these projects as well.

"SuperEMFL" and "ISABEL": EMFL consortium receives 7,8 M€ 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 (SuperEMFL, 2.9 M€), and one to expand EMFL's industrial and user community (ISABEL, 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.

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.

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

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 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.

Greetings from Wuhan in times of corona: Together we fight

Donation of WHMFC to all high-field facilities

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. On April 8, 2020, the Wuhan lockdown officially ended and the situation on the Wuhan National High Magnetic Field Center was slowly getting back to normal. Meanwhile, the focus of attention in the fight against the new coronavirus SARS-CoV-2 was 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.

National roadmap grant for HFML-FELIX

HFML-FELIX has been awarded 15.1 million euros for the development of advanced instrumentation and new experimental techniques. The grant is part of the National Roadmap for Large-Scale Research Facilities of the Dutch Research Council (NWO) which enables the building or renovation of research facilities with international allure.

HFML
Science in High Magnetic Fields

FELIX
Free Electron Lasers for
Infrared eXperiments

HFML-FELIX represents a world-unique research infrastructure in the Netherlands, working at the forefront in science and technology with respect to magnets and free-electron lasers. It serves as an open-access, international user facility, which hosts more than 500 guest researchers per year. Then again, HFML itself is one of the three European Magnetic Field Laboratories, joined in EMFL.

The awarded grant is dedicated to the development and exploitation of the facility (jointly operated by the Radboud University and NWO) as well as to develop experimental infrastructure and new instrumentation. The work will be executed in close collaboration with several partners from Dutch universities, institutes, companies, and hospitals.

Peter Christianen (director HFML): “We are delighted to have received this grant, which allows us to further develop pioneering technology and instrumentation. The innovative equipment will enable breakthroughs in a wide range of scientific domains and will contribute to solving societal challenges in the areas of Health, Energy, and Smart Materials. To give two examples: we will build instrumentation to image biomarkers in tissue to diagnose diseases and we will develop new experimental techniques aiming to reduce the energy required for magnetic data storage."

Britta Redlich (director FELIX): "These plans have been defined by identifying the most pressing requests from existing and prospective users to extend our experimental possibilities. In all projects, we work closely together with universities, institutes, companies, and medical centers across the country taking advantage of their expertise and experience in the corresponding areas. Ultimately, these developments will be opened to the research community worldwide."

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The combined HFML-FELIX building.

Jake Ayres: Former PhD student HFML awarded EPSRC fellowship

Experimental physicist Jake Ayres, a former PhD student at HFML, has been awarded a two-year fully funded EPSRC Doctoral Prize Fellowship to determine whether the elusive origin of high-temperature superconductivity can come from a newly revealed incoherent variety of electrons.

© Jake Ayres

"Using the high fields at the HFML during my PhD, I found signs that there appear to be two 'varieties' of electrons in high-temperature superconductors. One type behaves as we would expect 'normal' electrons to behave in magnetic fields, but the other variety is very unusual and appears to be incoherent. It's potentially very exciting because understanding high-temperature superconductivity is a 30 year old problem and one that numerous Nobel prize winners have contributed towards. Incoherent transport and how it might be linked to high-temperature superconductivity is a new line of thinking. I hope the planned thermodynamic measurements will tell us something new and fundamental about the problem."

Ayres is now working as a postdoc in the group of Nigel Hussey at the University of Bristol, but he will be visiting Nijmegen frequently (when possible) to use thermodynamic measurements developed for high-field experiments at the HFML.

EPSRC Doctoral Prize Fellowship

The EPSRC fellowship supports recent PhD graduates' transition into early career research. It is for recently graduated or final-stage outstanding PhD researchers who have been funded by the Engineering and Physical Sciences Research Council (EPSRC) for their research. They can launch their research career in a supportive environment. Doctoral Prize Fellows propose their own bespoke program to conduct innovative, ground-breaking research.

EMFL Prize Winner 2020: Zhe Wang

Due to the Corona pandemic, this year´s EMFL award ceremony took place less festive as usual. This time, Dr. Zhe Wang, junior group leader at the University of Cologne, had the honor to receive the prize. Due to the unusual circumstances, Jochen Wosnitza, Director of the Dresden High Magnetic Field Laboratory and chair of the prize committee, was forced to hand over the award via mail. Dr. Zhe Wang received the award for his pioneering work in the field of quantum magnetism, in particular for the experimental detection of Bethe strings using terahertz spectroscopy at very high magnetic fields.

The German Physical Society had previously nominated him as laureate for the Walter Schottky prize 2020 for his contributions to the field of solid-state physics. Due to the pandemic and oddly enough, this award ceremony got affected as well and had to be postponed to a later date. Since 2009, the EMFL members award annually the EMFL prize for exceptional achievements in science done in high magnetic fields.

The EMFL prize winner 2020, Dr. Zhe Wang.

ISABEL: Improving the sustainability of EMFL

One of the great challenges of society is innovation through the development of new and advanced materials. We need such tailored materials in all key-technological areas, from renewable energy concepts, through next-generation data storage to biocompatible materials for medical applications. Furthermore, many of these future materials will be synthesized on a nano-scale. In order to reach these goals, researchers are in need of state-of-the-art analytical tools. High magnetic fields are one of the most powerful tools available to scientists for the study, modification, and control of states of matter, and EMFL provides such fields (both continuous and pulsed) to Europe's many active and worldleading researchers.

In recognition of the importance of the EMFL, and in order to assure its long-term sustainability, the EU has decided to fund the H2020-ISABEL project (Improving the SustAinaBility of the EMFL). This project unites 18 partners, both academic and industrial, and aims to strengthen the long-term sustainability of the EMFL through the realization of three objectives:

- Strengthening the EMFL structure by enlarging its membership and by improving several organizational aspects, such as data management, outreach, and access procedures.
- Strengthening the socio-economic impact of the EMFL, by bridging the gap with industry.
- Strengthening of the role of high magnetic field research in Europe and worldwide.

The project is coordinated by Geert Rikken (LNCMI) with a total budget of 4.9 M€, and it will start on 1/11/2020, for a duration of 4 years, with the kickoff video-meeting on 20/11/2020.

Delivery of the superconducting coil for 43+ T Grenoble hybrid magnet

The hybrid magnet in construction at LNCMI-Grenoble is based on the combination of resistive inserts, made of Bitter and polyhelix coils, with a large-bore superconducting outsert. It will produce in a first step, an overall continuous magnetic field of 43 T in a 34 mm warm-bore opening. The superconducting coil will provide a nominal magnetic field of 8.5 T in a 1.1 m cold-bore diameter.

