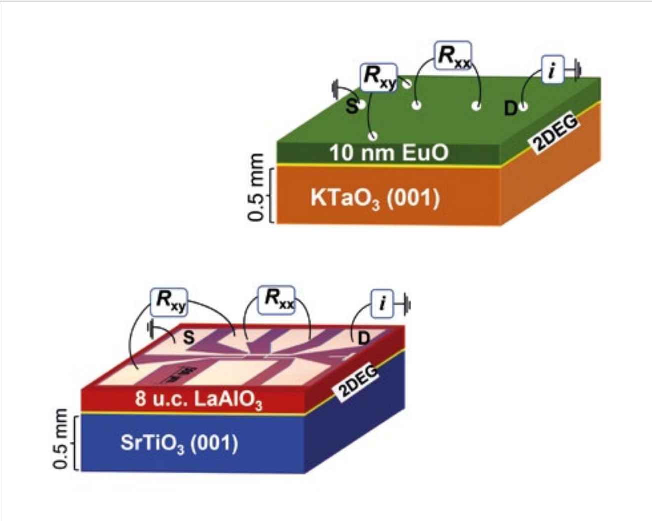
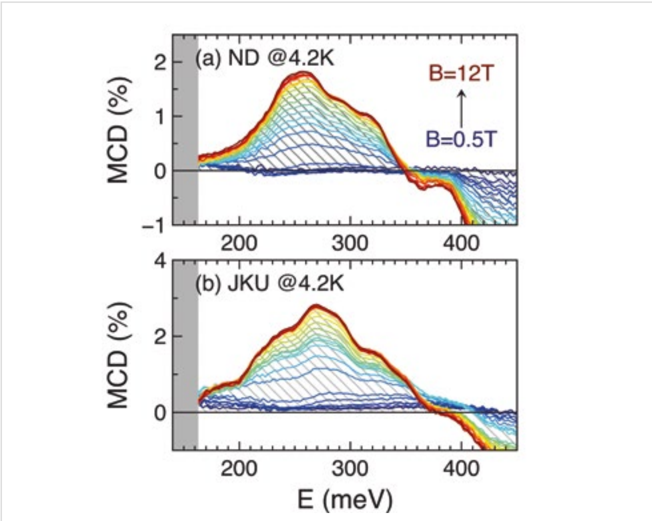
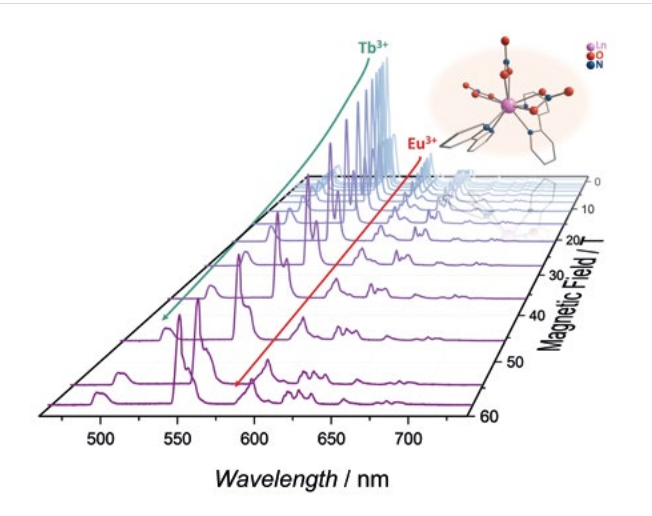
European Magnetic Field Laboratory

