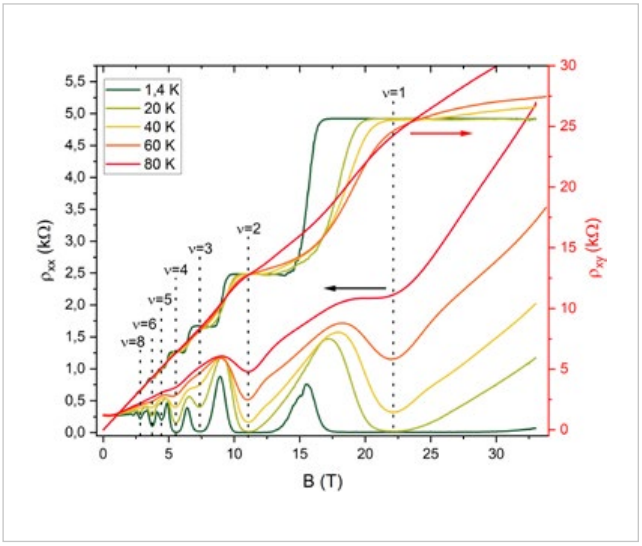
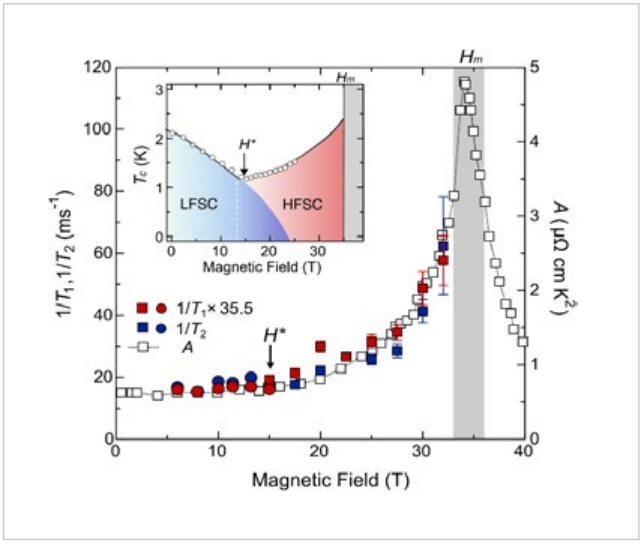
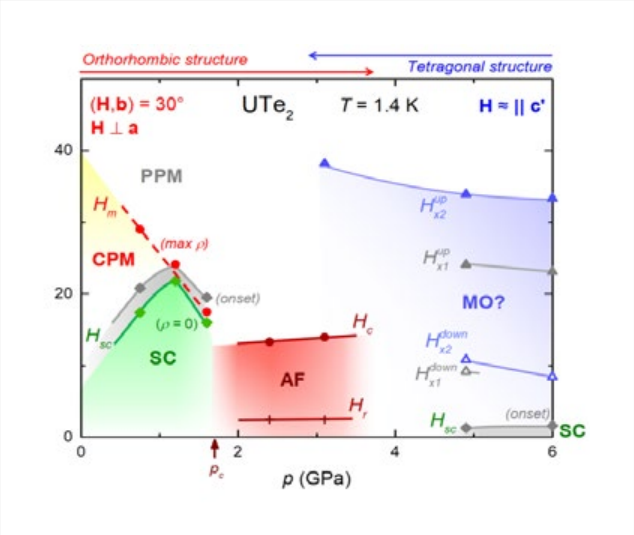
European Magnetic Field Laboratory

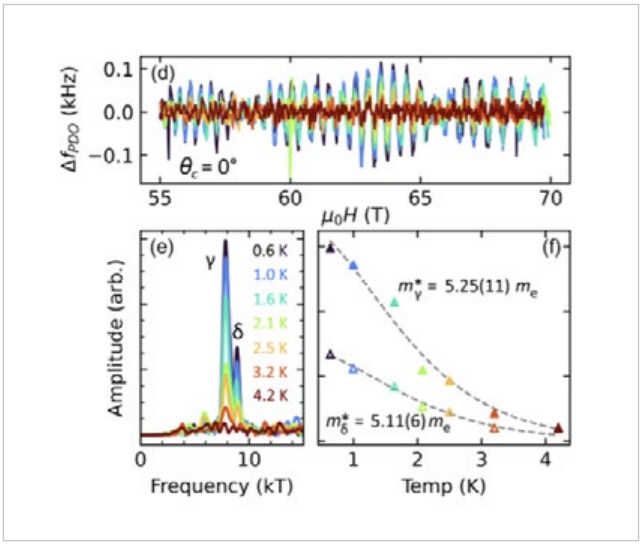
EMFLNEWS

N°2 2024









CONTENTS

DEAR READER

It is with great pleasure that we present the summer edition of EMFLNews, a unique opportunity to share with you the latest exciting developments from our international laboratory. As with every edition, we highlight recent scientific achievements of our research teams and we have the privilege of introducing you to a distinguished member of our laboratories, and this time we feature Inès Dupon-Lahitte from Toulouse.