It relies on the novel development of a Nb-Ti/Cu Rutherford Cable On Conduit Conductor (RCOCC) cooled down to 1.8 K by a bath of superfluid helium at atmospheric pressure. The novelty of the RCOCC development concerns the assembly and the induction soft soldering of the multi-strand Rutherford cable on a Cu-Ag hollow stabilizer (Figure 1). This allows for a strict control of the interstrand contact resistance and, therefore, of the AC losses within the superconductor to prevent a magnet quench in case of resistive-insert voltage trips. Thorough tests and validation phases were conducted at LNCMI-Grenoble as well as in industry prior to the in-house industrial production of the RCOCC [1]. This included the trial production of the hard-drawn Cu-Ag hollow stabilizer in continuous lengths of 325 m as well as studies, developments, and integration of the industrial production line at LNCMI-Grenoble. The production of 43 RCOCC unit lengths wound in a single pancake of 2 m internal diameter was completed end of July 2017 and sent to the coil manufacturer Bilfinger Noell GmbH. We consider this as one the first great achievements of the project.

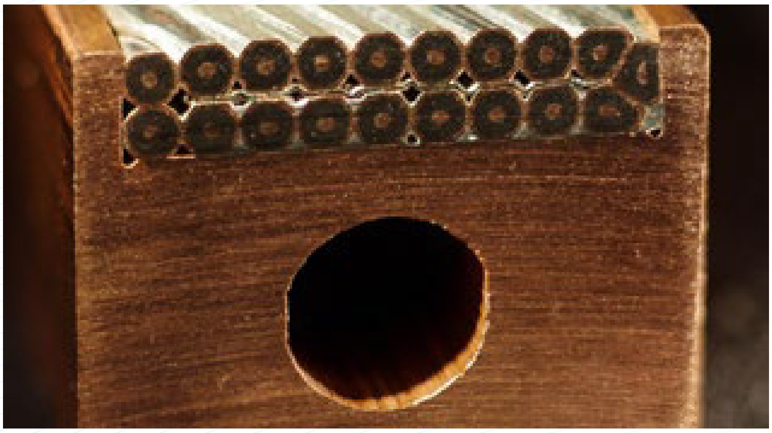

Figure 1: Cross section of the produced RCOCC of dimensions 17.92 x 12.96 mm².

A new milestone was achieved with the delivery of the superconducting coil at LNCMI-Grenoble. It consists of the thorough assembly of 37 double pancakes, vacuum impregnated separately (Figure 2), which can be exchanged in case of a serious damage during operation [2].

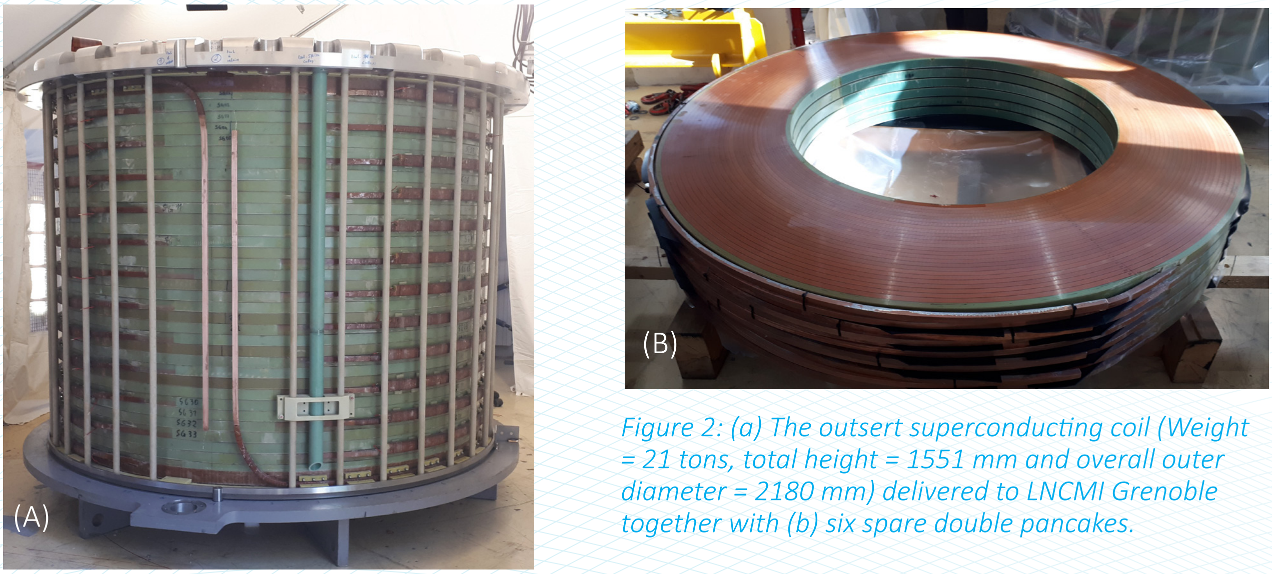

Figure 2: (a) The outsert superconducting coil (Weight = 21 tons, total height = 1551 mm and overall outer diameter = 2180 mm) delivered to LNCMI Grenoble together with (b) six spare double pancakes.

The remainder of the project focusses on:

- The construction of the cryogenic line connecting the cryogenic satellite to the magnet cryostat and
- The final assembly expected to end 2021.

This project is funded by the CNRS, the French Ministry of Higher Education and Research in the framework of the “Investissements pour l’avenir & Equipements d‘excellence” Equipex LaSUP (Large Superconducting User Platform), the European Funds for Regional Development (FEDER) and the Rhône-Alpes region.

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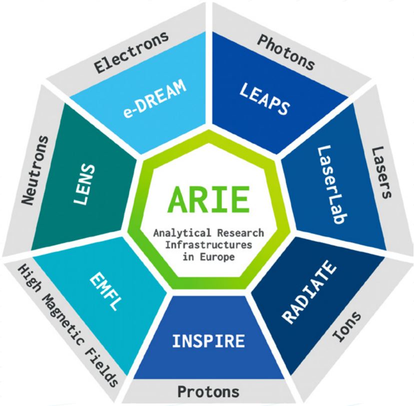
[2] From Manufacture to Assembly of the 43 T Grenoble Hybrid Magnet, P. Pugnat, R. Barbier, C. Berriaud, R. Berthier, T. Boujet, T. Disparti, P. Graffin, C. Grandclément, B. Hervieu, K. Juge, B. Mallery, F. Molinié, H. Neyrial, M. Pelloux, C. Peroni, R. Pfister, L. Ronayette, Hans J. Schneider-Muntau, and B. Vincent, IEEE Trans. Appl. Supercond. 30, 4300605 (2020).

ARIE: Joint position papers

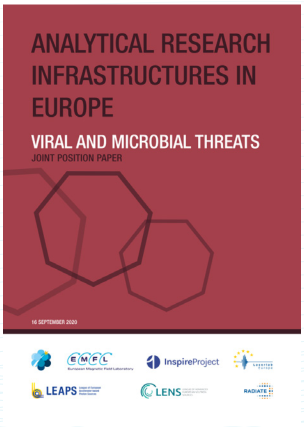
EMFL is a member of the Analytical Research Infrastructures of Europe (ARIE) consortium. The ARIE members are centers of scientific and technological excellence, delivering services, data, and expertise to a growing and diverse user community of more than 40,000 researchers in academia and industry, across a range of domains: the physical sciences, energy, engineering, the environment and the earth sciences, as well as medicine, health, food, and cultural heritage. They include powerful photon sources, such as synchrotrons, laser systems and free-electron lasers; sources of neutrons, ions, and other particle beams; and facilities dedicated to advanced electron microscopy and high magnetic fields.