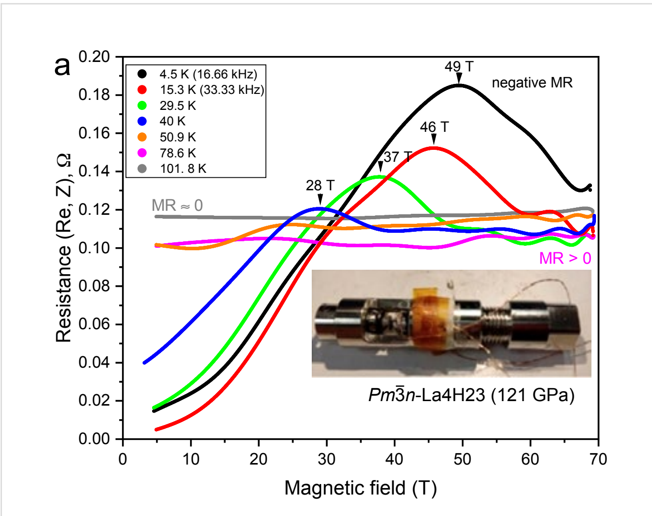
EMFLNEWS

Nº 4/24









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DEAR READER

First of all, on behalf of the entire EMFL staff, I would like to wish you all the best for the New Year, with great scientific results in high magnetic fields. At the beginning of this year, there were some personnel changes within EMFL. As usual, we had a change in the chairperson of the Board of Directors. After the excellent work of Charles Simon during the last two years, I now have the pleasure to taking over this job. Thank you, Charles!

Britta has taken on a new role as division director at DESY in Hamburg. Therefore, she is no longer director of HFML-FELIX and a member of the Board of Directors. We would like to thank her for the fantastic and very constructive collaboration within EMFL and wish her all the best in her new position. We welcome Frank Linde as a new member of the Board of Directors. He is now interim director of HFML-FELIX.

Another very pleasant development is that HFML-FELIX assured structural funding for the next 10 years and will continue its great work as world-renowned user facility within a large national partnership consisting of Radboud University, the NWO, and six other Dutch universities. That means that HFML-FELIX will move forward as a new NWO institute within the Foundation for Dutch Scientific Research Institutes NWO-I.

We further are proud to announce the successful test of the new 42 T hybrid magnet in Grenoble. This is an outstanding achievement by the team at LNCMI. Congratulations!

Of course, our users and EMFL staff produced also a lot of great science. Four highlight examples follow on the next pages. You further may find information on the outcome of the last call for access and our activities in transfer and industry cooperation.

Finally, you may mark the date of the next user meeting in your calendar: We plan this meeting for June 17, 2025, in Lecce, Italy. The Selection Committee meeting will take place the day before.
Enjoy reading,

Jochen Wosnitza
Director HLD, Chairman EMFL

MEET OUR PEOPLE

Ana Kurtanidze, HLD

I recently joined the Dresden High Magnetic Field Laboratory (HLD) as a PhD student. My journey in physics began at Ivane Javakhishvili Tbilisi State University and continued at the Andronikashvili Institute of Physics in Georgia. Under the supervision of Professor Alexandre Shengelaya, I worked on high-temperature superconductors, which introduced me to the fascinating world of superconductivity. Being part of an exceptional research group deepened my passion for science. After completing my Master's degree, I undertook a short internship at the Paul Scherrer Institute in Switzerland under Dr. Zurab Guguchia, who broadened my horizons.

In my quest for continuous development, I applied to the EMFL Spring School and had the great pleasure of participating. It was an invaluable experience. The lectures by renowned experts in condensed-matter physics were inspiring and meeting leading scientists, including Nobel laureate Klaus von Klitzing, was a highlight. What made the School especially meaningful for me was visiting the HLD in Dresden. From the moment I arrived, I knew this was where I envisioned my future. The cutting-edge facilities and vibrant community solidified my desire to join the HLD. After the interview, I was fortunate to be accepted for a doctoral position in the large and warm HLD family, beginning my journey into the world of high magnetic fields.

Ana Kurtanidze, HLD

I am currently involved in the HIBEF project, focusing on X-ray diffraction experiments under pulsed magnetic fields. In October, I participated in my first beamtime measurement at the European XFEL, which was a rewarding experience that reinforced my belief in the power of hard work and passion. Part of my PhD work is to study the magnetic and electronic properties of kagome magnets, exploring the interplay between magnetic order and topological electronic properties. The EMFL offers exceptional opportunities to conduct diverse experiments, essential for understanding these complex materials.

UNCONVENTIONAL ELECTRONIC STATES IN OXIDE INTERFACES

Km Rubi, NHMFL Los Alamos, USA, Walter Escoffier, LNCMI Toulouse, Uli Zeitler, HFML-FELIX Nijmegen

In the last two decades, two-dimensional electron systems (2DES) have been observed at the surfaces and interfaces of several perovskite transition-metal oxides, so-called complex oxides. In particular, the widely studied 2DESs based on $SrTiO_3$ (STO) and $KTaO_3$ (KTO) exhibit various intriguing phenomena, such as a large magnetoresistance, Rashba spin-orbit interaction, 2D superconductivity, and magnetism, which do not exist in their bulk counterparts.