This edition particularly focuses on two aspects that were important to us at EMFL. We feature our user meeting in Nottingham (UK), during which we have given our annual EMFL prize to Elena Blundo. I take this opportunity to wish her a brilliant future in science. Many thanks to the Nottingham organizing team and, in particular, to Amalia Patanè, who made this very inspiring event possible. During this meeting, Oxford Instruments and Siemens Magnet Technology excelled with very interesting presentations about the role of industry in magnet technologies.

The HFML-FELIX team organized the RHMF (Research in High Magnetic Field) conference in Nijmegen in July 2024. This was a great opportunity to meet the high-field community from USA, China, Japan, India, and Europe for the first-after-COVID conference in this field.

The European FlexRICAN project was launched in Lund (Sweden). This project, which will help EMFL, together with ESS (European Spallation Source) and ELI (Extreme Light Infrastructure), to reduce the carbon footprint of large research infrastructures in Europe.

We hope you will appreciate the dynamism and achievements of EMFL as described in this issue and take the opportunity to submit new proposals to our next call.

On behalf of the entire team, I wish you a very pleasant summer 2024.

Charles Simon
Director LNCMI
Chairman EMFL

MEET OUR PEOPLE

Inès Dupon-Lahitte, LNCMI-Toulouse

Since April of this year, I am EMFL´s new Industrial Liaison Officer for the ISABEL project. My role is to bring the EMFL closer to industry. To that end, I work closely with our researchers, engineers, and technicians to update the skill map. I will also be representing the EMFL at industrial events such as the Big Science Business Forum or the Cryogenics Operation. Finally, I intend to invigorate the Industrial Partners Club to foster collaborations between our industrial partners and the EMFL.

To introduce myself briefly, I have a Master's Degree in Business Law. Having a strong interest in public research, I started working in the research department of the Université Toulouse Capitole, where I was in charge of supporting doctoral students as well as the valorization of research. In this role, I was helping PhD candidates to obtain financial support for their thesis. I was responsible for the liaison with the companies, who were employing PhD candidates as part of a system of an industrial agreement for training through research (CIFRE in French). I was also responsible for the valorization of research, mainly through research collaboration contracts and managing intellectual property. The very diverse aspects of the valorization management led me to look for a greater challenge, which is why I am glad to be now part of this important European laboratory and to work alongside many different people, coordinating with multiple countries. Not having a background in physics, I am very enthusiastic about everything I get to learn in the laboratory. I am also very happy to work with all these people who take the time to answer my questions and help me promote the EMFL to industry.

› *Inès Dupon-Lahitte*

QUANTUM HALL EFFECT IN InAsSb QUANTUM WELLS AT ELEVATED TEMPERATURES

Maurice Bal, HFML Nijmegen

Since its discovery in 1980 by von Klitzing et al., the quantum Hall effect (QHE) has been measured in many different 2D systems, mainly at cryogenic temperatures. Currently, graphene is the only material that displays the QHE at room temperature (RT). Considering that the robustness of the QHE is, amongst others, governed by the Landau-level spacing (about 2000 K at 30 T for graphene), InSb with its small effective mass (0.014m, with m_e the free-electron mass) would conceptually also be a good material for the observation of a RT QHE. Optimally alloying InSb with InAs can reduce the effective mass even further, by utilizing the band bending commonly observed in ternary III-V compound semiconductors.

Recently, a group of scientists from HFML-FELIX and ETH Zürich have investigated InSb and InAsSb modulation-doped quantum wells (QWs) to determine the robustness of the QHE in these systems. Temperature-dependent magneto-transport measurements show that the QHE survives up to 60 K (figure). Despite the fact that the QHE is observable at relatively high temperatures, our InAsSb QWs are still outperformed by graphene devices. A possible explanation can be found in the effective mass of the charge carriers. From the mass analysis, performed with two complementary techniques (the temperature dependence of Shubnikov–de Haas oscillations and cyclotron resonances), it can be concluded that the masses are larger than those of the corresponding bulk values, which can be attributed to the fact that asymmetric doping can skew the potential well, effectively reducing its width and resulting in a higher mass due to stronger confinement.

Using coincidence experiments in tilted magnetic fields, it was also possible to determine the g-factors, which are consistent with band-structure calculations for InAsSb. Additionally, an interaction-induced enhancement of the g-factor is observed in both InSb as well as in InAsSb.

In summary, we have performed important proof-of-principle experiments on InAsSb quantum wells, a promising system with the potential of realizing a low mass and high g-factor system.