2020 saw the publication of two crucial joint position papers. The first one, "A Key Resource for the Five Horizon Europe Missions", highlights how a common, complementary approach will strengthen the European analytical research infrastructures collectively and will address societal challenges of the Horizon Europe Missions framework program.

With the second joint position paper, "Viral and Microbial Threats", the consortium enhances its cross-border, multidisciplinary collaboration to offer Europe a strong and valid weapon against the present COVID-19 challenge and other possible, similar future crises.


ANALYTICAL RESEARCH INFRASTRUCTURES IN EUROPE
A KEY RESOURCE FOR THE FIVE HORIZON EUROPE MISSIONS
JOINT POSITION PAPER
PRE-RELEASE 8 JULY 2020 / PRIOR TO MISSION BOARDS FEEDBACK


ANALYTICAL RESEARCH INFRASTRUCTURES IN EUROPE
VIRAL AND MICROBIAL THREATS
JOINT POSITION PAPER
16 SEPTEMBER 2020

Scientific Highlights

Aperiodic quantum oscillations in the two-dimensional electron gas at the $LaAlO_3/SrTiO_3$ interface

The discovery of a two-dimensional electron gas (2DEG) at the interface between the two insulators $LaAlO_3$ (LAO) and $SrTiO_3$ (STO) has not only enhanced the expectations of oxide-electronics but has also brought new and exciting opportunities to explore the novel physics of 2DEG with unmapped parameters. First-principles calculations of the band structure reveal the occupancy of several non-degenerate sub-bands d_{xy}, d_{xz}, and d_{yz}, originating from crystal-field-split Ti 3d – t_{2g} orbitals; located at the interface or in its vicinity. The existence of many anisotropic and non-parabolic sub-bands, together with a large spin-orbit splitting at the crossing point of the d_{xy} and $d_{xz/yz}$ bands, provides a complex band structure which has received only partial support from transport experiments. In this study, we investigated the transport properties of a high-mobility quasi-2DEG at this interface under high magnetic field (55 T) and provided new insights in its electronic band structure by analyzing the Shubnikov-de Haas oscillations. Interestingly, the quantum oscillations are not periodic in 1/B and produce a highly non-linear Landau plot (Landau-level index versus 1/B). The aperiodic character of the oscillations entails the failure of standard Fourier-transformation data processing.

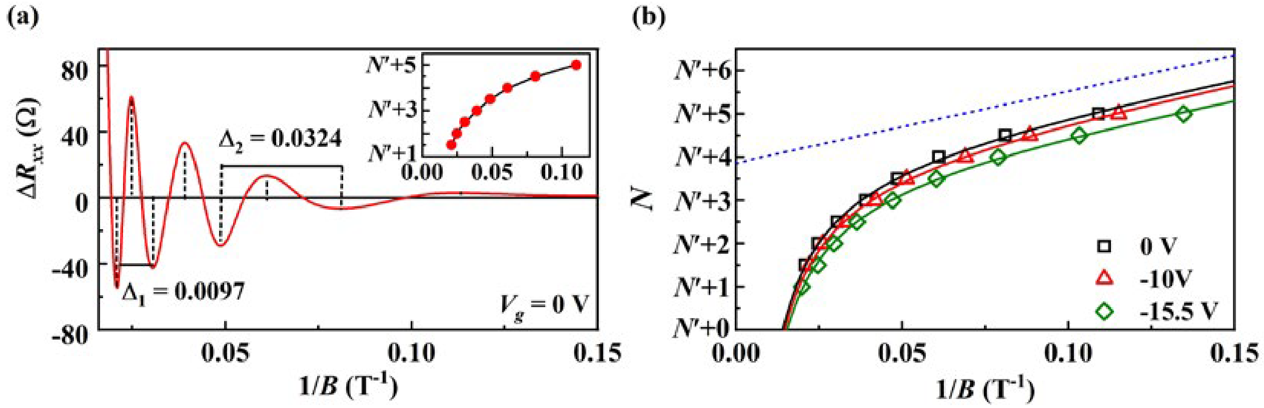


Figure: (a) Main panel: Inverse-field dependence of relative resistance oscillations, ΔR_{xx}, for zero gate voltage. Inset: Corresponding Landau-level plot. (b) Landau-level plots (symbols) for various gate voltages together with fits derived from the generalized Onsager relation (solid lines). The dashed line represents the asymptote for zero gate voltage. The index N is given within an integer offset N'.

Very low temperatures combined with high-field measurements are necessary to address the multi-band origin of the measured non-1/B-periodic oscillations. We explore several alternative scenarios, and in particular the generalized Onsager relation involving the magnetic response functions of the system. This study brings further evidence for a non-trivial band structure at the Fermi energy of this system, consistent with density-functional-theory calculations.

Reference

Rubi, K., J. Gosteau, R. Serra, K. Han, S. Zeng, Z. Huang, B. Warot-Fonrose, R. Arras, E. Snoeck, Ariando, M. Goiran and W. Escoffier (2020). “Aperiodic quantum oscillations in the two-dimensional electron gas at the $LaAlO_3/SrTiO_3$ interface”. *npj Quantum Materials*, 5 (1): 9.

Evidence for an exotic high-field superconducting state in FeSe

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.

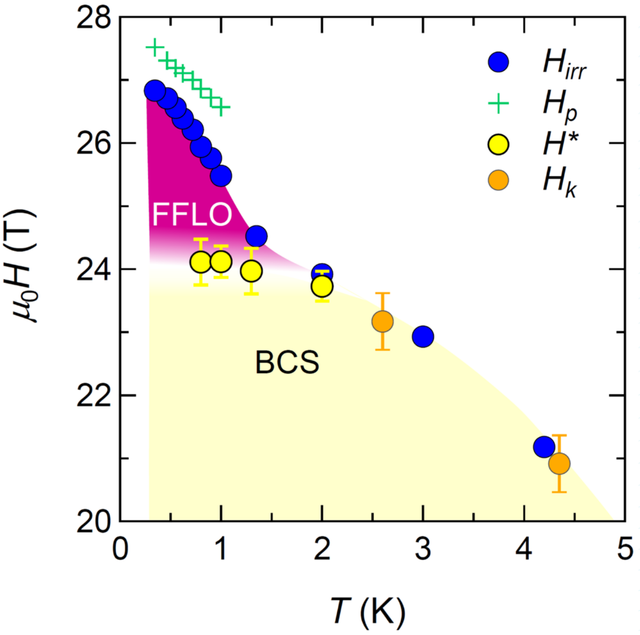


Figure: High-field phase diagram of FeSe for field aligned parallel to the layers. Blue circles and green crosses show the irreversibility field, H_{irr}, and peak field, H_p, determined by resistivity measurements. Orange and yellow circles show the fields H_k and H^*, where thermal-conductivity data 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.

