EMFL Annual Report 2022

EMFL

European Magnetic Field Laboratory

European Magnetic Field Laboratory

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Science in High Magnetic Fields

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FELIX
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European Magnetic Field Laboratory
Annual report 2022

Contact

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Board of Directors	Prof. Peter Christianen (HFML, Chair) Prof. Jochen Wosnitza (HLD) Dr. Charles Simon (LNCMI)
Executive Manager	Dr. Martin van Breukelen (until June 2022)

Postal Address	Helmholtz-Gemeinschaft Brussels Office Rue du Trône 98 1050 Ixelles, Brussels Belgium
Website	www.emfl.eu
Facilities	High Field Magnet Laboratory (HFML) Toernooiveld 7 6525 ED Nijmegen, The Netherlands Hochfeld-Magnetlabor Dresden (HLD) Bautzner Landstr. 400 01328 Dresden, Germany Laboratoire National de Champs Magnétiques Intenses at Grenoble (LNCMI-G) 25 rue des Martyrs, B.P. 166 38042 Grenoble cedex 9, France Laboratoire National de Champs Magnétiques Intenses at Toulouse (LNCMI-T) 143 avenue de Rangueil 31400 Toulouse, France

https://www.linkedin.com/company/emfl/

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Members

Radboud University
Houtlaan 4,
6525 XZ Nijmegen, The Netherlands
and
the Institutes Organisation of the Dutch Research Council (NWO)
Winthontlaan 2,
3526 KV Utrecht, The Netherlands
Parent organisation HFML

Centre National de la Recherche Scientifique
3 Rue Michel Ange, Paris, France
Parent organisation LNCMI Grenoble and Toulouse

Helmholtz-Zentrum Dresden-Rossendorf e. V.
Bautzner Landstr. 400
01328 Dresden, Germany
Parent organisation HLD

University of Nottingham
University Park
Nottingham, NG7 2RD, United Kingdom

University of Warsaw
Krakowskie Przedmieście 26/28
00-927 Warszawa, Poland

CEA-IRFU
Centre de Saclay,
91191 Gif-sur-Yvette Cedex, France

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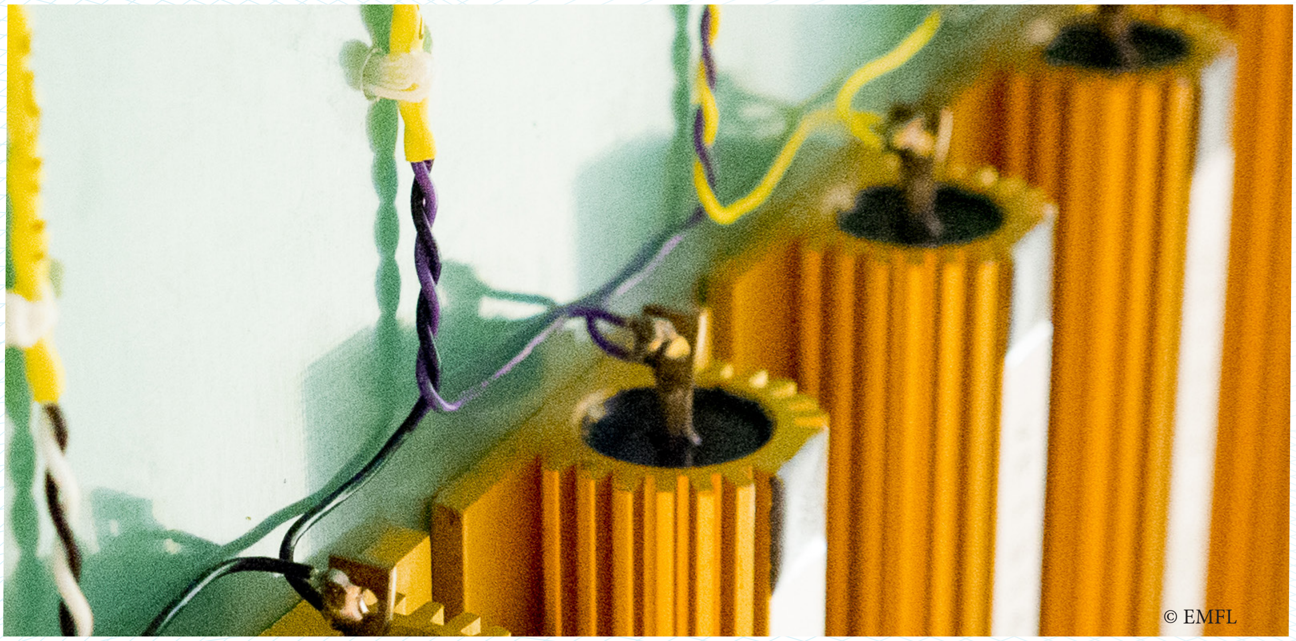


Foreword

Dear Reader,

It is a great pleasure to present to you the eighth annual report of the European Magnetic Field Laboratory, presenting many excellent scientific highlights and important developments.

In 2022, EMFL, after COVID-19, returned to normal operation. Despite the ongoing electric-energy challenges in the continuous field facilities (Grenoble and Nijmegen), our stakeholders have provided enough budget to ensure that high magnetic field science can continue at a "normal" level. This is excellent news for our users. We are also actively working on strong programs for energy efficiency in high magnetic field science in our laboratories.

One of these initiatives is the start of the H2020-SuperEMFL project, which focuses on the development of all superconducting user magnets at unprecedented field strengths of 40 T and beyond. SuperEMFL will produce a conceptual design report addressing all key questions concerning the realization and implementation of this type of user magnets in the European high-field infrastructure.

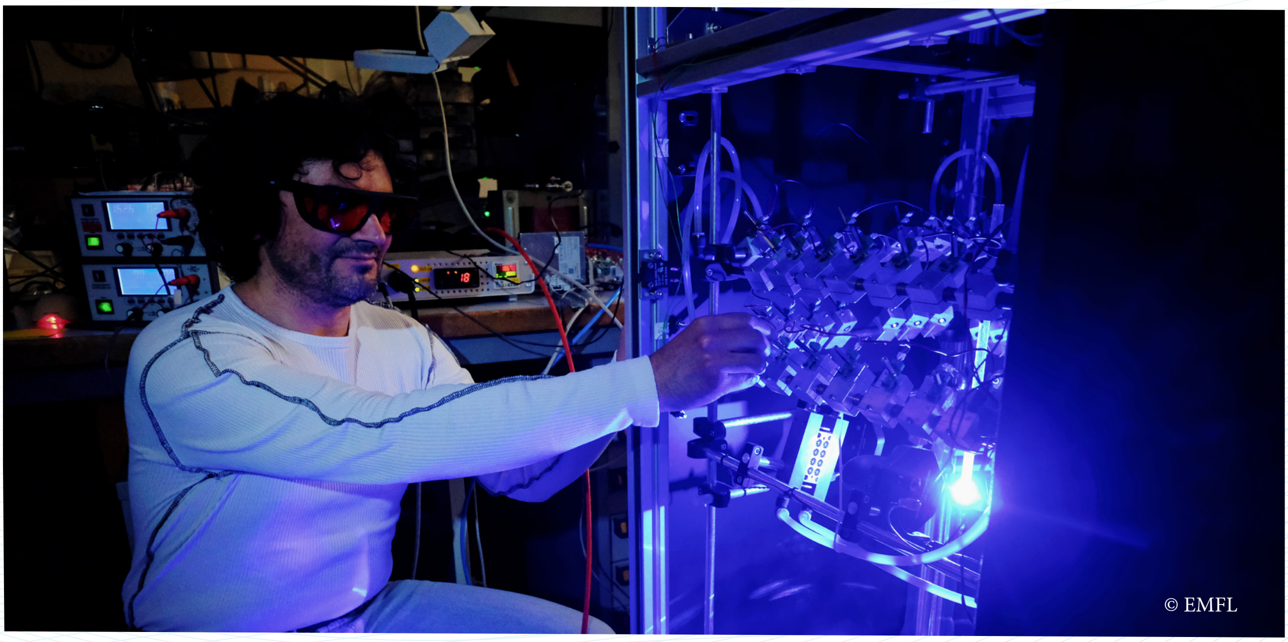
2022 also marks significant progress within the H2020-ISABEL project. Together with our partners, both from academia and industry, a large number of initiatives are ongoing to strengthen the structure of EMFL and its coordinating role and socio-economic impact on an European and global scale.

Finally, I would like to thank all the staff and users of the EMFL facilities for their hard work, resilience and flexibility, to make 2022 such a successful year.

Charles Simon

Chairman EMFL

Director LNCMI/CNRS



Mission

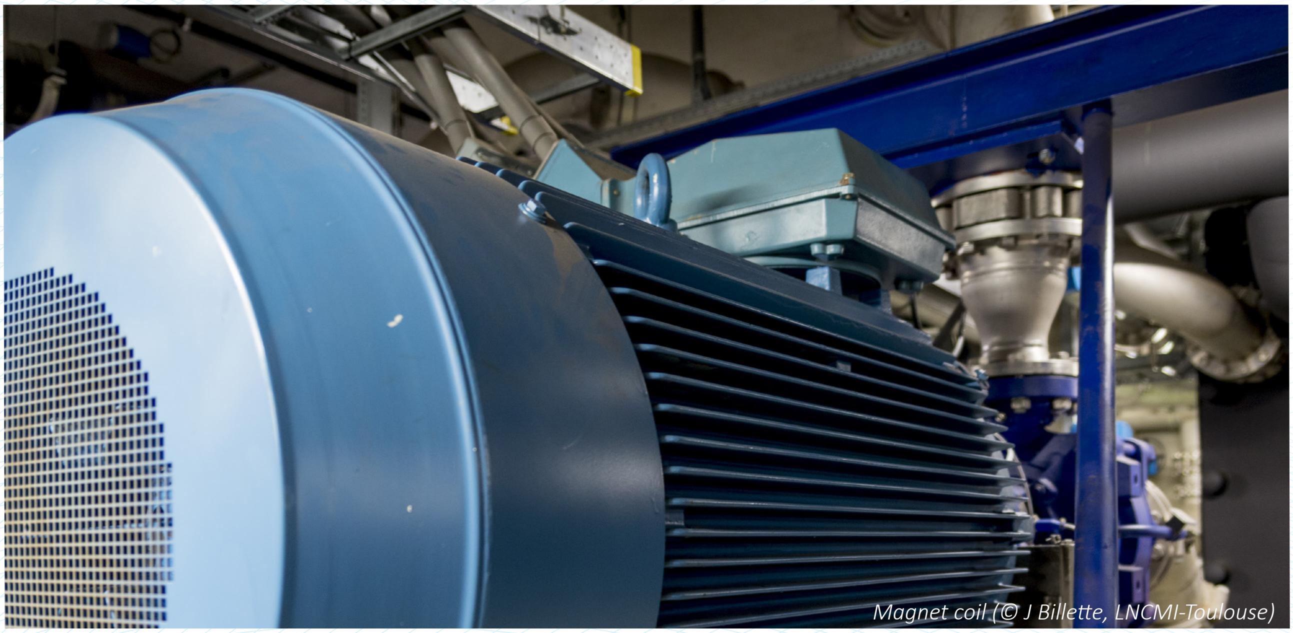
The EMFL develops and operates world class high magnetic field facilities, to use them for excellent research by in-house and external users

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.