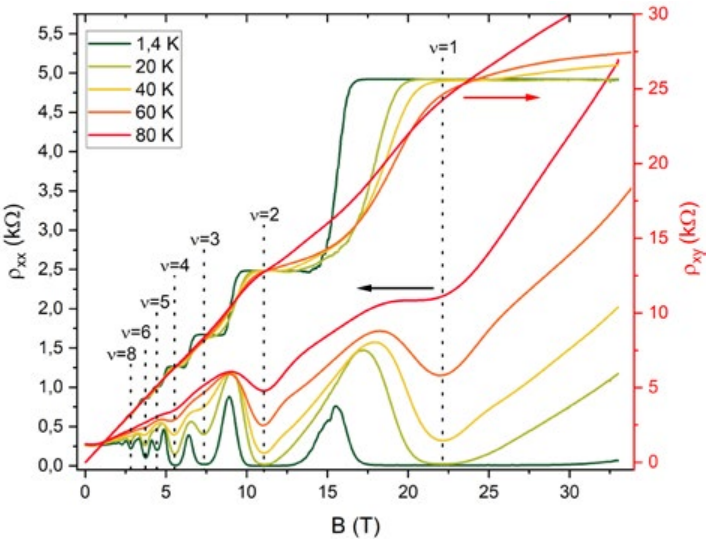


Figure: Magnetic-field dependence of ρ_{xx} and ρ_{xy} at different temperatures for an InAsSb QW Hall bar.

Quantum Hall effect in InAsSb quantum wells at elevated temperatures, M. E. Bal, E. Cheah, Z. Lei, R. Schott, C. A. Lehner, H. Engelkamp, W. Wegscheider, and U. Zeitler, Phys. Rev. Res. **6**, 023259 (2024).

Contact: maurice.bal@ru.nl, uli.zeitler@ru.nl

HIGH-FIELD NMR UNVEILS FIELD-REINFORCED SUPERCONDUCTIVITY IN UTe_2

Y. Tokunaga, Japan Atomic Energy Agency, Tokai, Japan, M. Horvatić and Steffen Krämer, LNCMI Grenoble

The uranium-based superconductor UTe_2 provides an attractive platform for studying the novel physics of spin-triplet and topological superconductivity in bulk materials. Resistivity measurements performed in 2019 at LNCMI, both in continuous and pulsed fields, revealed that superconductivity in UTe_2 is significantly enhanced when the magnetic field (H) is applied along the crystallographic b axis (inset of figure). This leads to an increase of the upper critical field up to the field of a metamagnetic transition at H_m = 35 T. It was proposed that an essential ingredient for this field-reinforced superconductivity is the interplay with U-5f-electron spin fluctuations.

To confirm the presence and elucidate the nature of spin fluctuations in UTe_2, we conducted ^{125}Te-NMR experiments in high magnetic fields using specially prepared, ^{125}Te-enriched, high-quality single crystals having T_c = 2.0 K, synthetized using the molten-salt flux method discovered recently by our team. The natural abundance of ^{125}Te is only 7 %, so that our enrichment up to 99 % largely enhanced the NMR signal, allowing us to measure the field dependence of the NMR relaxation rates $1/T_1$ and $1/T_2$ up to 32 T.

The observed magnetic-field dependence of these data for H || b (figure) and the scaling between the two relaxation rates, $T_2^{-1}/T_1^{-1} \approx 36$, demonstrates that the dominant fluctuations in this material are longitudinal ones. While $1/T_1$ and $1/T_2$ are nearly field independent at lower fields, both quantities start to increase above about 15 T and show a tendency to diverge above 32 T, where the NMR spin-echo signal becomes unobservable because T_2 becomes shorter than the dead time of our NMR spectrometer. This confirms the divergence of spin fluctuations near the field-induced metamagnetic transition at H_m. Previous macroscopic studies gave H* ≈ 15 T as the characteristic field above which T_c shows an upturn and a high-field superconducting phase emerges on top of a low-field superconducting phase (inset of figure). Our NMR results show that H* is also the characteristic field above which spin fluctuations begin to develop on approaching the metamagnetic transition, confirming that these fluctuations indeed enhance the pairing interactions.

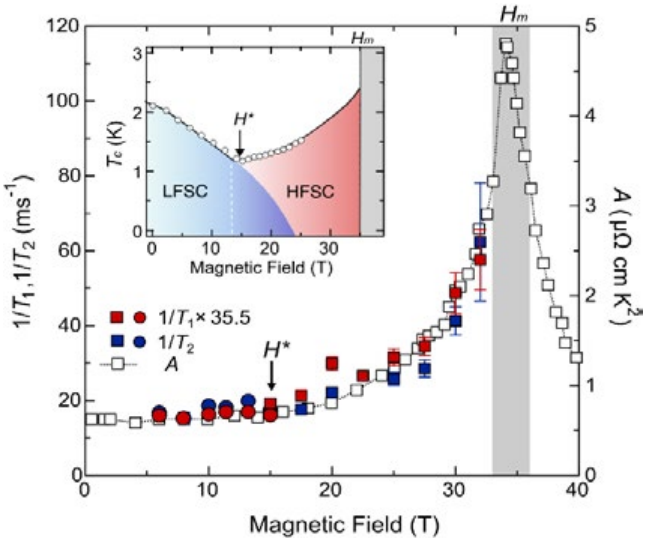


Figure: Magnetic-field dependence of $1/T_2$ and $1/T_1$ (scaled by a factor 35.5) in UTe_2 for H || b, compared to the previously published quadratic coefficient A of the low-T resistivity data. The data provide a direct signature of longitudinal spin fluctuations related to the metamagnetic transition at 35 T. Inset: Field-dependent T_c data and corresponding schematic H-T phase diagram, presenting a high-field (HFSC) as well as a low-field (LFSC) superconducting (SC) phase.