In a quest to understand comprehensively the complex electronic structure in oxide interfaces that gives rise to such interesting phenomena, an international collaboration of researchers conducted a thorough experimental investigation of the Shubnikov-de Haas (SdH) oscillations at the interfaces of EuO/KTO, LAO/STO, and amorphous (α)-LAO/KTO. In order to capture the oscillations with utmost precision, the researchers performed electronic-transport experiments in high magnetic fields, utilizing both pulsed fields (60 T) at NHMFL, Los Alamos, and DC fields (35 T) at HFML-FELIX, Nijmegen, accompanied by low temperatures down to 0.5 and 0.1 K, respectively.

More specifically, by examining the tilt-angle dependence of the resistance oscillations for EuO/KTO and LAO/STO, it was possible to reveal the presence of itinerant electrons confined in the 2D interface region, coexisting with the charge carriers that disperse deeper into STO and KTO. Interestingly, all three interfaces investigated exhibit a progressive linear increase in the effective cyclotron mass as well as a quadratic increase of the SdH frequency with increasing magnetic field.

A model involving a combination of linear and parabolic dispersion relations with Zeeman interaction can explain these peculiar, but still rather universal findings. Indeed, theoretically simulated SdH oscillations support the presence of both types of dispersions and suggest the existence of nontrivial electronic states, potentially linked to the Rashba spin-orbit interaction and/or the linear dispersion along Γ-M due to spin-orbit interaction.

Our experimental findings provide a versatile model for a deeper understanding of interfaces in complex oxides and offer a promising starting point to explain similar observations in other materials exhibiting nontrivial electronic states. This includes, for example, other topological materials such as Dirac and Weyl semimetals, for which strong spin-orbit interactions are a prerequisite.

Unconventional quantum oscillations and evidence of nonparabolic electronic states in quasi-two-dimensional electron system at complex oxide interfaces, K. Rubi, D. R. Candido, M. Dumen, S. Zeng, A. Ammerlaan, F. Bangma, M. Goiran, A. Ariando, S. Chakraverty, W. Escoffier, U. Zeitler, and N. Harrison, Phys. Rev. Research **6**, 043231 (2024).

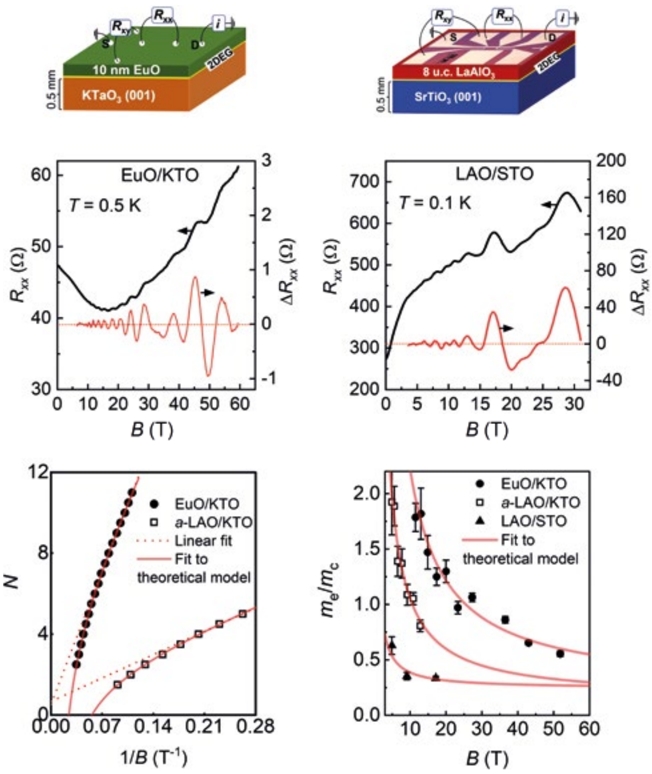

Figure: (Top) Schematics of the two heterostructures used, EuO/KTO (left) and LAO/STO (right).
(Middle) Longitudinal resistance, Rxx (B) for the two structures. The red lines show the oscillatory contribution after background subtraction.
(Bottom) Non-linear Landau plots (left) and cyclotron-mass enhancement with field (right), described using a theoretical model, which suggests the existence of non-trivial electronic states in both STO- and KTO-based interfaces.