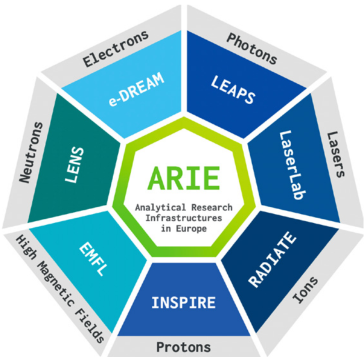
The European Magnetic Field Laboratory (EMFL) was founded in 2015 and awarded the Landmark status in March 2016 during the ESFRI Roadmap presentation in Amsterdam. EMFL provides the highest possible fields (both continuous and pulsed) for its researchers. The EMFL is dedicated to unite, coordinate, and 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 top-level 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 center of excellence for a multitude of magnetic-field-based material-characterization techniques in very high fields


Magnet coil (© J Billette, LNCMI-Toulouse)

Developments 2022

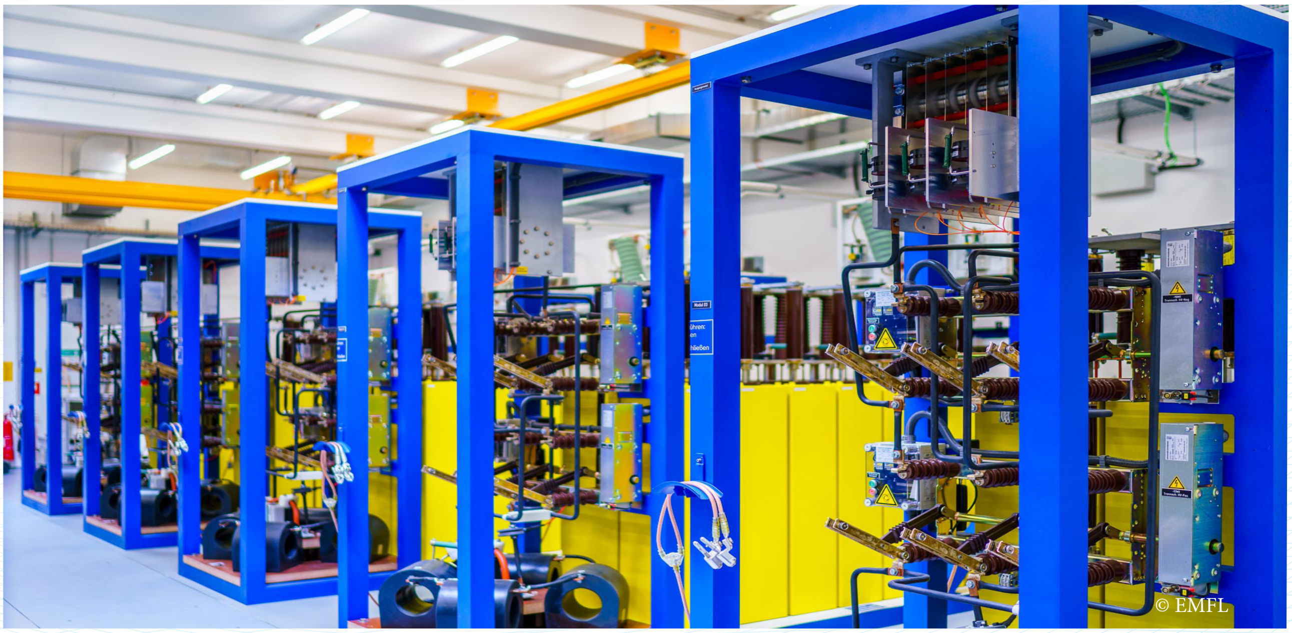


ARIE

Since 2020, EMFL has joined the Analytical Infrastructures in Europe umbrella network (ARIE, https://arie-eu.org/). ARIE is a multidisciplinary network of large-scale research infrastructures in Europe and includes about 120 large-scale instrument infrastructures. Through its wide range of analytical methods, instruments and services, it aims to enable European researchers through cutting-edge research to gain new insights into materials and living matter, which are necessary for the success of Horizon Europe missions. In 2022, Jochen Wosnitza represented the European network ARIE as its spokesperson.

COVID-19

2022 was characterized by the mitigation of the Corona crisis and the associated reduction in protective measures. The reduced mobility of the user community during the Corona pandemic posed very significant challenges to many research projects and resulted in an increased proportion of "mail-in" and "remote-access" experiments. Within the ISABEL project, we still offer these kinds of access modes to allow for a sustainable user operation and to reduce the amount of user travel. However, the key is to find the right balance between sustainable user operation through the "mail-in" option and "remote access" operation and, on the other hand, maintaining the scientific exchange with the user community on site. A more sustainable user operation in this sense with significantly fewer users on site at the experiments, however, requires reinforcement of the personnel there as well as additional investments in order to be able to cope with the increased workload for the operating personnel at the experiment stations and necessary automation developments.



Solidarity with the Ukrainian people

There is no justification for Russia's military attacks in Ukraine since February 24, 2022. As an international research consortium, EMFL condemns this blatant breach of international law. We reject any use of force to resolve political issues. The people of Ukraine – and especially our research partners there – can count on our solidarity. Science thrives on worldwide exchange, for which peace is the fundament. People from many countries have been working peacefully together at our EMFL partner facilities for many years. We remain convinced that research can build bridges across national and political borders. We fully support the sanctions imposed by the European Community and its international partners.

For the time being, all cooperations with Russia and Belarus remain suspended. We honestly regret this development.

Novel access modes

After many years of operation of the EMFL organization and supported by a study of ongoing practices at other RIs, additional access pilots are being developed and implemented in the frame of the EU-funded ISABEL project. The design of these novel access modes is intended to address the needs of current and potential users of EMFL.

Dual-access mode

As reported already last year, EMFL trials a novel dual-access procedure wich invites users at an early stage of their research projects and lower the barrier for access. Within one experiment proposal, users have the possibility to apply both for first-step access to research equipment dedicated to the moderate-field range accessible with superconducting magnets, and in a subsequent second step to the highest possble magnetic fields at the EMFL installations in Grenoble, Nijmegen, Toulouse, and Dresden.

This dual-access mode started from the first call in 2021 and has has attracted already quite a number of new users. For performing experiments in the moderate-field range, thanks to the ISABEL project, EMFL has partnered with wellequipped and experienced regional facilities distributed over Europe. In total, ISABEL has gathered 7 regional partners facilities:

- Superconducting magnet laboratory, University of Nottingham (UNOT)
- Oxford Centre for Applied Superconductivity, University of Oxford (UOXF)
- Nicholas Kurti High Magnetic Field Laboratory, University of Oxford (UOXF)
- Laboratory of Low Temperatures and High Magnetic Fields, Universidad Autonoma de Madrid (UAM)
- Research Laboratories of the Faculty of Physics, University of Warsaw (UWAR)
- Materials Growth and Measurement Laboratory, Charles University, Prague (UCHA)
- Research Facilities of the National Institute of Chemical Physics and Biophysics, Tallinn (NICPB)
- Spintronics and Nanomagnetism Laboratory, University of Salento, Lecce (USAL)

Long-term access mode

In order to meet the demand for long-term access schemes such as complex high-level science cases which require a sequel of high-field experiments, we have developed a tailored long-term access mode. Long-term proposals have started to be evaluated in fall 2022 by the EMFL BoD as a special category, and if positively evaluated, the applicants can obtain an extended amount of access over a two to three-year period.

First-time access mode

As a further trial access mode, EMFL has set up a novel access scheme with the aim of lowering the threshold for researchers who want to use the EMFL facilities for the first time. Prospective users are encouraged to contact a staff member at one of the EMFL labs who will offer support in preparing a proposal. Additionally, EMFL will offer reinforced on-site support and reimbursement of travel and accommodation expenses. The first-access proposals will be evaluated by the EMFL Selection Committee, who will facilitate access for these proposals.

Industrial access mode

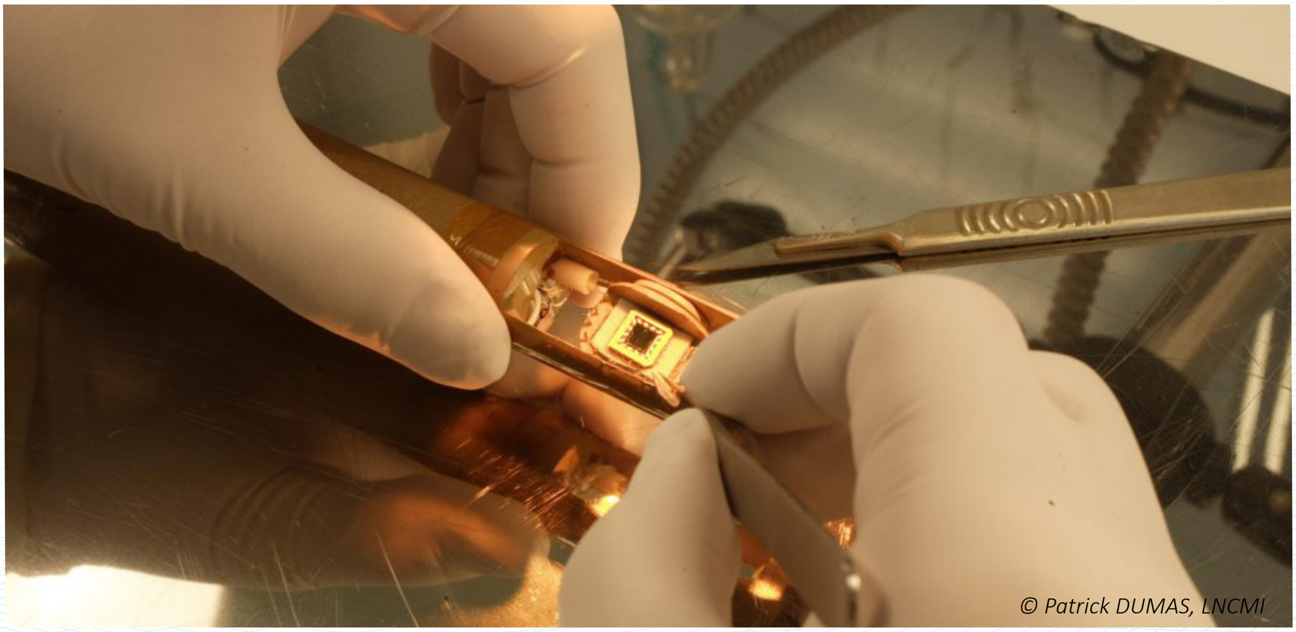
EMFL wants to stimulate the use of its infrastructure and know-how for any kind of experiment or test that industry may have. EMFL can provide cryogenic devices, pulsed and continuous magnets, data acquisition equipment and extensive know-how. This access mode is specifically adapted to the requirements of confidentiality that industrial users may have.