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Longitudinal Spin Fluctuations Driving Field-Reinforced Superconductivity in UTe_2,
T. Y. Tokunaga, H. Sakai, S. Kambe, P. Opletal, Y. Tokiwa, Y. Haga, S. Kitagawa, K. Ishida, D. Aoki, G. Knebel, G. Lapertot, S. Krämer, and M. Horvatić, Phys. Rev. Lett. **131**, 226503 (2023).

POSSIBLE METAMAGNETISM IN THE HIGH-PRESSURE TETRAGONAL PHASE OF UTe_2

Tristan Thebault, William Knafo, LNCMI Toulouse, Daniel Braithwaite, Gérard Lapertot, Georg Knebel, CEA-Grenoble, and Dai Aoki, Tohoku University

The interplay between magnetism and unconventional superconductivity in UTe_2 was extensively studied in the past few years. Multiple superconducting phases were found to be induced near to a metamagnetic transition under magnetic field either at ambient pressure or combined with pressure. A structural orthorhombic-to-tetragonal phase transition was also recently discovered at a pressure $p^* \approx 3.5$ - 8 GPa.

In this work, we have investigated the electrical resistivity of UTe_2 in pulsed magnetic fields up to 58 T combined with pressures up to 6 GPa. The field was applied in a direction tilted by 30° from b to c in the low-pressure orthorhombic structure, which is identified as the direction c' of the high-pressure tetragonal structure. In the tetragonal phase, possible metamagnetic transitions are observed at $\mu_0 H_{x1} = 24$ T and $\mu_0 H_{x2} = 34$ T. They disappear at temperatures higher than $T_x = 235$ K, at which an electronic phase transition is reported from the zero-field resistivity. We propose that magnetic ordering drives the transition at T_x and that magnetic-moment reorientations are induced at H_{x1} and H_{x2}. Further challenges will be to determine the nature of the electronic phase stabilized below T_x and to understand how the properties of the tetragonal phase may be related to those of the orthorhombic phase.

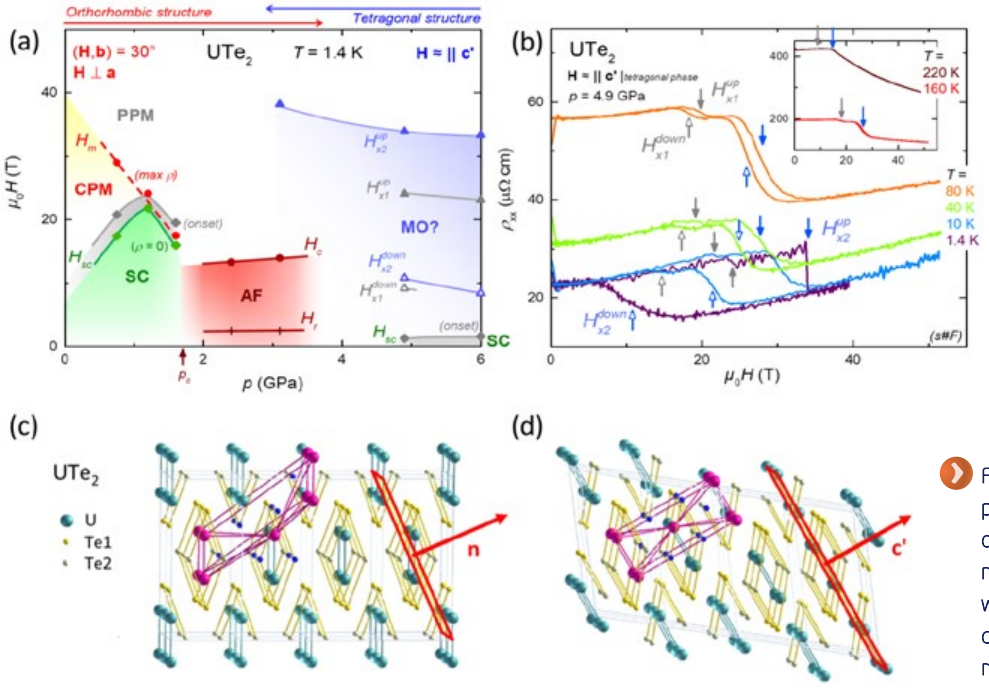


Figure: (a) Pressure-magnetic-field phase diagram of UTe_2. (b) Evolution of the electrical resistivity under magnetic field for temperatures between 1.4 and 220 K at 4.9 GPa. Three dimensional views of (c) the orthorhombic and (d) the tetragonal phase.