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.

Reference

Kasahara, S., 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 (2020). “Evidence for an Fulde-Ferrell-Larkin-Ovchinnikov State with Segmented Vortices in the BCS-BEC-Crossover Superconductor FeSe”. *Physical Review Letters*, 124 (10): 107001.

Fermi-surface instabilities in the heavy-fermion superconductor UTe_2

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 reentrant 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.

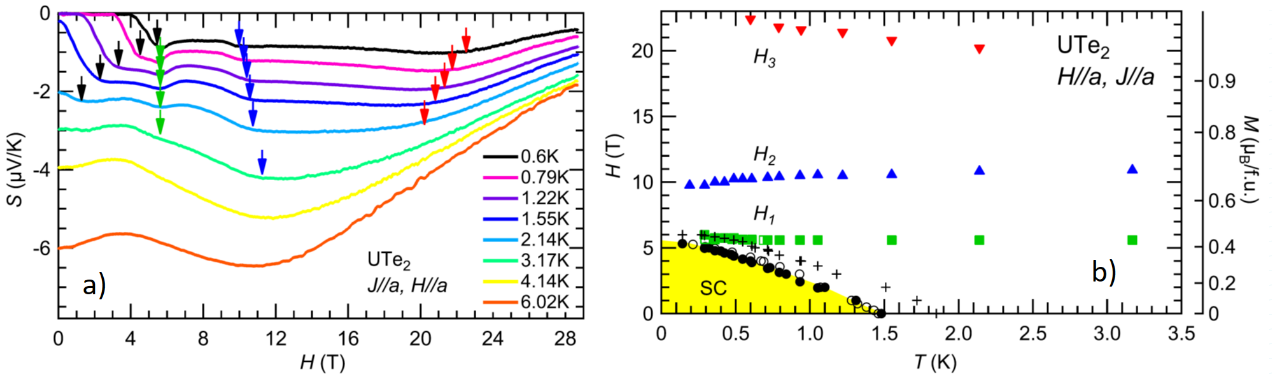


Figure: (a) Field-dependence of the thermopower at different temperatures exhibiting anomalies at the superconducting transition (black arrows) and at 3 successive electronic instabilities (critical fields) for H II a. (b) Magnetic field-temperature phase diagram with the superconducting phase and critical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

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Knebel, G., M. Kimata, M. Valiska, F. Honda, D. Li, D. Braithwaite, G. Lapertot, W. Knafo, A. Pourret, Y.J. Sato, Y. Shimizu, T. Kihara, J.-P. Brison, J. Flouquet and D. Aoki (2020). “Anisotropy of the Upper Critical Field in the Heavy-Fermion Superconductor UTe_2 under Pressure”. *J. Phys. Soc. Jpn.*, 89 (5): 053707.

Scaffold-free and label-free biofabrication technology using levitational assembly in high magnetic field

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.

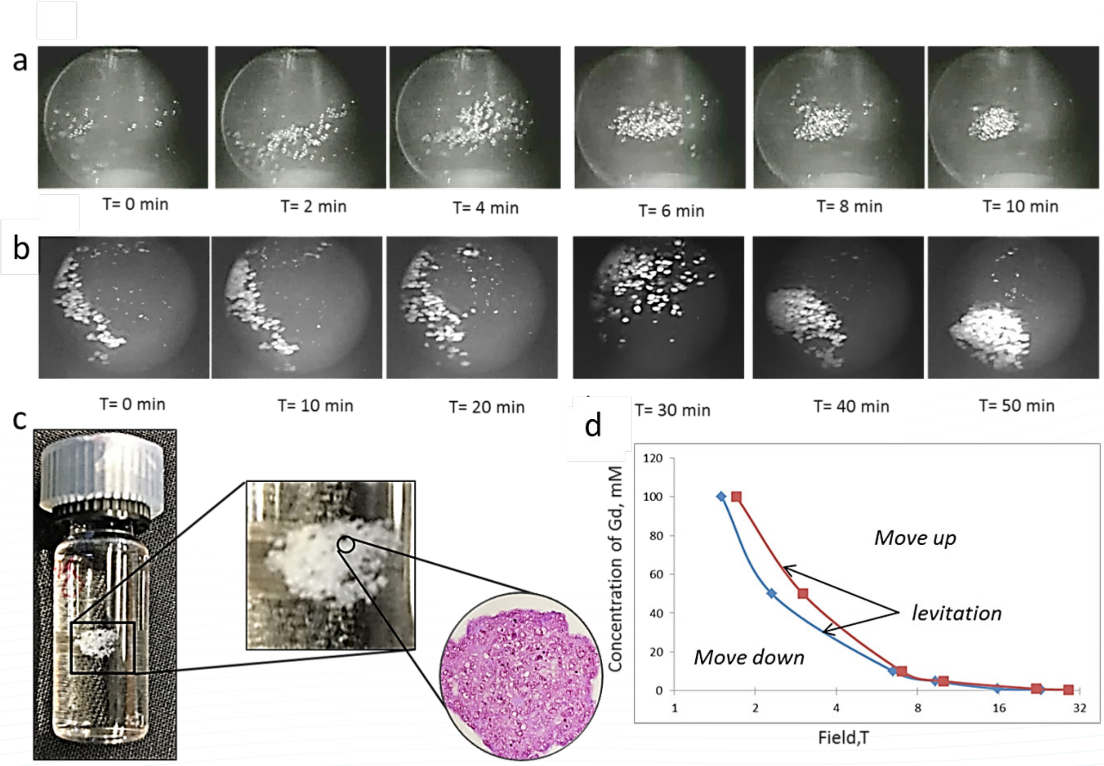

Figure: Construct assembly under high magnetic field levitation. a) Polystyrene beads assembling at 0.5 mM gadobutrol and in a magnetic field of 22 T. b) Tissue spheroids assembling until a stable construct was obtained at 0.8 mM gadobutrol and a magnetic field of 19 T. c) Construct assembled after 3 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).

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.

Reference

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Origin of the large upper critical field of a stoichiometric iron-based superconductor, $CaKFe_4As_4$

$CaKFe_4As_4$ 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).