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PROBING BERRY CURVATURE IN A MAGNETIC TOPOLOGICAL INSULATOR USING MAGNETO-OPTICS

Badih Assaf, University of Notre Dame, USA, Milan Orlita, LNCMI-Grenoble

Magnetic circular dichroism (MCD) is a widely known phenomenon with a long history in physics that dates back to the original experiments carried out by Faraday, dealing with the interaction of light with matter subjected to an externally applied magnetic field. It refers to preferential absorption of one of two circular polarizations of light propagating in the direction of the magnetic field. In solids, MCD often arises as a direct consequence of the Zeeman splitting of electronic bands. However, it can also originate purely from orbital effects, such as the cyclotron motion of electrons.

Recently, a broad consortium of researchers from USA, Austria, Belgium, and France performed infrared MCD studies on thin bulk layers of $MnBi_2Te_4$. This material had previously been identified as the very first experimentally realized intrinsic antiferromagnetic topological insulator, characterized by a significant exchange-driven gap in its surface states. Moreover, $MnBi_2Te_4$ may host a diverse range of magnetic and topological phases, depending on specific parameters such as strain, layer thickness, and applied magnetic field. As a result, $MnBi_2Te_4$ has emerged as a platform for experimentally exploring intriguing theoretical predictions for this class of materials, including the quantum anomalous Hall effect and the axion insulator phase.

In this study, the team investigated MCD in thin $MnBi_2Te_4$ films at low temperatures within the infrared spectral range, around the absorption edge for interband transitions that bring electrons across the bulk band gap. The MCD signal, absent at low magnetic fields in the antiferromagnetic state of $MnBi_2Te_4$, emerged during the magnetic-field-driven phase transition to the canted ferromagnetic state (figure). This observation was attributed to the abrupt onset of Berry curvature as $MnBi_2Te_4$ transitions from an antiferromagnetic topological insulator to a doped Chern insulator. These findings highlight the potential of MCD as an effective probe for exploring Berry curvature in other emerging magnetic topological materials.

Probing Berry curvature in magnetic topological insulators through resonant infrared magnetic circular dichroism, S.-K. Bac, F. Le Mardelé, J. Wang, M. Ozerov, K. Yoshimura, I. Mohelský, X. Sun, B. A. Piot, S. Wimmer, A. Ney, T. Orlova, M. Zhukovskyi, G. Bauer, G. Springholz, X. Liu, M. Orlita, K. Park, Y.-T. Hsu, and B. A. Assaf, Phys. Rev. Lett. **134**, 016601 (2025).

Figure: MCD signal for two different $MnBi_2Te_4$ samples [(a) "ND" and (b) "JKU"] as a function of energy for selected magnetic fields. (c) Spectrally integrated MCD signal for both samples as a function of magnetic field in antiferromagnetic (AFM), spin-flop (SF), canted, and ferromagnetic (FM) phases.

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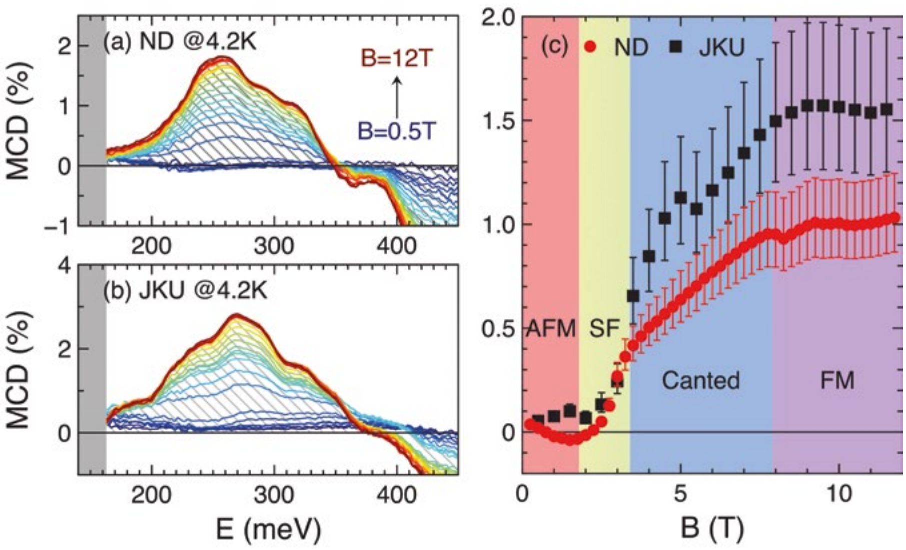