Possible metamagnetism in the high-pressure tetragonal phase of UTe_2, T. Thebault, D. Braithwaite, G. Lapertot, D. Aoki, G. Knebel, and W. Knafo, Phys. Rev. B **109**, 214420 (2024).

Contact: tristan.thebault@lncmi.cnrs.fr, william.knafo@lncmi.cnrs.fr, daniel.braithwaite@cea.fr

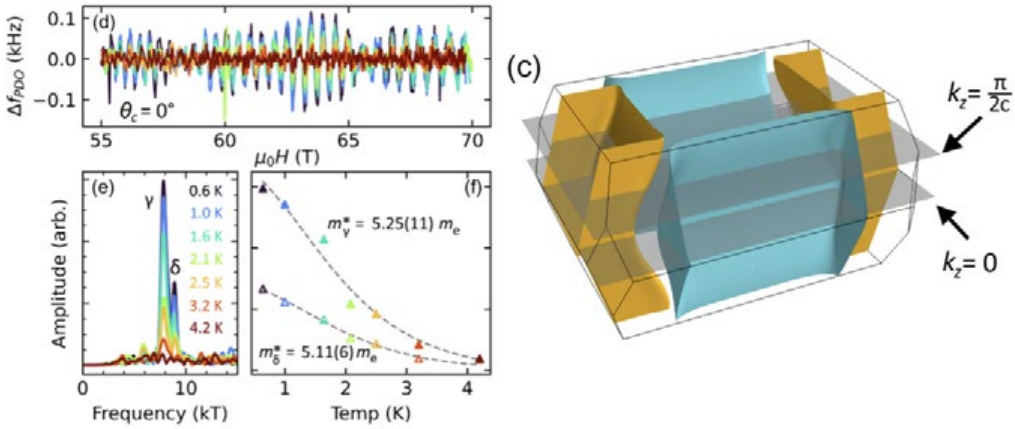
QUANTUM INTERFERENCE BETWEEN QUASI-2D FERMI-SURFACE SHEETS IN UTe_2

Alex Eaton, University of Cambridge, UK and Yurii Skourski, HLD

Scientists from the UK, USA, Czech Republic, and Germany have studied the Fermi surface of the heavy-fermion superconductor UTe_2. This material is of particular interest given its high likelihood of hosting a spin-triplet Cooper-pairing mechanism. Evidence for this stems primarily from the observation of only a small change in the NMR Knight shift on cooling through T_c, along with anisotropic upper critical fields that greatly exceed the Pauli limit in all directions.

The dimensionality of Fermi-surface sheets in triplet superconductors can have important implications regarding the possible topological properties of the superconductivity. A recent study of the magnetoconductance of UTe_2 was interpreted as indicating the presence of a 3D Fermi-surface pocket. Here, by combining high-field magnetoconductance oscillation measurements using a 70 T coil at HLD-Dresden along with measurements in the 41 T resistive magnet in Tallahassee, researchers were able to show that actually the profile of the magnetoconductance oscillations in UTe_2 can be very well described by considering quantum interference between magnetic-breakdown orbits across quasi-2D Fermi-surface sections previously identified in dHvA-effect studies. Such quantum interference effects – first observed by Stark in the 1970s in experiments on magnesium – occur when the k-space separation between Fermi-surface sheets is very small, allowing quasiparticles to tunnel across the sheets in accessible magnetic-field strengths. Furthermore, the datasets of this study were found to be incompatible with the presence of any 3D Fermi-surface pockets.

This confirmation of the quasi-2D nature of the UTe_2 Fermi surface sets the groundwork for future theoretical developments. Excitingly, the Fermi surface of UTe_2 appears to be remarkably simple, consisting exclusively of two cylindrical sheets of hole and electron type, respectively. This is markedly simpler than comparable heavy-fermion systems such as UPt_3, URhGe, etc., which possess complex multi-sheet Fermiologies. Despite a wealth of exotic physical phenomena at play in UTe_2, the simplicity of its electronic structure gives hope that meaningful theoretical progress at understanding this material is within our grasp.



Quantum Interference between Quasi-2D Fermi Surface Sheets in UTe_2, T. I. Weinberger, Z. Wu, D. E. Graf, Y. Skourski, A. Cabala, J. Pospíšil, J. Prokleška, T. Haidamak, G. Bastien, V. Sechovský, G. G. Lonzarich, M. Vališka, F. M. Grosche, and A. G. Eaton, Phys. Rev. Lett. **132**, 266503 (2024).

Figure: Quantum-interference oscillations measured in a 70 T pulsed magnet at HLD by the PDO technique, alongside a rendering of the quasi-2D Fermi-surface sheets of UTe_2.

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OUTCOME OF THE THIRTY-FIRST CALL FOR ACCESS

After the deadline of the 31st call for access to the EMFL facilities on 15 May 2024, the Selection Committee evaluated the proposals on 10 June 2024, just before the EMFL User Meeting.