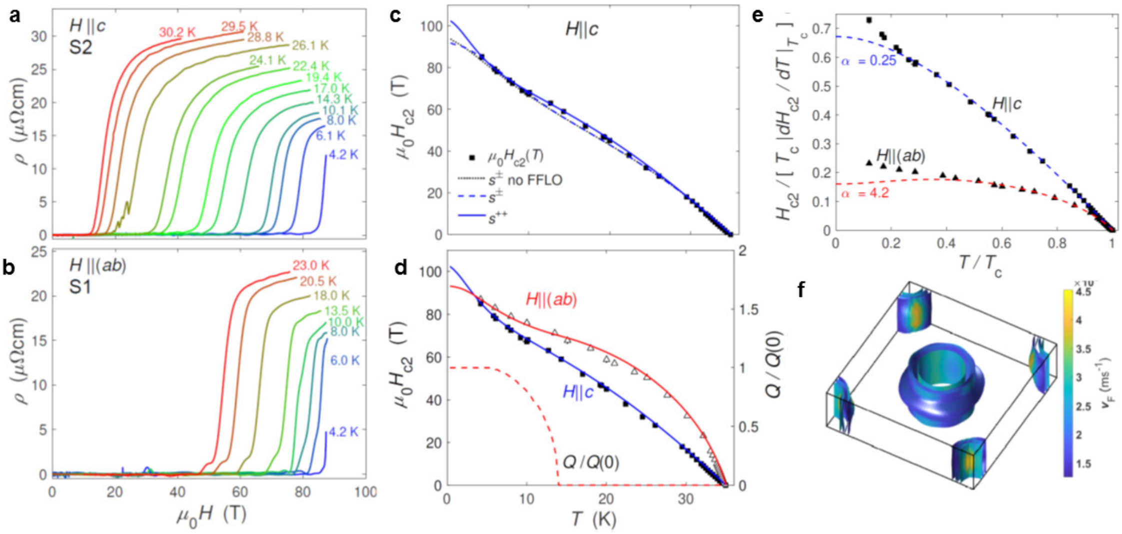

Figure 1: Resistivity versus magnetic field at constant temperatures measured in pulsed fields up 90 T, for (a) H || c (S2) and (b) H || (ab) (S1). The two-band model describes the temperature dependence of the upper critical field for the two different pairing symmetries for H || c in (c) and including 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 $CaKFe_4As_4$.

Reference

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

Reconstructed Fermi surface in the charge-density-wave state of $TiSe_2$

$TiSe_2$ features a charge density wave (CDW) driven by condensation of excitons, i.e., pairs of electrons and holes, alongside electron-phonon coupling. The CDW transition at 202 K gaps out most of the Fermi surface. Quantum-oscillation measurements at the HFML Nijmegen provide a clear view of the newly formed Fermi surface inside the CDW state. Above the CDW transition, the Fermi surface consists of a hole-like cylindrical pocket and an electron-like distorted and tilted ellipsoidal pocket. The formation of electron-hole pairs gaps out the complete hole pocket but leaves a small part of the electron states. Indeed, our quantum-oscillation measurements show that the low-temperature state contains a single electron-like ellipsoid without tilt.

Identifying the size and shape of the Fermi surface was done with angular-dependent measurements in magnetic fields up to 35 T and using a rotator probe inside a 3-He cryostat at the HFML, Nijmegen. The increase of the quantum-oscillation frequency shows that the Fermi surface is approximately ellipsoid, and the semi-axes have been extracted from the data (Figure). Together with the effective mass determined from the temperature dependence of the quantum-oscillation amplitude, this allows detailed comparison with specific heat, ARPES, and our 2-band transport analysis which shows that this is the only pocket.

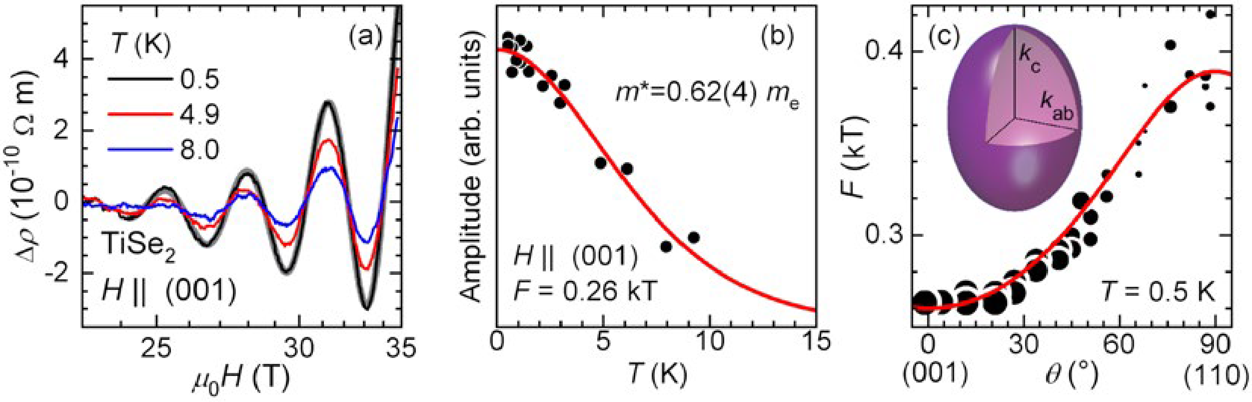

Figure: Highest resolution in the quantum oscillations measurements were realized with samples optimized for large resistance signal and using low-noise transformers. (a) The oscillations show a single frequency in $TiSe_2$ at lowest temperatures. (b) From the temperature dependence of the amplitude the effective electron mass was extracted. (c) The angular dependence of the quantum-oscillation frequency is fitted by an ellipsoid model (red line).

This knowledge of the Fermi surface of $TiSe_2$ enabled a study across the Fermi-surface reconstruction at the CDW transition. The team of Dr. Friedemann analyzed magnetoresistance and Hall-resistivity measurements performed at the University of Bristol to trace the elimination of the hole pocket and the shrinkage of the electron pocket. They found that electron scattering is maximum right at the CDW transition and, thus, probably driven by the CDW fluctuations and highlights that the CDW is dominating the electronic properties of $TiSe_2$.

Reference

Knowles, P., B. Yang, T. Muramatsu, O. Moulding, J. Buhot, C.J. Sayers, E. Da Como and S. Friedemann (2020). "Fermi Surface Reconstruction and Electron Dynamics at the Charge-Density-Wave Transition in $TiSe_2$". *Physical Review Letters*, 124: 167602.

Squeezing out field-induced reentrant hidden-order URu_2Si_2

The mystery of the hidden-order (HO) phase in the correlated electron paramagnet URu_2Si_2 is still unsolved. To address this problem, one strategy is to search for clues in the subtle competition between this state and neighboring magnetically ordered states. It is now well established that long-range antiferromagnetic order can be stabilized in this metal when it is under pressure and that a spin density wave manifests itself when a magnetic field is applied along the easy magnetic axis c. However, the complete boundaries of the HO phase in the pressure-magnetic-field plane of the phase diagram have not been determined so far.