ILLUMINATING A FRONTIER: LUMINESCENT THERMOMETERS IN EXTREME MAGNETIC FIELDS

Jérôme Long, ICGM, Montpellier, France, Luís D. Carlos, University of Aveiro, Portugal, Paulina Plochocka, LNCMI Toulouse

Luminescence thermometry has gained significant attention as a versatile and non-invasive tool for remote temperature measurements in diverse fields, including nanomedicine, microelectronics, catalysis, and plasmonics. One of its perceived advantages is the presumed immunity to strong electromagnetic fields, making it seemingly ideal for use in environments, where conventional thermometers fail. However, this assumption lacks experimental validation, particularly for thermometers that rely on magnetic ions, such as lanthanides, which are known for their strong interaction with magnetic fields. Addressing this gap, our study investigates the thermometric performance of the molecular thermometer $[Tb_{0.93}Eu_{0.07}(bpy)_2(NO_3)_3]$ (bpy = 2,2'-bipyridine) under pulsed magnetic fields reaching up to 58 T.

Using a unique setup in LNCMI-Toulouse, we explored its luminescent response across a broad temperature range (2 – 290 K) and varying magnetic field strengths (up to 58 T). The widely utilized Tb^{3+} and Eu^{3+} emission transitions ($^5D_4 \rightarrow {}^7F_5$ and $^5D_0 \rightarrow {}^7F_2$), highlighted in the figure, which are typically employed to define thermometric parameters, were found to exhibit significant correlations with both temperature and magnetic fields. This thermo-magnetic dependence compromised their reliability for accurate temperature sensing, even under relatively weak magnetic fields. To address this challenge, we employed Pearson correlation analysis to identify alternative electronic transitions that demonstrated minimal sensitivity to magnetic fields. This innovative approach allowed us to establish a new thermometric parameter capable of reliable temperature measurements in fields up to 20 T. Moreover, at temperatures exceeding 120 K, the molecular thermometer maintained operability under even stronger magnetic fields.

This work represents the first systematic evaluation of a luminescent-thermometer performance in extreme magnetic-field conditions, challenging the long-held belief in magnetic immunity. It highlights the material-specific nature of thermometric behavior and offers a robust framework for developing next-generation thermometers suited for high-magnetic-field environments.

Rethinking assumptions: Assessing the impact of strong magnetic fields on luminescence thermometry. M. Aragon-Alberti, M. Dyksik, C. D. S. Brites, J. Rouquette, P. Plochocka, L. D. Carlos, and J. Long, J. Am. Chem. Soc. **146**, 33723 (2024).

Figure: Magnetic-field dependence of the luminescence of a molecular thermometer (shown in the inset).