Fast-track access mode

The novel fast-track access mode is permanently open since 2022. A convincingly urgent scientific case may be addressed any time as request to the EMFL Board of Directors (BoD). The request will be evaluated and decided within typically two weeks by the BoD, who may optionally consult one or more EMFL Selection Committee members, and check the feasibility with the facility manager and the local contact. If the fast-track proposal is accepted, the user is asked to get in contact with the facility to schedule and plan the experiment in a timely fashion. Otherwise the user may submit a regular proposal at the next call.

Technical development access mode

This access is dedicated to the interests of scientists wishing to develop and improve technical installations and metrological procedures that could also be of great interest to other EMFL users. It aims at improving the quality of EMFL installations with clear benefit to the wider EMFL user community.



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EMFL workshops:

In order to develop a scientific case for high-field experiments at advanced sources, ISABEL support of four joint workshops in collaboration with other large research facilities. The goal is to establish the scientific case for such experiments and to make an inventory of the user needs of magnet characteristics, instrumentation, and organization.

Two workshops were held in 2022:

"Perspectives with High Magnetic Fields at Neutron Sources"

This workshop was co-organized by staff from the Laboratoire National des Champs Magnétiques Intenses (F. Duc, LNCMI-Toulouse), the Institut Laue Langevin (M. Boehm, E. Lelièvre-Berna, B. Dubouloz, ILL) and the Dresden High Magnetic Field Laboratory (S. Chattopadyay). It was financially supported by the European project ISABEL and the ILL. The venue was the EPN Science Campus, Grenoble (Chadwick amphitheatre, ILL). It was held in hybrid mode (both in person and virtual).

This workshop gathered scientific and technical experts of high-field and neutron facilities with the aim of identifying the needs of the neutron community, evaluating the technical challenges, and preparing a roadmap for developing unprecedented capabilities. It had 64 registered participants, coming mostly from Europe. It consisted of 22 invited contributions on scientific and instrumental aspects. Ample time was reserved for discussions after and between presentations.

7th workshop on Magnetic Fields in Laboratory High Energy Density Plasmas (LaB)

This workshop was co-organized by staff from the LNCMI and the Laboratoire pour l'Utilisation des Lasers Intenses. It was financially supported by the European project ISABEL and the International Research Network MHEDP. The venue was the first day at the Sorbonne Université in Paris and the two following days on the Campus of Ecole Polytechnique in Palaiseau. A visit of the recently commissioned multipetawatt laser Apollon was organized on the second day. This workshop gathered scientific and technical experts of high-field and power-laser facilities with the aim of identifying the needs of the high energy density physics community, evaluating the technical challenges, and preparing a roadmap for developing unprecedented capabilities. It has been a success with 51 registered participants from all over the world. It consisted of 37 invited contributions on scientific and instrumental aspects. Time was reserved for discussions after each presentation.

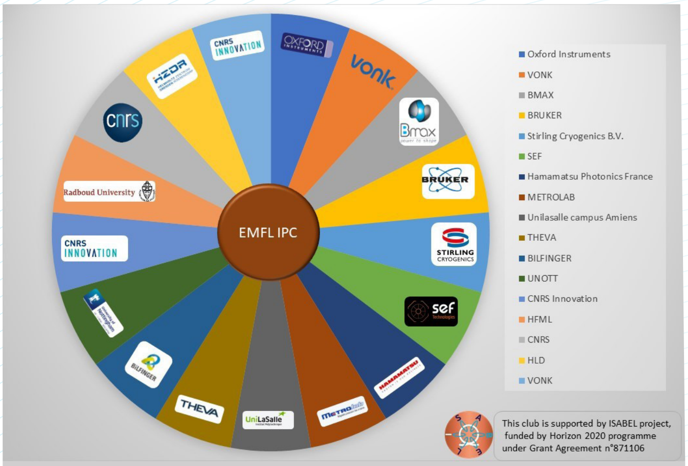
User Meeting of the European Magnetic Field Laboratories

After the online user meeting last year, it was a pleasure to see quite a number of users and staff in reality during the 2022 meeting. The EMFL user meeting took place in Grenoble at the LNCMI on June 15 in hybrid format. With up to 90 participants, 35 on site and 55 remotely connected, the 2022 meeting was once again well attended. The in-person discussions during coffee and lunch breaks were particularly productive in exchanging ideas and experiences between users and EMFL staff. Another aim of the meeting was to present scientific results and to discuss about possibilities for improving the facilities' attractiveness.

The meeting started with a warm welcome by Peter Christianen, chairperson of the EMFL Board of Directors and director of the HFML. Jochen Wosnitza, chair of the Selection Committee, announced this year's EMFL prizewinner, Mateusz Dyksik (see article on the following page), who, afterwards, presented his work in a talk on „Excitonic properties of 2D layered perovskites revealed by magneto-spectroscopy".

The audience was then able to appreciate the excellent talks of eight invited speakers, who presented their work done as users at the EMFL facilities. Stanislaw Galeski (Max Planck Institute CPfS, Dresden) covered his high-field research on the topological semimetal $ZrTe_5$. Charis Quay (LPS Orsay) presented results on tunneling spectroscopy of few-monolayer $NbSe_3$ in high magnetic fields and Shravani Chillal (Helmholtz-Zentrum Berlin and TU Berlin) on magnetic phase diagrams of quantum magnets. Marco Bonura (University of Geneva) presented more applied results on record-high upper critical field in the superconductor MgB_2. After an excellent lunch (for in-person participants), Elena Blundo (Sapienza University Rome) gave a talk on k-space direct and indirect excitons in strained WS_2 monolayers and Maciej Molas (Warsaw University) on excitons in monolayers of transition-metal dichalcogenides. Touching a more exotic topic, Julien Fuchs (LULI) reported on recent advances in laboratory astrophysics using laser-driven magnetized plasmas. Finally, Michael Schmitz (Aachen University) presented results on graphene in high magnetic fields. In the afternoon, chaired by Raivo Stern (NICPB, Tallinn, Estonia), the User Committee met to discuss critically the strengths and weaknesses of user-related issues of the EMFL and reported back to the Board of Directors (see article on the next page). In particular, the Committee discussed the newly introduced access modes for magnet time (fast-track, dual-access, etc.), complementing the existing conventional access modes.

After not being able to meet in person for 2 years, the hybrid meeting was a big success. It was a great pleasure to renew and deepen contacts in person and to include the participants in remote mode. We hope to be able to maintain this format in the future as well. The next user meeting will take place in Nijmegen, again in June, and we are looking forward to see many of our users there in person.



EMFL industrial partner club

To strengthen the connection between socio-economic needs and academic research, EMFL has created an Industrial Partners Club. EMFL proposes to all of its partners and every interested industrial enterprise to join and discuss different topics. Highly skilled EMFL staff will interact with entrepreneurial and innovation experts.

The EMFL Industrial Club has been launched on the 12th of December, with 17 organizations represented- including 12 companies.

EMFL Prize Winner 2022: Mateusz Dyksik

After two years of rather impersonal prize ceremonies, the EMFL Board of Directors was happy to hand over the EMFL prize 2022 in person to Dr. Mateusz Dyksik, who currently holds an assistant professor position at the Wrocław University of Science and Technology in Poland. The prize ceremony took place during the EMFL User Meeting in Grenoble. Mateusz Dyksik received the award for his cutting-edge research performed at the EMFL facilities. He used optical spectroscopy to understand the fundamental electronic properties of organic-inorganic perovskite thin films and nanocrystals which have important applications in light harvesting and photovoltaics. Mateusz employed a rather unique combination of low-temperature optical spectroscopy together with high pulsed magnetic field. His work allowed to elucidate many of the exotic properties of two-dimensional perovskites. Since 2009, a prize committee, chaired by Jochen Wosnitza, director of the Dresden High Magnetic Field Laboratory, awards the EMFL prize annually for exceptional achievements in science done in high magnetic fields.

Report of the annual EMFL User Committee meeting 2022

During the annual meeting of the User Committee (UC), which is open to all users to attend and provide feedback, recommendations from the user community were discussed and presented to the BoD. Currently, the UC consists of 10 members. With the user community of EMFL steadily growing, the UC repeats their request for a renewed, much stronger mandate to better represent the interests of the high-field users. The UC wants to stress that the first priority should be the satisfaction of users' needs and the goal of performing world-class research. This priority implies a scientifically active staff with a significant amount of time dedicated to their in-house research and developing cutting-edge methods. We are happy that this priority is well recognized and adopted by the BoD. In addition, the development of new techniques should be driven by the collaboration of user-support staff with users.

A key part of the UC work is to review prior feedbacks and how the EMFL BoD has incorporated it. A point of review this year was the availability of information for users on accessible magnets, cryogenic infrastructure, and experimental techniques. The UC together with the attendees concluded a very slow if any progress in this area, particularly on the new EMFL website. Those users who requested a more detailed description with available resolution and documentation are asked to specify their needs with local contacts in the labs. The UC encourages the users to also address these comments and requests via email to one of the UC members such that progress in this regard can be monitored and reviewed..