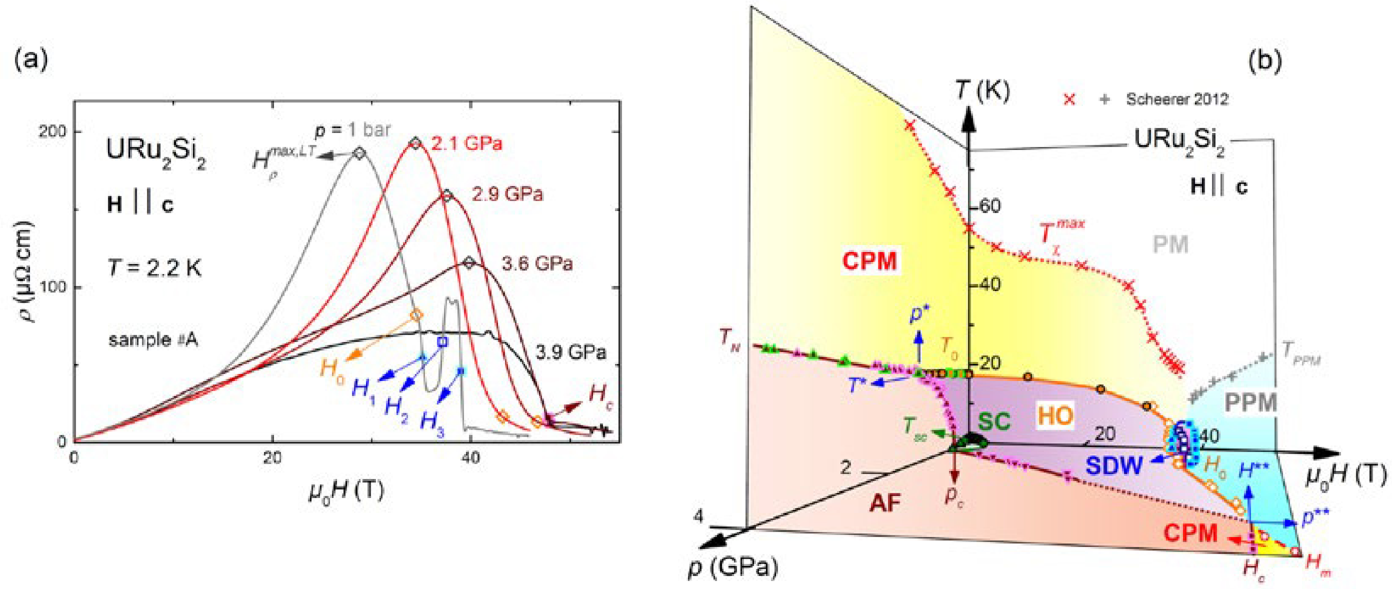

Figure: (a) Low-temperature electrical resistivity versus magnetic field and (b) three-dimensional phase diagram of URu_2Si_2 under pressure and magnetic field applied along c.

In this work, we have extracted the three-dimensional magnetic-field-pressure-temperature phase diagram of URu_2Si_2. Its magnetoresistivity was measured in magnetic fields up to 60 T combined with pressures up to 4 GPa. We find a rich phase diagram indicating a subtle competition between the different types of electronic interactions. The main features are the disappearance of the field-induced spin-density-wave phase and a squeezing out of the HO phase under high pressure. We emphasize that many of the boundaries of the 3D phase diagram are controlled by the field and pressure dependences of a single parameter characterizing the electronic correlations. This gives new constraints for theories that model the electronic correlations and ordered phases in URu_2Si_2.

Reference

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Broad tunability of carrier effective masses in two-dimensional halide perovskites

Two-dimensional organic-inorganic halide perovskites have generated tremendous interest in the field of optoelectronics for applications in low-cost and efficient light absorbers and emitters. Similar to their three-dimensional (3D) ancestors, the layered perovskite derivatives exhibit promising performance in photovoltaic and light-emitting devices, while presenting enhanced stability at ambient conditions, a haunting burden yet for their 3D counterparts. The enhanced environmental stability stems from the large hydrophobic organic cation L – a building block of two-dimensional perovskites – serving also as a spacer between consecutive inorganic sheets (see Figure for structure schematics). In contrast to 3D hybrid organic-inorganic perovskites, where the organic molecules cannot be chosen arbitrarily, there is a plethora of available large organic cations L leading to stable compounds. This makes 2D perovskites an unprecedented material system regarding tuning flexibility of its optoelectronic properties, because the large organic spacers provide control over the dielectric confinement as well as crystal and band structure and, as a result, the effective mass.

The effective mass is of specific interest as a fundamental parameter characterizing any semiconductor, governing the charge transport and optical-absorption phenomena, yet to date not measured for 2D perovskites. Such lack of experimental reports results in an unnecessary confusion as the estimated values of effective mass span over a broad range. Here, we demonstrate, for the first time, a direct experimental determination of the effective mass in 2D $(PEA)_2PbI_4$ and $(PEA)_2SnI_4$ perovskites (PEA = phenethylamine). Using high-magnetic-field spectroscopy, we observe interband Landau-level transitions. The energy separation of the Landau levels provides a direct handle for the reduced effective mass of the charge carriers μ. Combining our results with first-principles calculations, we find that μ can be tuned from a very low value of 0.05 m_0 to 0.15 m_0 by metal composition, which is a much wider range than that previously reported for 3D perovskites. Furthermore, we observe that the effective mass in 2D halide perovskites can be even lower than in the corresponding bulk material (Figure), which is in striking contrast to what is known for classic epitaxial quantum wells. Our direct experimental approach to determine the effective mass together with our calculations render a broader perspective on the available ways to modify effective masses in this fascinating material system.

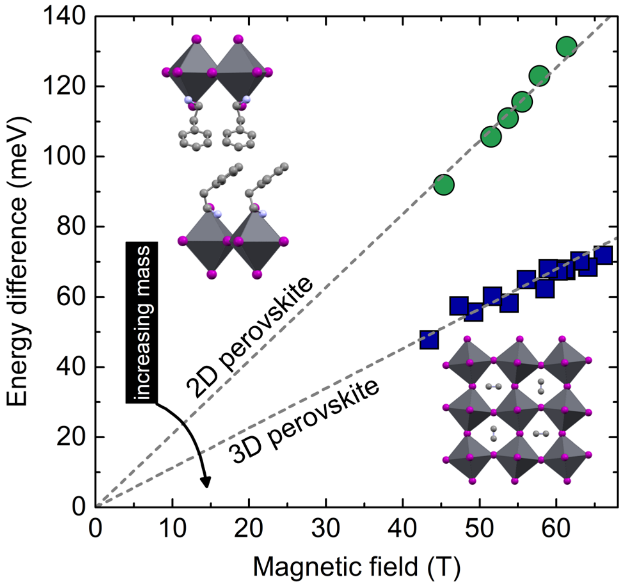

Figure: Energy difference between consecutive Landau levels versus magnetic field. Circles represent the 2D perovskite (PEA_2SnI_4), squares stand for 3D $FASnI_3$ (FA = formamidinium). Dashed lines are fits with $\Delta E = eB/\mu$, from which we directly determine the value of μ. The smaller the slope of the fitted curve the higher the effective mass. Although both compounds belong to the tin family, the 2D structure shows a lower reduced effective mass, atypical when the quantum confinement plays a role. The inset shows the crystal structure (c axis pointing upwards) of 2D (top left) and 3D (bottom right) perovskites. The sheets of inorganic cages of 2D perovskite are separated by large organic molecules containing phenyl rings.