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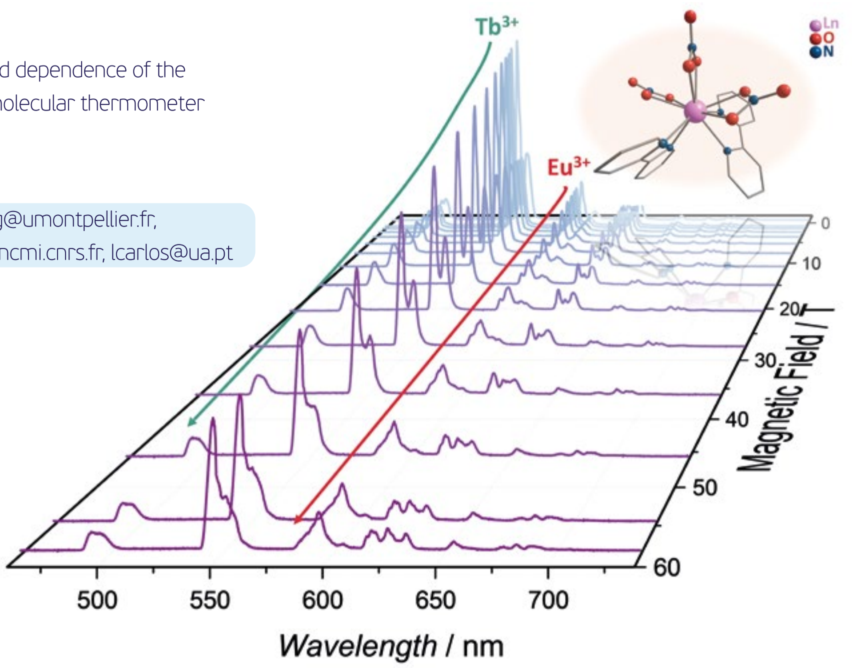
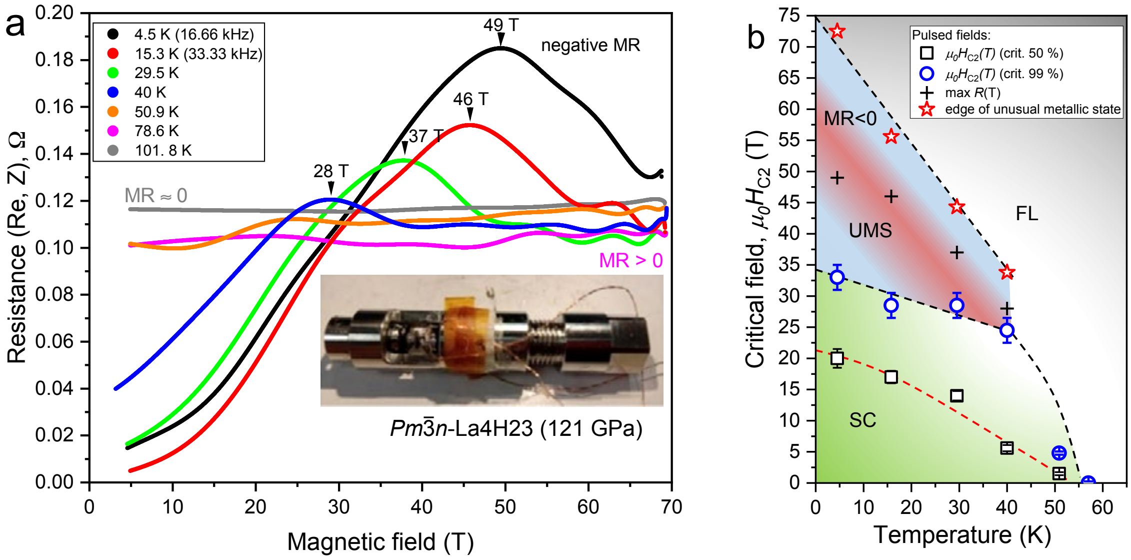


UNUSUAL METALLIC STATE IN SUPERCONDUCTING A15-TYPE LA4H23

Toni Helm, HLD

Superhydrides are metallic hydride compounds that exhibit superconductivity (SC) under mega-bar pressure at extraordinarily high temperatures. The observation of superconducting critical temperatures, T_c, as high as 250 K has revived scientists' dream of room-temperature superconductivity. While current research has focused on pushing T_c even higher, room-temperature applications based on hydride SC are limited by the small sample space and extreme condition inside the required diamond-anvil pressure cells (figure).



The basic mechanism behind the superconductivity in superhydrides is believed to be conventional in nature, i.e., Cooper pairs may form with the help of phonons, according to the Bardeen-Cooper-Schrieffer (BCS) theory. Nevertheless, among the ever-growing family members of superhydrides (to date, more than 20 compounds are known) also rather unusual behavior is observed that contradicts conventional theories.

An international team of researchers has looked into the rather unusual normal-state properties of the superhydride La_4H_{23} with the help of pulsed magnetic field up to 70 T. The study reports experimental evidence for an unusual metallic state in a newly synthesized hydride, cubic A15-type La_4H_{23}, with a T_c reaching 105 K at 118 GPa. Below 40 K, the researchers observed a large negative magnetoresistance in the non-superconducting state, i.e., above the critical magnetic field H_{c2}, detectable for a particular region in the magnetic phase diagram presented in the figure. The work reveals anomalous electronic properties of A15-type La_4H_{23} under high magnetic fields that hint at unconventional transport in the normal state, reminiscent of what was found in the strange-metal state of unconventional superconductors, such as the famous cuprate high-T_c superconductors. Similar unusual behavior has been reported for Ce-based superhydride compounds before. The results demonstrate the diversity of superhydrides apparently hosting physics that stretches beyond normal metallic behavior.

Figure: (a) Magnetic-field dependence of the electrical resistance of La_4H_{23} at 121 GPa. Inset: DAC used for the pulsed-field experiments. (b) Magnetic phase diagram of La_4H_{23} at 121 GPa.