Another example of continuous and steady progress is aimed at the users themselves. Without their feedback and clear communication of the needs for their experiments, the UC cannot help. We still emphasize our call here to all users to give sustentive feedback via the EMFL website.

Further issues which were discussed include general data protection rules (GDPR), open data strategy, and online safety trainings. Many of these activities are currently being run under the project "ISABEL". Proposals were made for part-week test experiments and/or for testing new perspective samples in advance of full proposals. Such programs are available at other facilities in the field of synchrotron and elsewhere and help to attract new principal investigators. Feedback from the users is very welcome on this matter to discuss the implementation of such a system with the BoD.

The user community is still concerned about the shortage of "workhorse" equipment. To get a better understanding the most widely used magnets, we ask the user community to get in contact with the UC and name the magnet they would find most suitable for their experiments, and participate actively in the respective survey from "ISABEL". The UC will then combine this input and discuss strategies with the BoD on how to meet the needs of the community.

The UC welcomed two initiatives at the EMFL. First, the secondment activity allows scientists and technicians from member states to visit other laboratories and teams. This is greatly strengthening the collaboration between the different members and helps shape a stronger EMFL. Second, travel support for early-stage scientists from Europe and developing countries for attending the EMFL User Meeting and learning about the EMFL and experimental possibilities there.

To improve dissemination activities, it was suggested that EMFL would be present with a booth at various European Physical Societies meetings whilst also organizing topical sessions and giving talks on recent research achievements. Postings on additional social media platforms (ResearchGate, Instagram, YouTube) might also boost the visibility of the EMFL; presence on Twitter and LinkedIn is already quite active.

Finally, the UC acknowledged the organizing team from LNCMI-G and the BoD for arranging an excellent user workshop, where both users and representatives of the EMFL reported on recent developments of high-magnetic-field infrastructures/equipment, 2D materials in high magnetic fields, magnetocaloric materials in pulsed magnets, and research in topical areas as well as novel material systems of fundamental and technological interest. This rich program was well received by the user community. Last but not least, the UC on behalf of all users would like to thank the EMFL laboratories and their staff for the help during the past years in carrying out experiments on a remote basis. This new operational scheme has challenged both the users as well as their local contacts on finding new ways to communicate, long extra hours in the laboratory, as local contacts had to carry out experiments themselves and logistics to get samples to the laboratories safely.

We believe that the desire of EMFL to return to a full on-site experience for the users as fast and as safely as possible confirms the excellence obtained in the laboratory and is further strengthened by the implementation of the project “ISABEL” to ensure that this expertise is widely available. It does, however, necessitate this expertise not only to be developed but also maintained in-house and, hence, a significant increase in the number of permanent staff members is required to safeguard a smooth and reliable operation now and in the following years.

EMFL school 2022 in Kerkrade, the Netherlands

After a four-year break, we continued the tradition of holding a summer school for the high magnetic field community in Europe. This year, the school was held at Abdij Rolduc, a medieval abbey located on the edge of the town of Kerkrade in the far south-east of the Netherlands, from 21 to 25 September.

The school was dedicated to recent advances in science in high magnetic fields. Renowned speakers covered topics from soft condensed matter, low-dimensional semiconductors, topological matter, strongly correlated electron systems, magnetism, superconductivity, and high magnetic field technology. Two sessions were dedicated to science communication. Furthermore, we organized two sessions in which current research questions and challenges in different fields, and experimental techniques were discussed.

The participants of the school, in total 48, were selected primarily among young researchers such as PhD students and postdocs. These included participants working at one of the EMFL laboratories, but also at universities and research institutions in Europe and worldwide. All participants had the opportunity to present their own research results to their peers during three specially dedicated pitch sessions.

EMFL days 2022 in Kerkrade, the Netherlands

This fifth edition of the EMFL Days was organized in Kerkrade from September 19-21. About 120 EMFL staff members gathered right on the Dutch-German border, benefiting from Rolduc Abbey's sublime ambience and a serene autumnal atmosphere. The aim of the meeting was to continue to learn more about each other's work at the different sites, exchange ideas, and define a common strategy for the future of EMFL. This included scientific work, but as well work on technological and administrative aspects, giving also a podium to express concerns about soaring energy prices.

The program was divided into two parts: A formal program with plenary sessions and workgroups dealing with various topics, and an informal program, crowned by a visit to GaiaZOO. The EMFL Days started on Monday afternoon by a plenary session with an opening and welcome by Peter Christianen, chair of the EMFL Board of Directors. The directors of the three laboratories – Peter Christianen (HFML), Charles Simon (LNCMI), and Jochen Wosnitza (HLD) – presented the current state and future plans of their facilities. Further, Geert Rikken and Xavier Chaud gave overviews on the EU projects ISABEL and SuperEMFL, respectively. An informal evening program closed the day, when staff joined the icebreaking EMFL pub-quiz. Exchange of information and discussions started Tuesday morning during the two first sessions of the workgroups. This year, the workgroups covered the topics: i) Magnets and facilities development, ii) Instrumentation, iii) Administration/hosting users communication, and iv) PhD/Post-Doc session.

The afternoon was dedicated to an informal tour through Kerkrade, allowing to visit cultural attractions, as well as burning a few extra calories on hiking trails in the pleasant Limburgian surroundings while marveling the few remains standing testament to the long-gone golden age of coal mining in the area. The highlight of the day was a thorough visit of the roughly 100 different species of GaiaZOO, only to be topped by the dinner, disguised as a culinary safari.

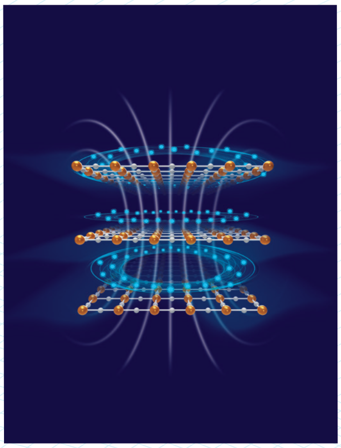
Wednesday morning, the groups continued their work during the two last sessions and defined their vision of a common strategy for EMFL. The morning ended with the wrap-up plenary meeting during which the outcome of the different sessions was shared. Looking back, the EMFL Days are ideal for exchanging information between EMFL staff, whether to discuss the development of a project and its opportunities or to stimulate ideas by creating stronger bonds and intensified dialogue between staff as well as by getting to know each other better. Indeed, the spot-on organized EMFL Days 2022 has been a very successful and fruitful meeting.

Scientific Highlights

Influence of high magnetic fields on electrons undergoing Planckian dissipation

In certain materials called “strange metals”, the electrical resistivity follows a perfectly linear temperature dependence at low temperature, in contrast to the quadratic dependence expected from standard Fermi-liquid theory. Remarkably, it has recently been shown that electrons in these strange metals undergo collisions with each other at a rate which is set by Planck’s constant. This intriguing phenomenon, dubbed “Planckian dissipation”, appears to be a universal property of strange metals, and it remains a fundamental puzzle. The question we asked ourselves is: How are electrons undergoing Planckian dissipation influenced by a magnetic field B?

Recent experiments on strange metals revealed that the electrical resistivity exhibits a B-linear dependence at low temperature, in contrast to the standard quadratic dependence expected of conventional metals. Is this anomalous B-linear resistivity another facet of Planckian dissipation? We carried out a series of high-field experiments at the LNCMI in Toulouse to measure the field dependence of the resistivity, or magnetoresistance (MR), of two cuprate superconductors – Nd-LSCO and LSCO – at a hole doping (p = 0.24) such that their electronic state is in the strange-metal regime. The experiments were mostly done in a configuration where the magnetic field is applied normal to the copper-oxide planes of the material (see Figure 1). We observed a B-linear dependence at low temperature, which evolves into a B-quadratic dependence at high temperature, as displayed in Figure 2a for Nd-LSCO. We then calculated the MR expected from conventional Boltzmann transport theory given the scattering rate that was previously measured for Nd-LSCO at p = 0.24 in a recent study of the angle-dependent magnetoresistance (ADMR). The results of this calculation are shown in Figure 2b. We see that the calculations reproduce well and quantitatively the measured MR. We find that the origin of the B-linear MR in Nd-LSCO and LSCO is linked to a strong in-plane anisotropy of the elastic scattering rate.



We conclude that Planckian dissipation is anomalous in its temperature dependence, but not in its field dependence and the scattering rate does not have a magnetic-field dependence. We hope that our work contributes to a better understanding of Planckian dissipation.

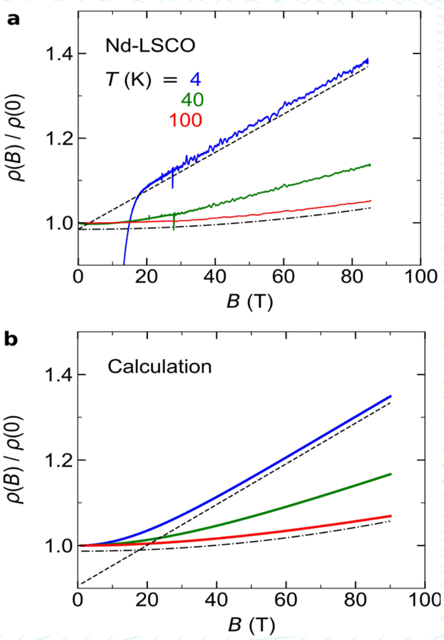


Figure 1: Sketch of electrons (cyan) moving in orbits within the copper-oxide planes of a cuprate material (Cu atoms in bronze, O atoms in silver) when a magnetic field is applied normal to the planes. Credit: Impakt Scientifik

*Figure 2: Measured and calculated magnetoresistance (MR) in the cuprate superconductor Nd-LSCO at a hole doping p = 0.24, plotted as ρ(B)/ρ(0) vs B, for J || a and B || c. (a) Isotherms measured up to 85 T, for T = 4 K (blue), 40 K (green), and 100 K (red). The MR at 4 K is linear in field above ~40 T, whereas the MR at 100 K is quadratic, as emphasized by the linear (dashed) and quadratic (dashed dotted) lines. (b) Calculated MR using the parameters for Nd-LSCO extracted from a prior ADMR study (Grissonnanche et al., Nature **595, 667** [2021]), for the same three temperatures.*

Reference

"Electrons with Planckian scattering obey standard orbital motion in a magnetic field", A. Ataei, A. Gourgout, G. Grissonnanche, L. Chen, J. Baglo, M-E. Boulanger, F. Laliberté, S. Badoux, N. Doiron-Leyraud, V. Oliviero, S. Benhabib, D. Vignolles, J.-S. Zhou, S. Ono, H. Takagi, C. Proust, and L. Taillefer, Nat. Phys. **18**, 1420 (2022).