Our four facilities

> LNCMI - Grenoble - France: Static magnetic fields to 36 T
> HFML - Nijmegen - the Netherlands: Static magnetic fields to 38 T
> HLD - Dresden - Germany: Pulsed magnetic fields to beyond 95 T
> LNCMI - Toulouse - France: Pulsed magnetic fields of long duration to over 99 T, and on the microsecond scale to beyond 200 T

are open to users worldwide. EMFL operates a joint transnational access program, which grants full access to these installations and all associated scientific infrastructure to qualified external users, supplemented by the necessary support from the scientific and technical staff on site.

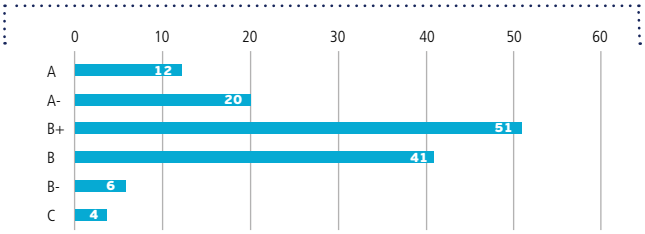
For this 31st call, 134 proposals from 22 different countries were submitted, of which 6 are proposals for dual access with regional partner laboratories, 1 for technical access, 7 for fast track (received from January to June 2024), and 20 proposals for first-time access to the EMFL high-field facilities. These novel access procedures are introduced within the EMFL-ISABEL project.

The Selection Committee consists of 18 specialists covering the following five scientific topics:

> Metals and Superconductors (28 applications),
> Magnetism (67 applications),
> Semiconductors (32 applications),
> Soft Matter and Magnetoscience (3 applications),
> Applied Superconductivity (4 applications).

Besides of ranking the proposals, the committee members decide on the number of accepted magnet hours and number of pulses.

NEXT CALL:
Launch: October 15, 2024
Deadline: November 15, 2024



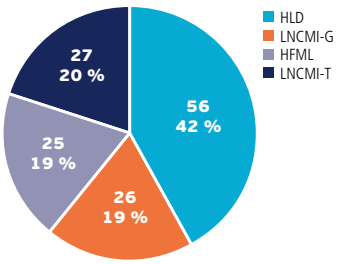
Evaluation of applications

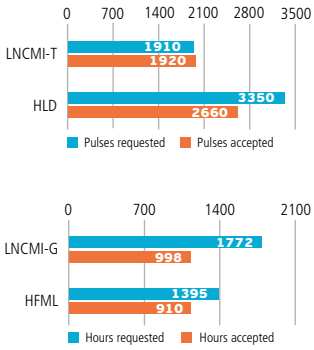
The proposals are ranked in three classes:

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

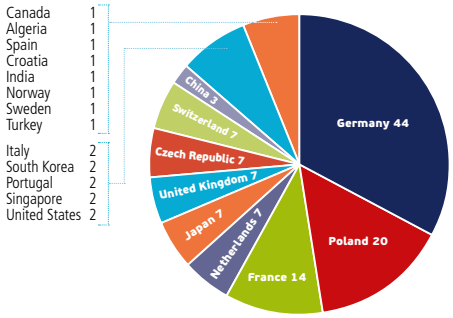
In the B category, the ranking + or - serves as a recommendation to the facility. This degree of freedom is necessary to allow the facilities to consider other aspects such as available capacity and equipment necessary for the successful outcome of a project.

Distribution by facilities
Number of applications





Distribution by country of PI affiliation



EMFL USER MEETING

The EMFL User Meeting 2024 took place at the University of Nottingham on 11 June; after 2017, the second time at this place. The EMFL Board of Directors has chosen this venue to underline the continuing collaboration of the UK community with EMFL, through grant agreements between EPSRC and EMFL as well as with the three host laboratories in France, The Netherlands, and Germany. Prof Amalia Patanè received a separate EPSRC grant for coordinating the UK activities connected to EMFL. She also hosted the meeting.

The User Meeting included the EMFL prize ceremony (see below), two scientific sessions, in which our users highlighted some of their most recent research, the User Committee meeting, chaired by Prof Raivo Stern (NICPB, Tallinn, Estonia), and, for the first time, a session allowing industry partners to present their activities and interest in high-magnetic-field technologies. Here, John Burgoyne form Oxford Instruments plc and M'hamed Lakrimi from Siemens Magnet Technology gave inspiring talks. The meeting started with an introductory lecture by Charles Simon, chair of the EMFL Board of Directors, who presented recent developments within EMFL. The scientific talks

covered a broad range of research enabled by the use of very high magnetic fields. This included magneto-hydrodynamics in stars, optical spectroscopy and transport in two-dimensional materials, all the way to unconventional superconductivity and extreme high-pressure studies of hydride superconductors.

We would like to thank Amalia Patanè and all the staff at the University of Nottingham for their excellent organization and for the diverse and inspiring meeting.