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Unusual metallic state in superconducting A15-type La_4H_{23}, J. Guo, D. Semenok, G. Shutov, D. Zhou, S. Chen, Y. Wang, K. Zhang, X. Wu, S. Luther, T. Helm, X. Huang, and T. Cui, Nat. Sci. Rev. **11**, nwae149 (2024).

RESULTS OF THE 32nd CALL FOR ACCESS

The 32nd call for access ended on 15 November 2024. Until mid-December, the EMFL Selection Committee ranked the proposals on a competitive basis.

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, supported by our scientific and technical staff on site.

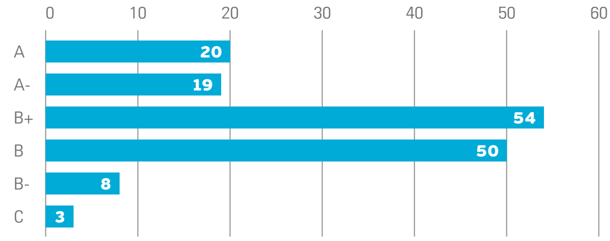
For this 32nd call, we received 154 applications from 23 countries. From these, 12 are proposals for dual access with regional partner laboratories, 4 are asking for technical-development access, and 8 for fast-track access (received between July and December 2024). 5 proposals ask for the use of high magnetic fields combined with neutron or laser sources at other large-scale facilities. Within all proposals, 21 were submitted by first-time users. 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 (45 applications),
- Magnetism (71 applications),
- Semiconductors (28 applications),
- Soft Matter and Magnetoscience (7 applications),
- Applied Superconductivity (3 applications).

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

NEXT CALL:
Launch: April 15, 2025
Deadline: May 15, 2025



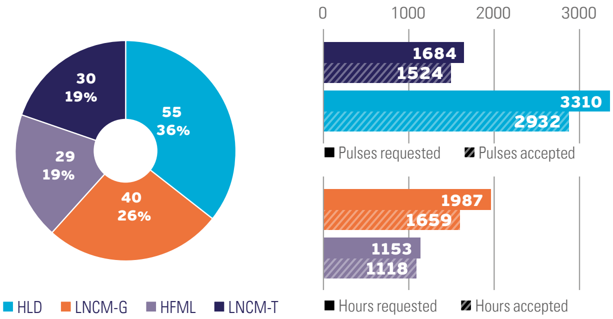
Evaluation of applications

The proposals are ranked in three classes:

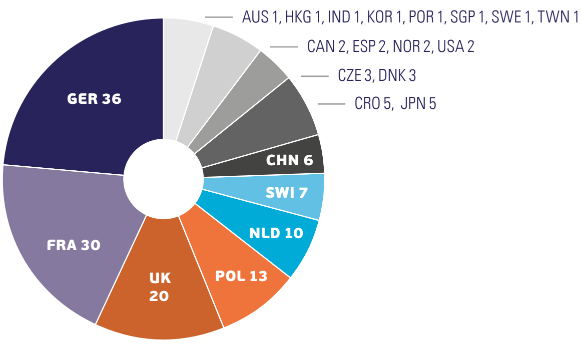
A (excellent proposal to be carried out),
B (should be performed, but each facility has some freedom considering other constraints),
C (poorly crafted proposal, or one that does not need any of the four unique high-magnetic-field facilities).

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 a successful outcome of a project.

Distribution by facilities
Number of applications



Distribution by country of PI affiliation



BRITTA REDLICH JOINS DESY AS DIRECTOR

Professor Britta Redlich has left her position as director at HFML-FELIX and as a member of the EMFL Board. As of January 1, 2025, she has taken over the prestigious new role as director of the **Photon Science division at the Helmholtz Center DESY** – Deutsches Elektronen-Synchrotron – in Hamburg, Germany.

Britta began her research as a postdoc at the German University of Münster, working at the Dutch Free-Electron Laser FELIX – at that time located at the FOM Institute Rijnhuizen near Utrecht – in the area of surface science. As staff scientist and facility manager, she was closely involved in the relocation of the FELIX facility to Radboud University in 2012/2013. She became chair and director of the FELIX laboratory and, in 2023, she also has been appointed as director of HFML and since then has lead the HFML-FELIX laboratory in Nijmegen.

Under her leadership, this laboratory has further put itself on the map nationally and internationally. As director of HFML-FELIX, Britta has been committed to the integration of both laboratories and the acquisition of a healthy operational and financial basis. By doing so, she formed a strong foundation for a flourishing research with high-field magnets and infrared/THz free-electron lasers. The proposed decision to establish an NWO institute gives HFML-FELIX a bright future and is the crowning glory of her work.