Predominance of electron-phonon scattering in the room-temperature quantum Hall effect in graphene

The quantum Hall effect (QHE), a paradigmatic phenomenon of two-dimensional (2D) electron systems in high magnetic fields, typically occurs only at very low temperatures of a few kelvin. Under these conditions, lattice vibrations (so-called phonons) are suppressed and, thus, play a marginal role in the electrical transport. Graphene, the purely 2D form of carbon, stands out from its 2D peers due to a giant energy gap between its first two Landau levels (LLs), which enables the observation of quantum Hall states up to room temperature (RT, ~300 K). Indeed, already more than 15 years ago, high magnetic fields crucially contributed to the first observation of this RT-QHE in graphene. However, only samples resting on SiO_2 had been studied in this regime, potentially missing out intrinsic physics due to detrimental substrateinduced disorder.

Now, a team of researchers from the Istituto Nanoscienze-CNR Pisa, the University of Salamanca, RWTH Aachen University, the Radboud University and HFML Nijmegen have investigated a collection of high-quality graphene samples encapsulated in hexagonal boron nitride (hBN, provided by researchers at NIMS). In zero field, the RT conductivity of these van der Waals sandwiches is known to be chiefly limited by electron-phonon scattering.What happens if one applies a magnetic field strong enough to realize the RT-QHE? Bearing this question in mind, the team made use of the HFML-EMFL facility to measure the so-called thermally activated resistivity, with the devices set to filling factor 2, where the most pronounced quantum Hall plateaus develops.

As the temperature is increased toward RT, mobile charge carriers are excited across the LL gap. The consequent exponential increase in the resistivity directly relates to the gap size as well as to the underlying charge-carrier scattering mechanism. Despite their LL gap being equal, the activated resistivity of the graphene-hBN devices turned out to be strikingly lower with respect to that of disordered reference samples. On the one hand, graphene on SiO_2 could be described by parameters associated to long-range disorder, not different from the standard low-temperature QHE. On the other hand, the new data strikingly follows a recent theoretical model by Alexeev et al., in which the temperature and field-dependent activated conductivity is ascribed to two-phonon-electron scattering alone.

Thanks to the data collected over several high-field runs, the researchers were able to reproduce this phenomenon in different samples, whilst finding a correlation between deviations from the RT-QHE phonon limit and their zero-field charge-carrier mobility. The observation of phonon-mediated quantum-Hall transport marks yet another unique property of graphene, underlying the central role of van der Waals technology for the study of transport phenomena in 2D.

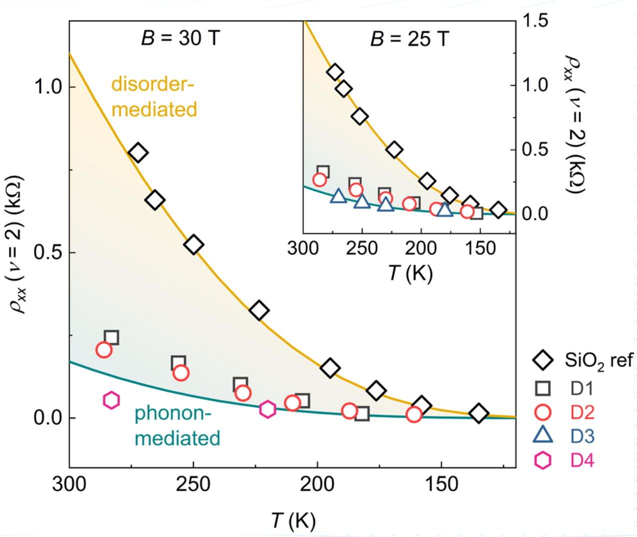


Figure: Thermally activated resistivity at ν = 2 in different hBN-encapsulated graphene devices (D1-D4), measured at B = 30 T (main panel) and 25 T (inset). The dark cyan and yellow solid lines are calculated curves, defining two different dissipation limits in the QH phase.

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Dimensional reduction and incommensurate dynamic correlations in a triangular-lattice antiferromagnet

Antiferromagnetic materials with spin 1/2 and triangular-lattice structures are in the focus of modern quantum physics, in particular, in connection with Anderson's idea of "resonating valence bond" states in frustrated spin systems. He proposed that the ground state could be a two-dimensional (2D) fluid of resonating spin-singlet pairs, with the elementary excitation spectrum formed by fractionalized mobile quasiparticles, so-called spinons. On the other hand, in spite of the 2D structure, magnetic correlations in such materials can have a pure 1D character, with the excitation spectrum also formed by spinons. This phenomenon is known as frustration-induced dimensional reduction. This was first observed in the triangular-lattice antiferromagnet Cs_2CuCl_4. Investigating the spin dynamics and ground-state properties of such systems is of prime interest in frustrated magnetism, both from experimental and theoretical points of view.

$Ca_2ReO_5Cl_2$ (CROC hereafter) is the second material, where a frustration-induced dimensional reduction was revealed. We performed high-field electron spin resonance (ESR) spectroscopy and magnetization studies, allowing us not only to refine the spin- Hamiltonian parameters, but also to investigate peculiarities of the spin dynamics and magnetic properties in a broad range of frequencies and fields, relevant to the energy scale of magnetic interactions in this new frustrated spin system.

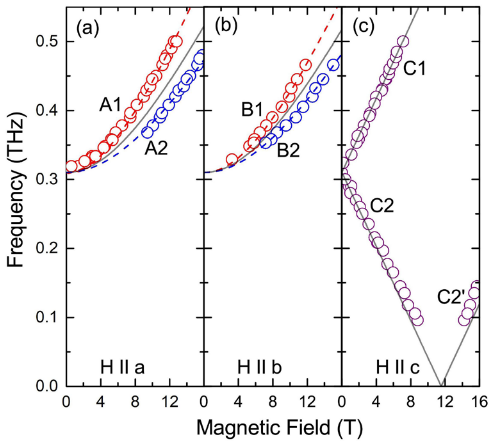

Figure 1: Frequency-field diagrams of magnetic excitations at 2 K in CROC with fields applied along the (a) a, (b) b, and (c) c axis. The solid lines are results of model calculations for a triangular-lattice antiferromagnet with reduced dimensionality uniform DMI

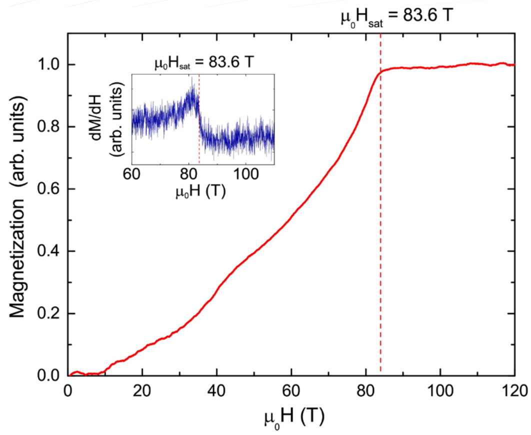

Figure 2: Magnetization of a CROC powder sample in magnetic fields up to 120 T, obtained using a pulsed singleturn magnet (initial temperature is 5 K). The inset shows the derivative of the as-measured magnetization M.

Based on our ESR results and model calculations for a triangularlattice antiferromagnet with reduced dimensionality (Figure 1), we conclude that the presence of uniform Dzyaloshinskii-Moriya interaction (DMI) shifts the spinon continuum in momentum space. As a result, a zero-field gap opens that we observed directly. Pulsed-field magnetization measurements of CROC powder up to 120 T revealed a saturation field of 83.6 T (Figure 2). We used this value to calculate the interchain exchange interaction. Based on our observations, we suggest that a pure DMI-spiral state can be realized in CROC, making this material an attractive toy model to explore details of the dimensional reduction and other effects of the geometrical frustration in low-dimensional spin systems with competing interactions. This work was done in collaboration between the HLD and the Institute for Solid State Physics, University of Tokyo.

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Evidence for a square vortex-lattice transition in a high T_c cuprate superconductor

In the physics of correlated electron systems, van Hove singularities play a key role. These are points in the band structure where the density of states is singular. When the Fermi level is tuned towards a van Hove singularity, new and exotic physics is expected, particularly in low-dimensional systems.

In two-dimensional d-wave superconductors, the presence of a van Hove singularity produces unconventional vortex-lattice phases and vortex transitions. These issues have been studied theoretically and an exotic vortex-lattice transition, occurring close to the upper critical field, has been predicted by Nakai and collaborators two decades ago (Phys. Rev. Lett. 89 237004 (2002)). Indeed, using Eilenberger's theory of the vortex lattice, they predicted that the competition between the four-fold symmetry of the d-wave superconducting order parameter and that of the Fermi velocity produced by the van Hove singularity would result in a rotation of the square vortex lattice. However, after two decades their prediction was still lacking an experimental confirmation.

The best current prospect material to observe such a transition is the high-T_c cuprate superconductor $La_{2-x}Sr_xCuO_4$ (LSCO) close to its doping-induced Lifshitz transition. However, this is a challenging task experimentally, as techniques traditionally used to study the vortex lattice are not appropriate in that case. The magnetic fields required to observe the vortex transition are far beyond the capabilities of small-angle neutron scattering and scanning tunneling microscopy is not applicable to LSCO as high-quality surfaces are not realized in this compound.

In this work, researchers at LNCMI, in collaboration with Zürich University (Switzerland), Hokkaido University (Japan), and Okayama University (Japan), use a new approach to test this prediction with ultrasound measurements up to 60 T. Ultrasound is sensitive to the elasticity and pinning of the vortex lattice, both of which are affected by such kind of transition. They found a new transition in the compression modulus of the vortex lattice of LSCO, observed in magnetic fields exceeding 35 T, deep within the mixed state. The transition is only observed within the pinned vortex solid phase indicating it is related to a structural transformation of the vortex-solid. Theoretical analysis, based on Eilenberger's theory of the vortex lattice using tight-binding parameters specific to LSCO with x = 0.17 support the interpretation of the discovered ultrasound anomaly in terms of the square-square vortex lattice transformation predicted by Nakai and co-workers 20 years ago.