ELENA BLUNDO WINS EMFL PRIZE 2024

During the User Meeting in Nottingham, Elena Blundo received the EMFL prize 2024. Jochen Wosnitza, chair of the EMFL prize committee, had the honor of presenting the prize in a traditional small prize ceremony. The EMFL prize was established in 2009 and recognizes outstanding achievements related to research in all disciplines utilizing high magnetic fields.

Elena received her PhD in Physics in January 2023 from the Department of Physics of Sapienza University of Rome. Currently, she is a distinguished postdoc fellow at the Walter Schottky Institut, at the Technical University of Munich.

The prize recognizes Elena's work related to the use of high magnetic fields in complex optical-spectroscopy experiments on two-dimensional (2D) crystals. She investigated the electronic and mechanical properties of 2D materials, such as monolayers and heterostructures of transition-metal dichalcogenides (TMDs), hexagonal boron nitride, nano-porous graphene, III-V nanowires, and perovskites. Remarkably is her research of the Moiré localization effect in TMD-based heterostructures and the development of a novel method to induce extremely high strains in TMDs that allowed her to unveil novel strain-induced effects in these materials.

RESEARCH FOR EUROPE'S ENERGY FUTURE - FLEXRICAN PROJECT KICK-OFF

The beneficiaries of the EU Horizon-funded "Flexibility in Research Infrastructures for global CArbon Neutrality" (FlexRICAN) project inaugurated its launch during a kick-off meeting held on March 11-12, 2024 at the European Spallation Source (ESS) in Lund, Sweden. The 3-year FlexRICAN project, coordinated by ESS, has the ambitious goal of revolutionizing energy-consumption patterns within large research infrastructures across Europe. By harnessing the diverse expertise and resources of its partners, the project's aim is to develop sustainable energy solutions that will not only benefit the European grid but also local heating networks.

The kick-off meeting was attended by representatives from leading European institutions and companies including Centre National de la Recherche Scientifique (CNRS), Helmholtz-Zentrum Dresden-Rossendorf (HZDR), European Magnetic Field Laboratory (EMFL), Stichting Radboud Universiteit, Extreme Light Infrastructure (ELI), Alfa Laval and Energy Pool, along with European Commission representative

Elena Garbarino. The meeting also included a workshop session for detailed discussions on project objectives and descriptions of work packages, during which each work-package leader outlined their specific responsibilities in the five-million-euros project.

RHMF 2024

The 13th International Conference on Research in High Magnetic Fields (RHMF 2024) was held in Nijmegen, the Netherlands from 7 to 11 July 2024. The conference was hosted by HFML-FELIX, Radboud University Nijmegen and attracted more than 100 participants from countries all over the world. The program consisted of 21 invited and 24 contributed lectures, as well as two very lively poster sessions on Monday and Tuesday evening, preceded by poster pitch sessions. The participants presented and discussed the latest advancements in fundamental and applied physics and related subject areas where high magnetic fields play a crucial role, with sessions on semiconductor physics and phenomena, superconductivity, magnetism, strongly correlated electron systems, semimetals, spin liquids, topological matter, magnetoscience, high magnetic field technology, and new experimental techniques in high magnetic fields. On Wednesday afternoon, the HFML-FELIX staff guided the participants through the laboratories, showing the high-field-magnet and free-electron-laser installations, as well as the experimental infrastructure. HFML-FELIX, Radboud University, the European Magnetic Field Laboratory, and the Dutch research Council NWO sponsored the conference.

SECOND EMFL INDUSTRIAL PARTNERS CLUB (IPC) WEBINAR

The Industrial Partners Club (IPC) of EMFL had its second webinar on June 20th, 2024. It brought together around 40 participants, of which 15 were from industrial companies, 5 from public institutions completed by scientific and technical staff from EMFL.

The webinar started with a brief presentation of the EMFL by the Industrial Liaison Officer introducing the facilities, European projects, and the tools to communicate and collaborate with industry. The Industrial Partners Club is one of these tools and the webinar was the occasion to give new momentum to the IPC. We informed the participants of our presence at some industrial events such as the Big Science Business Forum (BSBF) in October 2024, which will allow us to meet some of the participants in person.

After that, members who had volunteered to present their activities had 5 minutes each to present their company and their interests in high magnetic fields and/or the EMFL.