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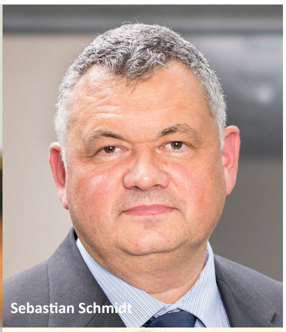
Organisational structure

EMFL's objective, without profit aim, is to unite world-class high magnetic field facilities and to make them available for excellent research by users. More specifically, EMFL is responsible for the management of access, networking and coordination activities of the high-field facilities in Europe.



Council

The Council is the highest governing body of EMFL and consists of the EMFL Member representatives. The council does:

- appoint and dismiss the Directors and approve the candidacy of the executive manager,
- admit and dismiss EMFL Members,
- approve the progress report, annual accounts and the budget presented by the Board of Directors,
- amend the Statutes and approve the vision, mission and definition of values of the Association,
- discuss and develop strategic, scientific and technical plans of the EMFL.

The Council exists of:

Han van Krieken (RU/NWO, chair)
Roland Sauerbrey (HZDR until 31/3/2020)
Sebastian Schmidt (HZDR from 1/4/2020)
Emmanuelle Lacaze (CNRS)
Amalia Patanè (University of Nottingham)
Adam Babiński (University of Warsaw)
Pierre Védrine (CEA-IRFU)

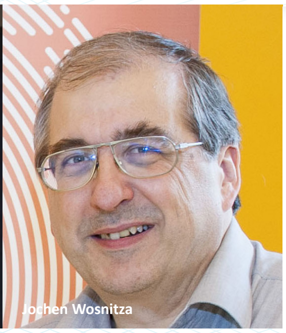
Board of Directors

The board of directors, composed of the laboratory directors, where needed seconded by an executive manager has the following tasks:

- define the vision and mission,
- execute the strategic operation,
- prepare the budget, the annual accounts and the progress report.

The Board of Directors exists of:

Geert Rikken (LNCMI, chair)
Jochen Wosnitza (HLD)
Peter Christianen (HFML)



Strategic Advisory Committee

The Strategic Advisory Committee will evaluate the research activities of the high magnetic field facilities operated by the Host Members of the EMFL and advice on future research or technological activities.

To achieve this, the Strategic Advisory Committee will:

- Evaluate the research activities of the high magnetic field facilities operated by the host members of the EMFL.
- Evaluate the strategic plans of EMFL.
- Report its advice to the Board of Directors.

The Strategic Advisory Committee members are:

Massimo Altarelli (Chair), MPI for the Structure and Dynamics of Matter, Hamburg, Germany
Ziad Melham, Oxford Instruments, UK
Claudia Felser, MPI for chemical physics of solids, Dresden, Germany
Ingrid Mertig, Martin-Luther-Universität Halle-Wittenberg, Germany
Georg Maret, SciKon, University of Konstanz, Germany
Andrew Harrison, Diamond Light Source, UK
Andzrej Wysmolek, University of Warsaw, PL
Gabriel Chardin, APC Laboratory (Astroparticles and Cosmology), University of Paris

Selection Committee

The task of the EMFL selection committee is to ensure that from the proposed experiments only those that are of excellent scientific quality and clearly benefit from the access to a high-field facility are performed in the EMFL facilities.

The Selection Committee evaluates the scientific proposals on the following three criteria:

- scientific quality and originality of the proposal;
- necessity for the use of the infrastructure;
- track record and past performance of the user group.

Xavier Chaud	LNCMI-G	Applied Superconductors
Jens Hänisch	KIT	Applied Superconductors
Andries den Ouden	HFML	Applied Superconductors
Toomas Rõõm	NICPB	Magnetism
Mathias Doerr	IFP	Magnetism
Yuri Skourski	HLD	Magnetism
Uli Zeitler	HFML	Magnetism
Tony Carrington	Univ. Bristol	Metals and Superconductors
Mark Kartsovnik	WMI	Metals and Superconductors
Alix McCollam	HFML	Metals and Superconductors
Ilya Sheikin	LNCMI-G	Metals and Superconductors
Duncan Maude	LNCMI-T	Semiconductors
Amalia Patanè	Univ. Nottingham	Semiconductors
Marek Potemski	LNCMI-G	Semiconductors

Steffen Wiedmann	HFML	Semiconductors
Yves Fautrelle	INP Grenoble	Soft Matter and Magnetoscience
Hans Engelkamp	HFML	Soft Matter and Magnetoscience
Simon Hall	Univ. Bristol	Soft Matter and Magnetoscience

User Committee

In order to represent the interests of the high-field user community, members (all external to the infrastructures) are elected for a period of three years by the user community during the annual User Meeting. The chairman of the User Committee will report to the Board of Directors on behalf of the users. During the User Meetings the User Committee will report to the users and collect the feedback.

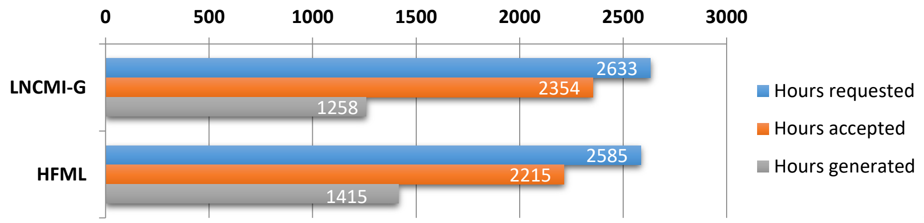
Raivo Stern (Chair)	NICPB, Tallinn	NMR/ESR
Ashish Arora	University of Münster	(Magneto)-optics of 2D semiconductors
Mathias Doerr	TU Dresden	Magnetism
Karel Prokes	Helmholtz-Zentrum Berlin	Magnetism
Carsten Putzke	EPFL	Metals/Superconductors
Antonio Polimeni	Sapienza Università di Roma	Optics/Semiconductors
Alexandre Pourret	IMAPEC-PHELIQS-INAC CEA	Magnetism/Superconductivity
Vassil Skumryev	ICREA, Barcelona	Magnetism/Magnetic materials
Stan Tozer	NHMFL	Magnetism/Superconductivity


(© Vincent Moncorgé, LNCMI)

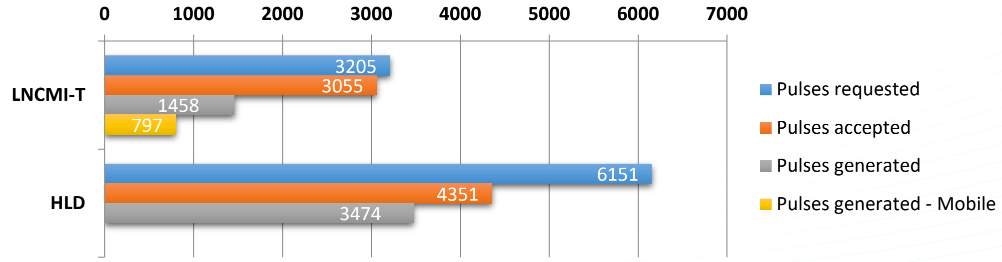
User Access

The 23rd and 24th call for proposals closed in May and November, resulting in 279 applications from 17 different countries in total. The Selection Committee (see page 23) has evaluated the proposals, covering the five types of scientific topics:

- Metals and Superconductors
- Magnetism
- Semiconductors
- Soft Matter and Magnetoscience
- Applied Superconductivity

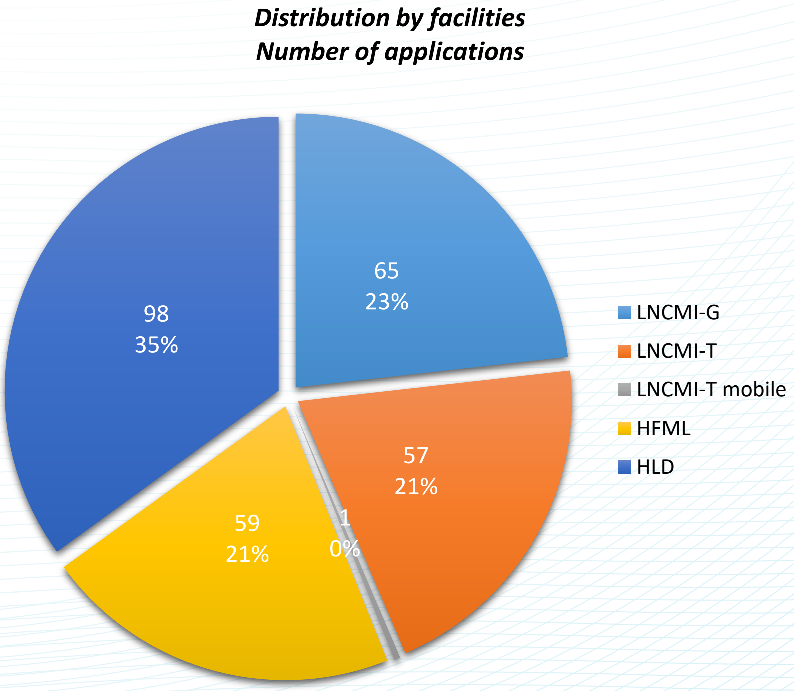


DC facilities



Pulsed facilities

The mobile pulses requested at LNCMI via EMFL at other large scale research infrastructures (ESRF, ILL, ...) are included as well. Access to this can be gained also via the proposal submission procedure of ILL, ESRF etc.

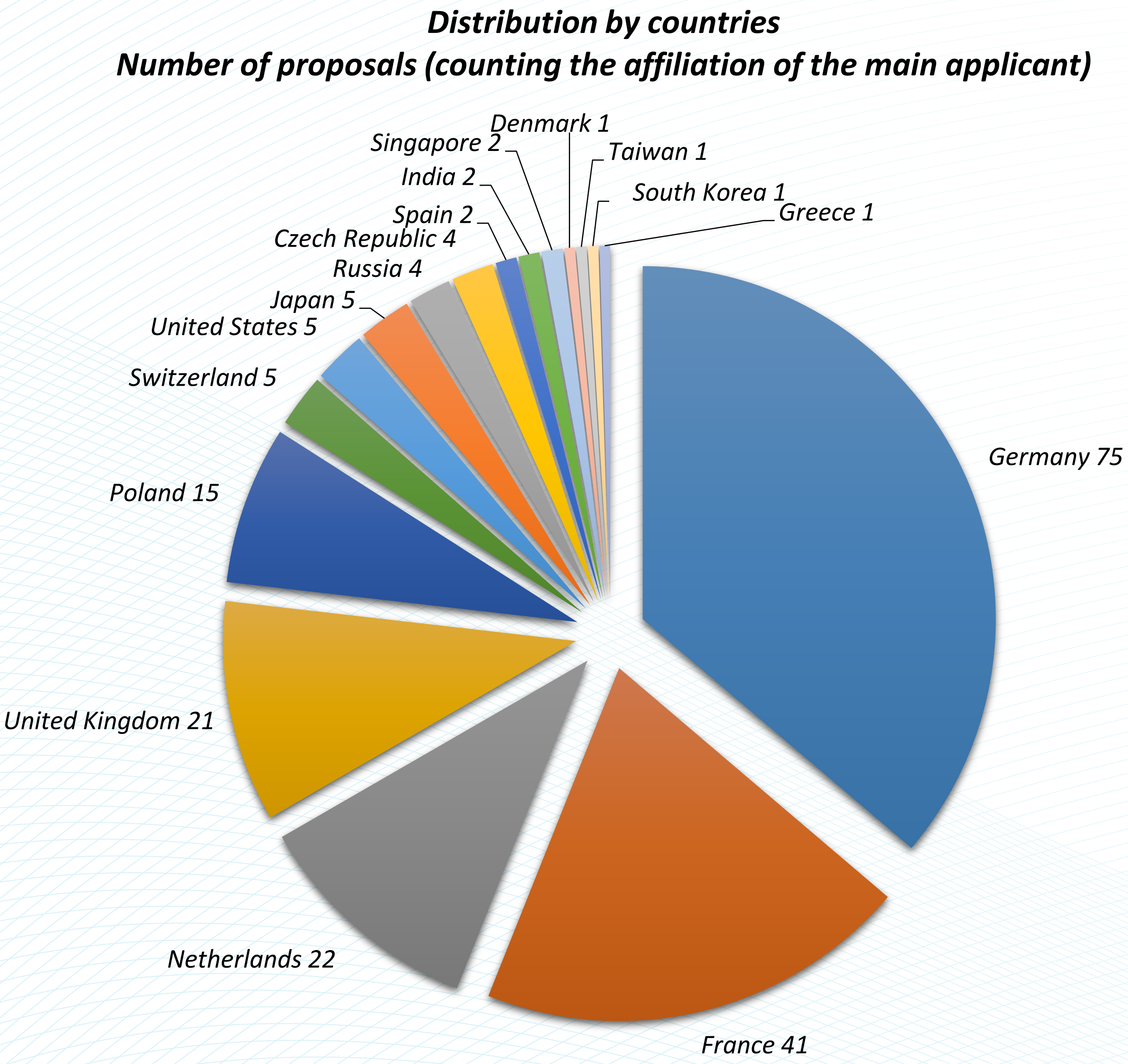


Evaluation of applications

Projects are classified in three categories:
A (excellent proposal to be performed),
B (should be carried out, but each facility has some freedom considering other constraints),
C (inadequate 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. Besides of ranking the proposals the Selection Committee recommends on the number of accepted magnet hours or number of pulses.

Information about the proposal application procedure can be found at
https://emfl.eu/apply-for-magnet-time/



Publications

Articles 2020

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Thesis defences 2020

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