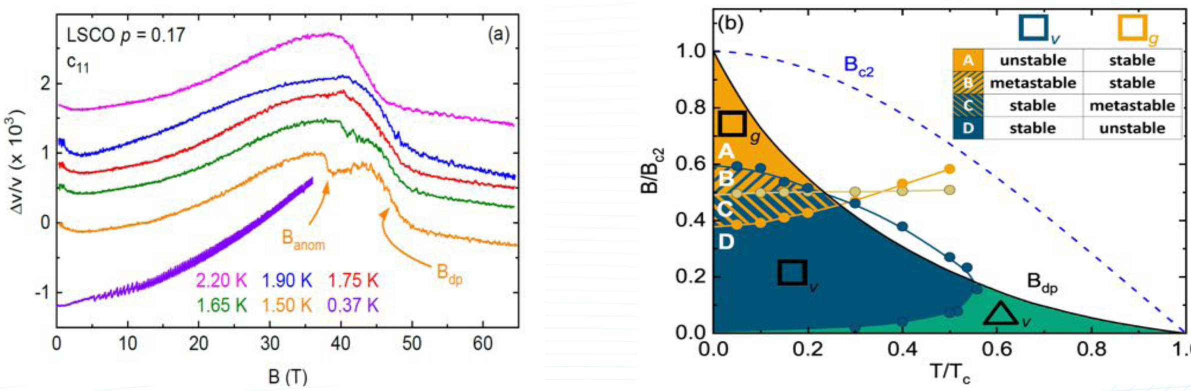

Figure: (a) The change in sound velocity of the in-plane longitudinal mode (c_{11}) of an LSCO crystal with x = 0.17 at different temperatures, as a function of magnetic field. The arrow marks the field of the anomaly, B_{anom}. (b) Theoretical phase diagram showing the different vortex-lattice configurations as a function of T and B. The hexagonal phase is stable in the green-colored area. In regions A and D, two different square vortex lattices are stabilized with a range of metastability emerging in rapidly varying magnetic field shown in regions B and C.

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High magnetic fields unveilstrain-induced exciton hybridization in 2D crystals

Strain plays an important role in two-dimensional (2D) semiconductors. Thanks to their all-surface nature, these 2D materials feature an extraordinary capability to bear mechanical deformations without fracturing. This resilience to stress reveals itself a precious property that can be exploited for flexible devices. Therefore, most studies were devoted to the effects of strain on the electronic, optical, and transport properties of 2D semiconductors, in particular of transition-metal dichalcogenide (TMD) monolayers (MLs). These latter are regarded as a promising platform for quantum optical technologies. In particular, excitons in TMD MLs can be exploited as valley-carrying bits, whose characteristics are embodied in the gyromagnetic (g) factor determinable by magneto-optical spectroscopies.

The interplay between strain and the exciton magnetic moment in TMD MLs has not been investigated. Typical straining devices hardly fit within the bore of a magnet, and performing experiments on strained microscale regions under high magnetic fields is challenging. This hurdle was recently overcome by a series of experiments performed at the EMFL facilities in The Netherlands and at the regional partner facility in Poland within the dual-access scheme of the ISABEL project.

WS_2 MLs were subjected to strong mechanical deformation by creating atomically thin microbubbles filled by highly pressurized hydrogen gas (bottom inset Figure 1). Consequently, biaxial strain values in excess of 2 % can be reached in the bubbles, leading to a reordering of the valence-band states and to a direct-to-indirect exciton transition (top inset of Figure 1). In particular, the strain of the bubbles engenders controllable on/off-resonance conditions between direct and indirect exciton energy levels, which eventually hybridize. Compelling evidence of this phenomenon required the use of intense magnetic fields coupled to micro-photoluminescence measurements (Figure 1) that revealed an unpredicted dependence of the exciton Zeeman splitting on strain. A drastic reduction of the exciton g-factor modulus was found (symbols in Figure 2). Advanced theoretical methods (lines in Figure 2) were required to reproduce the unexpected strain dependence of the exciton g-factor, unveiling the underlying exciton-state admixing.

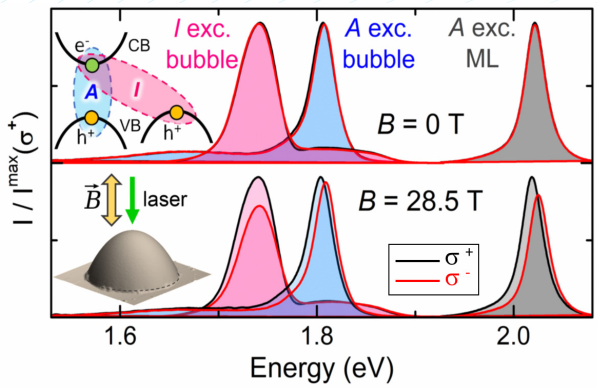

Figure 1: Room-temperature μ-PL spectra at 0 and 28.5 T. Bottom inset: sketch of the magneto-μPL experiment. Top inset: band-structure configuration under strain-driven resonant conditions between the K and G points of the valence band.

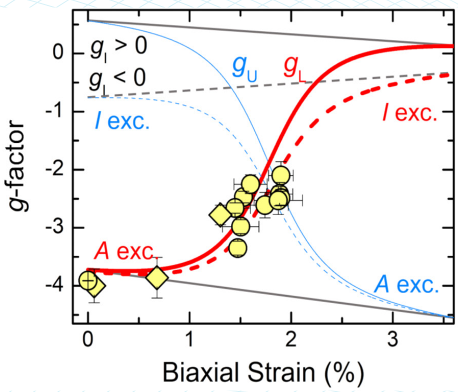

Figure 2: Calculated and experimental g-factors. Diamonds and circles refer to measurements at the regional partner facility in Warsaw and at the EMFL facility in Nijmegen, respectively. Gray (colored) lines refer to calculations performed in the absence (presence) of direct-indirect exciton state hybridization.

The evidence of straininduced exciton hybridization in a 2D system is not only crucial for future quantum-electronics applications of 2D materials, but it also opens the doors to novel research in the field. For instance, exciton hybridization could influence the charge-carrier lifetime and radiative efficiency or could represent an important ingredient in understanding and tuning the

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Magnetcally brightened dark excitons in two-dimentional metal-halide perovskites

The synthesis of colloidal nanocrystals with near-unity photoluminescence (PL) quantum yields has vastly extended the potential of metal-halide perovskites for solid-state lighting and display applications. It is possible to template the growth of nanocrystals to form planar, ultrathin perovskite sheets embedded between long organic molecules, which stabilize the colloids, referred to as nanoplatelets, shown schematically in the Figure (a).

These colloidal quantum wells are of interest as highly efficient emitters in the blue spectral region. In the context of light emitters, the splitting between optically dark and optically bright excitons is of paramount importance. After photogeneration, excitons usually relax to the lowest-lying dark state, which is detrimental for the device efficiency.

We performed optical-spectroscopy measurements with an applied in-plane magnetic field to mix the bright and dark excitonic states of $CsPbBr_3$-based nanoplatelets with a different thickness of the lead-halide slab, ranging from two to four layers of lead-halide octahedral planes. The induced brightening of the dark state allows us to directly observe an enhancement of the PL signal on the low-energy side of the spectrum, see Figure (b), which we explain as the magnetic-field-induced brightening of the dark state. In-plane magnetic fields allow us to extract accurately the energy splitting between the dark and bright excitons directly, without resorting to further measurements or modelling, see Figure (c).

We also evaluate the ratio between the intensities of the magnetic-fieldbrightened dark state and of the bright state. This ratio increases quadratically, as expected, but the experimental data can be described only by assuming a temperature of the excitons considerably larger than the lattice temperature, as shown in Figure (d). Thus, the evolution of the PL signal in magnetic field suggests that at low temperatures the exciton population is not fully thermalized, which is indicative of the existence of a phonon bottleneck.

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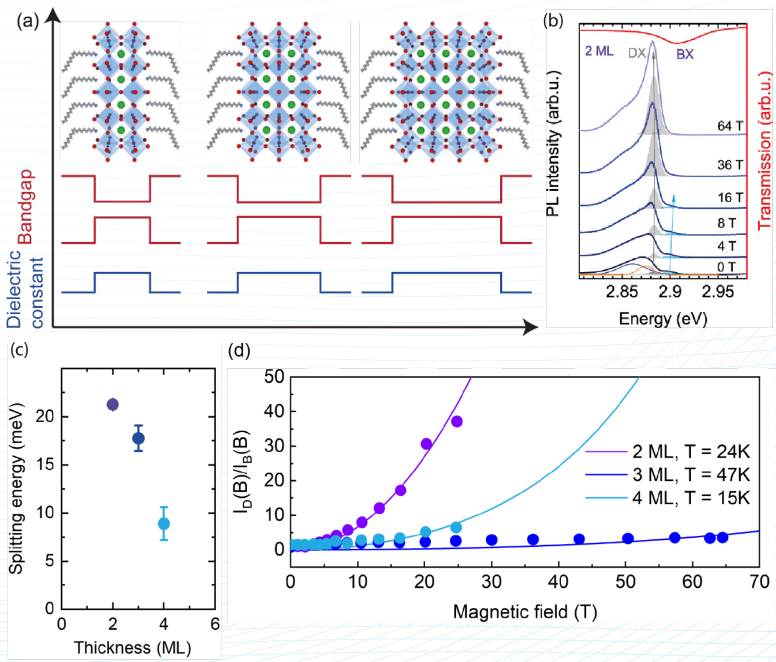

Figure:

(a) Top: schematic of the crystal structure of lead-halide perovskite nanoplatelets. Bottom: spatial dependence of the band gap and the dielectric constant.

(b) Magneto-PL spectra of anoplatelets. BX: bright exciton. DX: dark exciton.

(c) Measured bright-dark splitting as a function of nanoplatelet thickness.

(d) PL intensity ratio between dark and bright exciton states for the three nanoplatelet thicknesses investigated as a function of the applied magnetic field. Full circles represent experimental points. The curves are calculated using the temperature indicated in the legend

Magnetocaloric materials for the liquefaction of hydrogen

We are witnessing a great transition towards a society powered by renewable energies to meet the everstringent climate target. Hydrogen, as an energy carrier, will play a key role in building a climate-neutral society. Although liquid hydrogen is essential for hydrogen storage and transportation, liquefying hydrogen is costly using conventional methods based on the Joule-Thomson effect. As an emerging technology which is potentially more efficient, magnetocaloric hydrogen liquefaction can be a "game-changer" here.