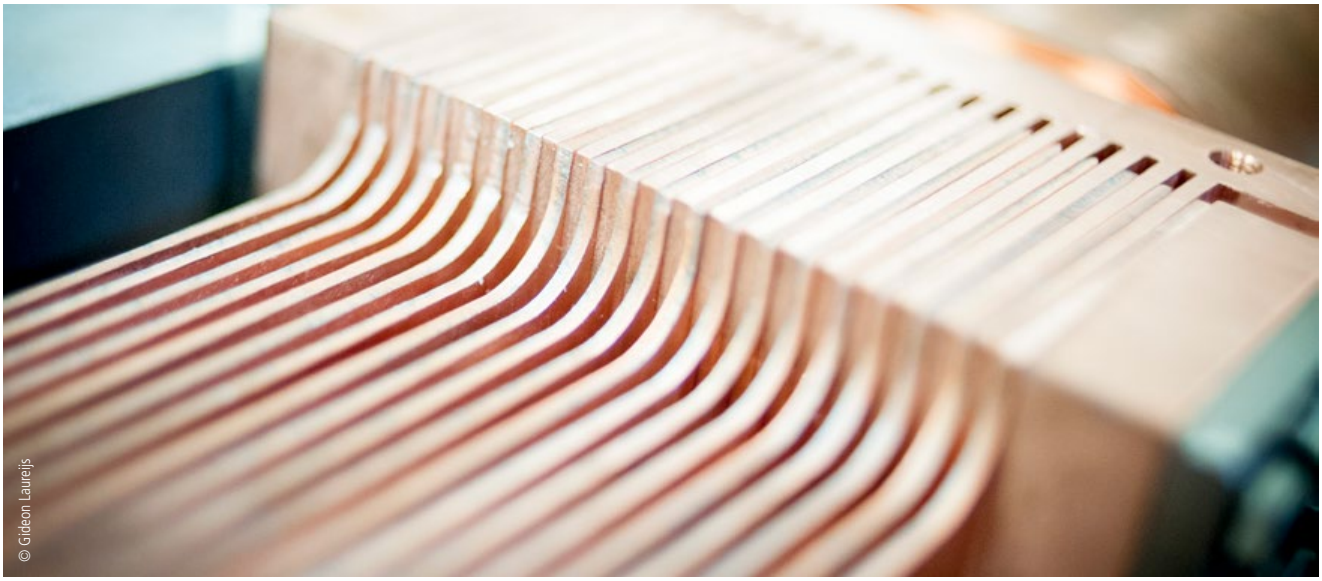
The speakers were from various sectors, such as the manufacturing of coils or parts of them, metal forming, and the production of all types of sensors and other tools of measurement or control systems. The industrial partners presenting were:

- Eric FANIO, CEO of SEF Technologies;
- Rafael DELLA GIUSTINA, Product Manager at Renaissance Fusion;
- Denis JOUAFFRE, Materials and Processes Engineer at Innovaltech;
- Olivier MASSEGLIA, Field Applications Engineer at Paragraf;
- Marc BERTHAUD, Sales Manager at FT Mesures;
- Antoine DARIDON, Business Development Manager at Metrolab;
- Daniel MARCHANTE, Business Manager Science and Digital Industry at Procon Systems.

Members of public institutions giving presentations were

- Olivier MALOBERTI, Researcher at UniLaSalle;
- Thanos PAPAZOGLOU, Business Development Officer at the ESRF;
- José ANTAO, Industrial Liaison Officer at the National Agency of Innovation of Portugal and member of the Accelerator Science and Technology Industry Permanent Forum (AIPF).

The various presentations initiated lively discussions. Afterwards, the EMFL presentation was sent to the participants as well as to all members on the IPC mailing list, including a link to answer a short survey of satisfaction. With that we aim to attract more persons for the next webinar, as well as to improve our ways of communicating with the industry.



UPCOMING EVENTS

1 Applied Superconductivity (ASC 2024), Salt Lake City, USA, September 1-6, 2024.
www.appliedsuperconductivity.org/asc2024/

2 International Conference on Infrared, Millimeter, and Terahertz Waves, Perth, Australia, September 1-6, 2024.
www.irmmw-thz.org/conference/

3 Flatlands Beyond Graphene 2024, Wroclaw, Poland, September 9 - 13, 2024.
https://flatlands2024.pwr.edu.pl/

4 25th International Conference on High Magnetic Fields in Semiconductor Physics (HMF-25), Warsaw, Poland, September 16 - 20, 2024.
https://hmf25.fuw.edu.pl/

5 International Symposium on Crystalline Organic Metals, Superconductors and Magnets (ISCOM 2024), Anchorage, USA, September 22 - 27, 2024.
https://sites.google.com/view/iscom2024/home

6 SUPERMAX - International Workshop on Superconductivity & Magnetism in f-Electron Quantum Materials under Extreme Conditions, Toulouse, France, October 14-18, 2024.
https://supermax.sciencesconf.org/

7 DPG Spring Meeting of the Condensed Matter Section, Regensburg, Germany, March 16-21, 2025.

8 APS March Meeting, Anaheim, USA, March 16-21, 2025.
https://march.aps.org/

9 13th International Conference on Highly Frustrated Magnetism, Toronto, Canada, May 25-30, 2025.
https://conference.physics.utoronto.ca/event/18/

10 30th International Conference on Low Temperature Physics (LT30), Bilbao, Spain, August 7-13, 2025.
https://www.lt30.es/

Bilbao cityview from Monte Artxanda

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Recherche Scientifique (CNRS)
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France
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