In this work, we have investigated the rare- earth-based Laves phases RAl_2 and RNi_2 (R being a rare earth) for magnetocaloric hydrogen liquefaction. We have noticed an unaddressed feature that the magnetocaloric effect of second-order magnetocaloric materials can become "giant" near the hydrogen boiling point. This feature indicates strong correlations, down to the boiling point of hydrogen, among the three important quantities of the magnetocaloric effect: the maximum magnetic entropy change ΔS_m, the maximum adiabatic temperature change ΔT_{ad}, and the Curie temperature T_c.

Results of our measurements of the magnetocaloric effect in static and in pulsed fields are shown in the figure. Moreover, we have developed a mean-field approach to describe these two trends theoretically. The dependence of the magnetocaloric effect on T_c revealed in this work helps researchers quickly anticipate the magnetocaloric performance of rare-earth-based compounds, guiding materials design and accelerating the discoveries of magnetocaloric materials for hydrogen liquefaction.

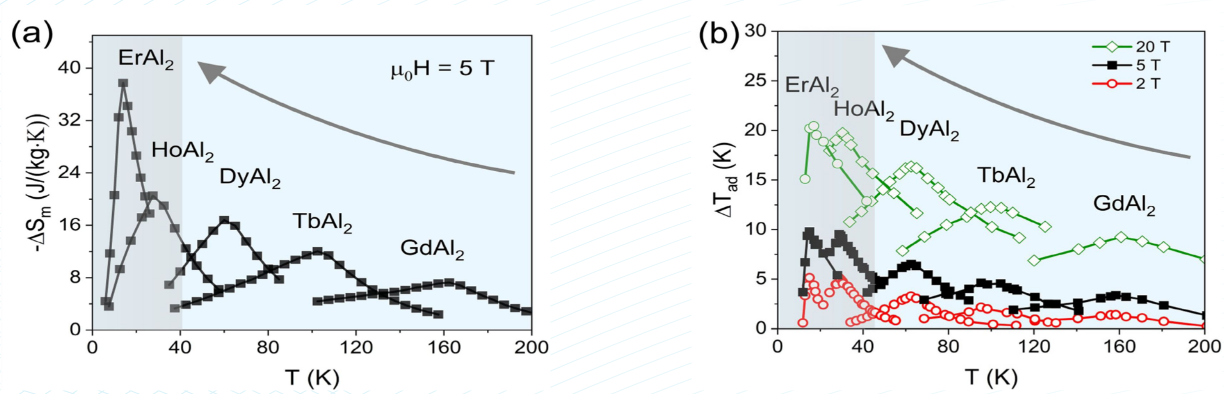

Figure: (a) Magnetic entropy changes in fields of 5 T and (b)direct measurements of adiabatic temperature changes of several Laves-phase materials in pulsed fields of 2, 5, and 20 T

Reference

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Nested magnetic breakdown in quntum-oscillation study on WTe_2

A team of researchers from HFML-FELIX, Aarhus University, and the University of Bristol has investigated the high-field electronic transport properties of the semimetal WTe_2. In quantumoscillations measurements, they revealed peculiar magnetic-breakdown trajectories of charge carriers between nested pockets of the Fermi surface.

WTe_2 is a material with extraordinary properties. Bound by weak van der Waals interaction, twodimensional layers can be exfoliated down to a monolayer, leading to emergent phenomena such as superconductivity and the quantum spin Hall effect. In its bulk form (as studied here), the material's resistance increases by more than 107% in the presence of a high magnetic field. Moreover, bulk WTe_2 has also been identified as a type-II Weyl semimetal, which essentially means that its electronic bands form tilted Dirac cones giving rise to small electron and hole pockets containing highly mobile charge carriers. In quantumoscillation measurements, the observed frequency of the 1/B-periodic oscillations is directly proportional to the extremal area of particular pockets of the Fermi surface. Key properties of the charge carriers such as their effective mass, quantum mobility, and nature (electrons or holes) can be determined from these experiments.

In high magnetic fields, the phenomeon of magnetic breakdown (MB) occurs, which is essentially a tunneling of charge carriers between different pockets of the Fermi surface. In quantum-oscillation measurements, MB orbits are characterized by the sum of individual areas (frequencies) of different pockets. By measuring quantum oscillations that originate from MB orbits at different tilt angles and temperatures and comparing those to band-structure calculations, it was found that the Fermi surface of WTe_2 can be explained within the model of a Matryoshka-doll nested Fermi surface of electron and hole pockets, i.e., electron and hole pockets in WTe_2 fit inside one another in precisely the same way. What is so peculiar is the fact that the onset of magnetic breakdown is solely determined by impurity scattering in contrast to magneticbreakdown scenarios in other metallic systems, which depends exclusively on the strength of the applied magnetic field. In addition, unlike in other systems, the phenomenon of MB in this material persists upon changing the magnetic-field orientation with respect to the two-dimensional layers of WTe_2.

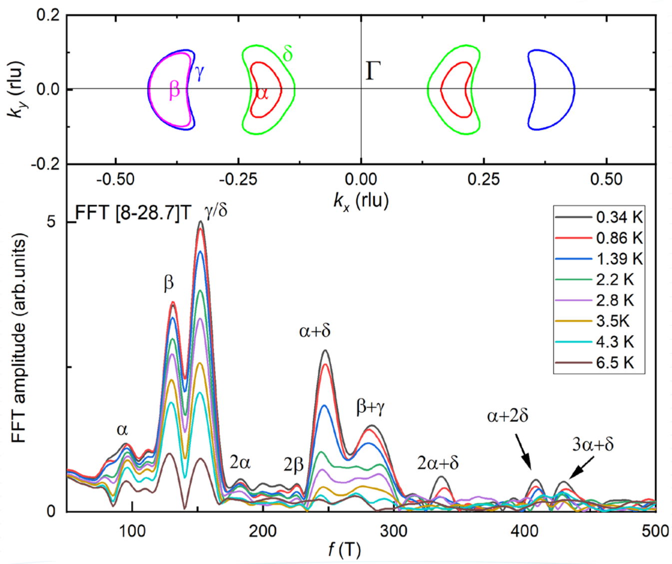

Figure: (top) Cut of the Fermi surface in the kx-ky plane highlighting the nested-doll configuration. (bottom) Fast-Fourier transform spectrum for the field range for different temperatures up to 6,5 K between 8 and 28,7 T. The corresponding individual (α, β, γ, δ) and breakdown orbits (sum of individual orbits) are labeled.

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Colossal angular magnetoresistance in ferrimagnetic nodal-line semiconductors

A group of researchers from Korea, USA, and HLD have demonstrated that topological nodal-line degeneracy of spin-polarized bands in magnetic semiconductors can induce an extremely large angular dependence in the magnetotransport. A phenomenon that the researcher called colossal angular magnetoresistance. The findings demonstrate that magnetic nodal-line semiconductors are a promising platform for realizing extremely sensitive spin- and orbital-dependent functionalities.

In ferromagnetic nodal-line semimetals, including previously reported Fe_3GeTe_2, $Co_3Sn_2S_2$, and Co_2MnGa, the band-crossing points of spin-polarized bands near the Fermi level (E_F) are protected by crystalline symmetry and form a line in momentum space. When spin-orbit coupling (SOC) is taken into account, opening and closing of the SOC gap (Δ_{SOC}) is determined by the relative orientation between the orbital angular momentum (L), fixed along a certain crystal axis, and spin direction (S), rotatable by external magnetic fields. A related but distinct behavior was expected in ferromagnetic semiconductors if the spin-polarized conduction or valence bands possess a topological nodal-line degeneracy. In such ferromagnetic nodal-line semiconductors, the SOC lifts the band degeneracy and pushes one of the bands towards E_F by $\Delta_{SOC}/2$, depending on the relative orientation of L and S (Figure 1). Therefore, when the bandgap Δ and Δ_{SOC} are comparable, spin rotation by external magnetic fields drastically modulates the bandgap and thus charge conduction, leading to the colossal angular magnetoresistance.

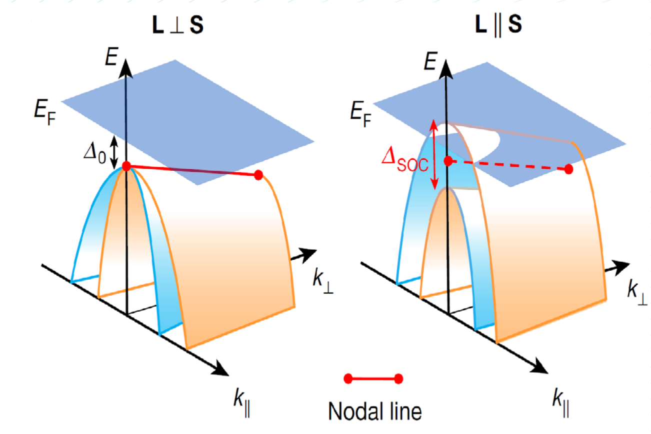

Figure 1: The electronic gap Δ remains intact for L ⊥ S in the presence of SOC, while the lifting of nodal-line band degeneracy for L ∥ S pushes one of the bands towards the Fermi level. This induces the insulator-tometal transition, controlled by the relative orientation of S against L, resulting in a colossal angular magnetoresistance.

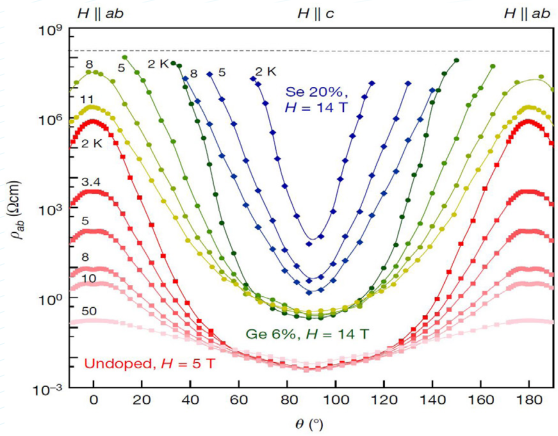

Figure 2: Angular response of ρ_{ab} for an undoped, Ge-doped, and Se-doped $Mn_3Si_2Te_6$ crystals as a function of magnetic-field orientation at different temperatures. For the doped samples, the resistivity taken at H = 14 T and low temperatures is beyond the measurement limit (dashed line) near H ∥ ab.

The researchers demonstrated this behavior successfully for the self-intercalated layered ferrimagnet $Mn_3Si_2Te_6$, both undoped and doped with Ge and Se. The resulting variation of the angular magnetoresistance with rotating magnetization exceeds a trillion percent per radian (Figure 2). Notably, the resulting angular magnetoresistance is controlled exclusively by spin rotation; pulsed-field measurements revealed no field-induced phase transitions up to at least 70 Tesla.

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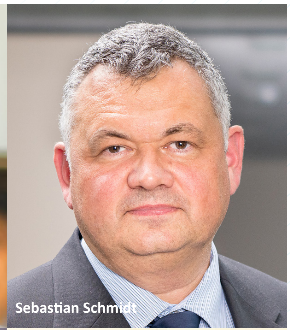
Organisational structure

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:

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Prof. Sebastian Schmidt (HZDR)
Dr. Sylvain Ravy (CNRS, Chair)
Prof. Amalia Patanè (University of Nottingham)
Prof. Adam Babiński (University of Warsaw)
Dr. 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:

Prof. Peter Christianen (HFML, Chair)
Prof. Jochen Wosnitza (HLD)
Dr. Charles Simon (LCNMI)

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 and 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:

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Dr. Ziad Melham, Oxford Quantum Solutions, UK
Prof. Claudia Felser, MPI for Chemical Physics of Solids, Dresden, Germany
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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
Alban Potherat	Coventry University	Soft Matter and Magnetoscience
Hans Engelkamp	HFML	Soft Matter and Magnetoscience
Anne-Lise Daltin	Univ. Reims	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	IISER	(Magneto)-optics of 2D semiconductors
Mathias Dörr	TU Dresden	Magnetism
Karel Prokes	Helmholtz-Zentrum Berlin	Magnetism
Carsten Putzke	MPI	for the Structure and Dynamics of Matter
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


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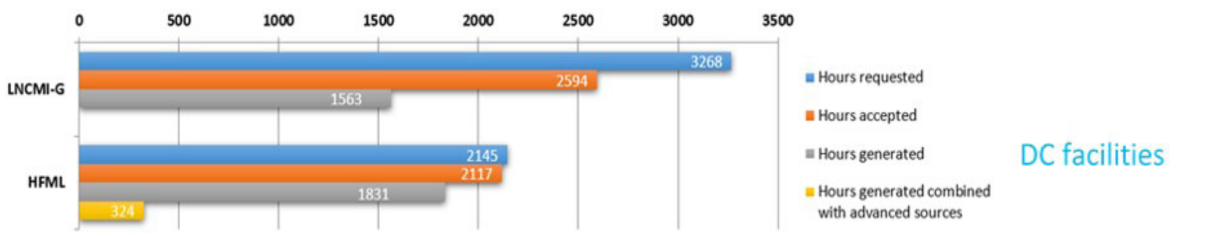
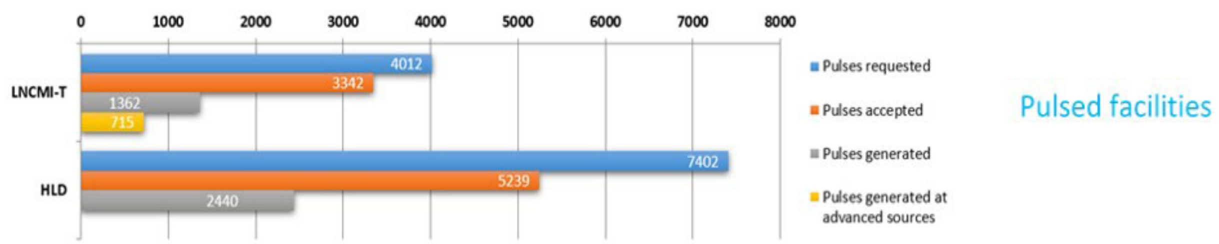
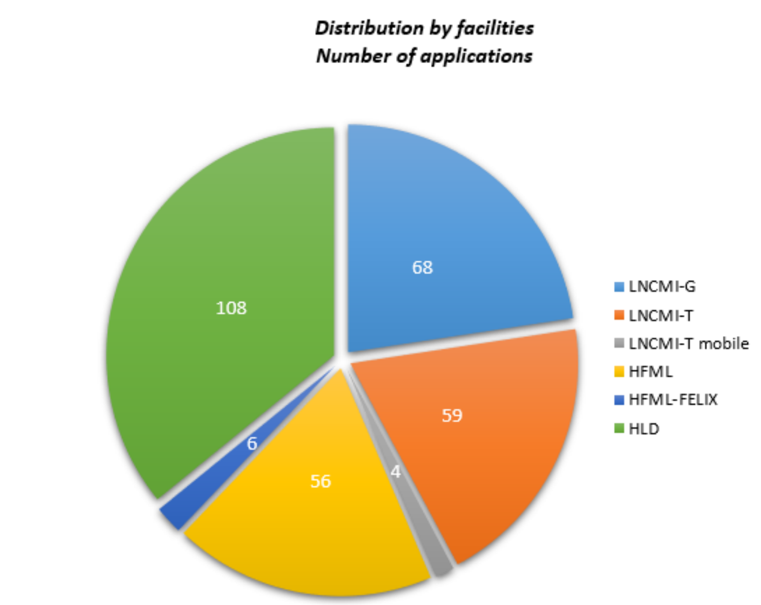
User Access

The 27th and 28th call for proposals closed in May and November 2022, resulting in 301 applications from 23 different countries in total. The Selection Committee (see page 26) has evaluated the proposals, covering five types of scientific topics:

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





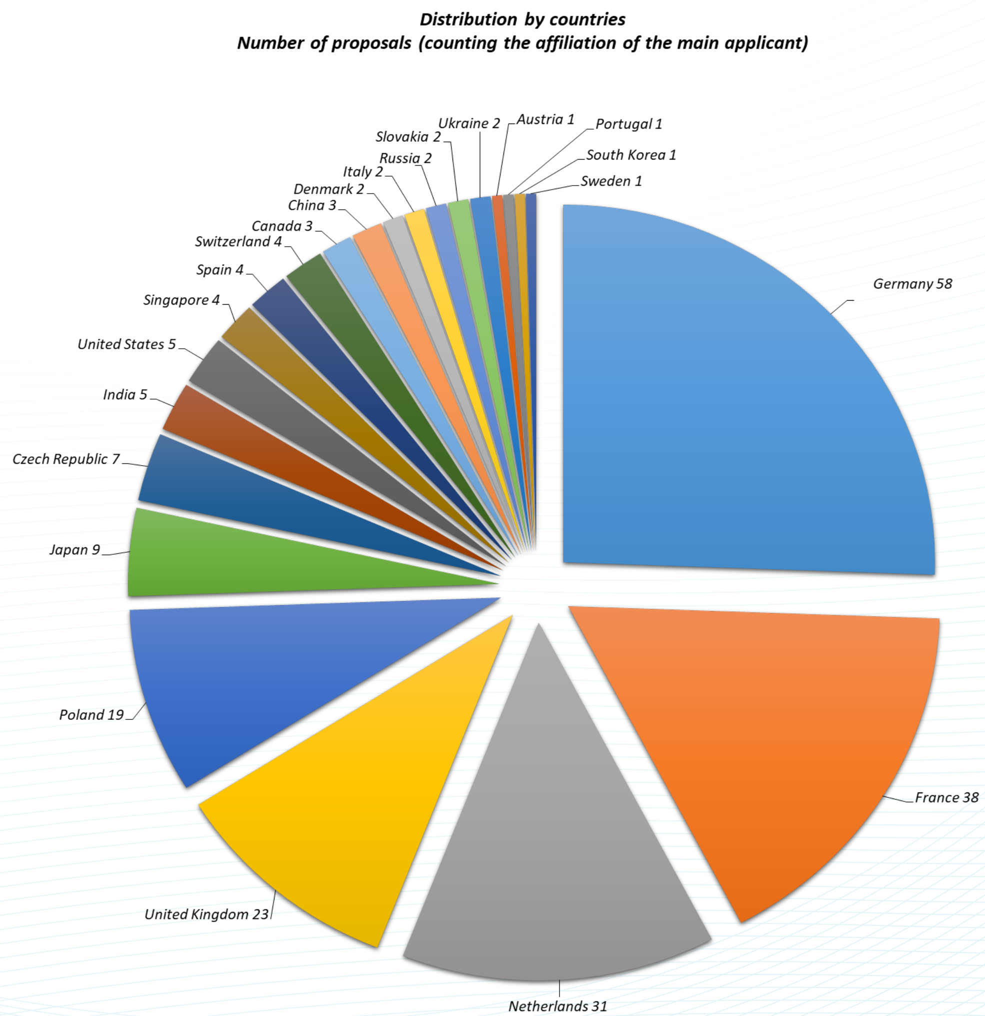


Evaluation of applications

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/



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Contact details

EMFL
Helmholtz-Gemeinschaft Brussels Office,
Rue du Trône 98
1050, Elsene, Brussels
Belgium

Tel +31-24-3653005
Fax +31-24-3652440
e-mail: emfl@science.ru.nl
www.emfl.eu

High Field Magnet Laboratory (HFML)
Toernooiveld 7
6525 ED Nijmegen, The Netherlands

Laboratoire National de Champs Magnétiques Intenses at Grenoble (LNCMI-G)
25 rue des Martyrs, B.P. 166
38042 Grenoble cedex 9, France

Laboratoire National de Champs Magnétiques Intenses at Toulouse (LNCMI-T)
143 avenue de Rangueil
31400 Toulouse, France

Hochfeld-Magnetlabor Dresden (HLD)
Bautzner Landstr. 400
01328 Dresden, Germany

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Responsible for the content:
Jochen Wosnitza (j.wosnitza@hzdr.de),
Charles Simon (charles.simon@lncmi.cnrs.fr),
Peter Christianen (peter.christianen@ru.nl),
Uli Zeitler (uli.zeitler@ru.nl)

Editor:
Larysa Zviagina

Photos:
G. Laureijs, J. Billette, O. Portugall, V. Moncorgé, HLD, LNCMI, HFML

Jaroslaw Rybusinski, University of Warsaw

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