We owe Britta many thanks for the great work for EMFL. We wish her every success in her new role at DESY.

As of January 1, 2025, Professor Frank Linde has been appointed interim director of HFML-FELIX. He will also be a member of the Board of Directors of EMFL.

Professor Britta Redlich

LNCMI'S HYBRID MAGNET REACHES 42 TESLA

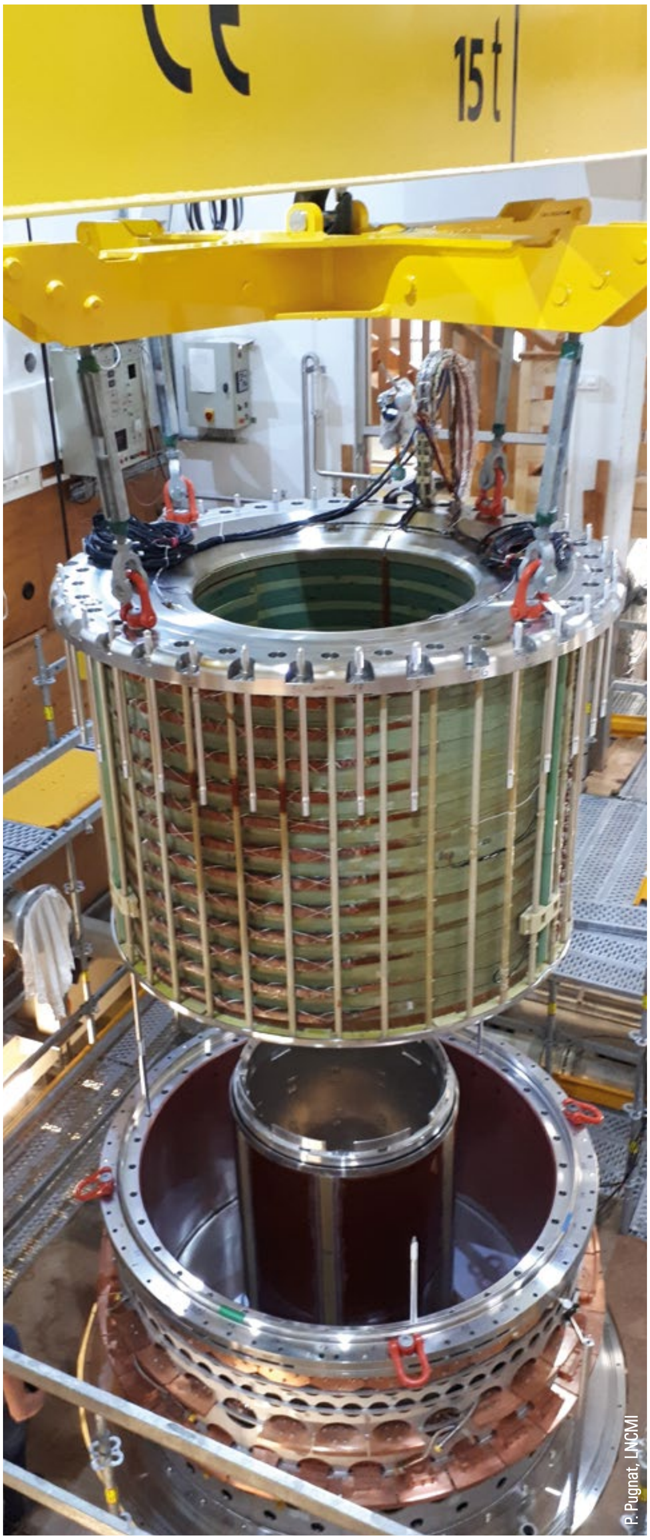
The hybrid magnet at the LNCMI in Grenoble is now reaching 42 T. This is the first time that a team of engineers and researchers achieved such high magnetic field in Europe by combining a superconducting coil and copper-alloy electromagnets. In a few months' time, LNCMI will make this magnet available to scientists at the European Magnetic Field Laboratory.

On 8 November 2024, the Equipex LASUP of the Laboratoire National des Champs Magnétiques Intenses (LNCMI, CNRS) achieved one of its objectives: The team created a continuous magnetic field of 42 T for around ten minutes in a coil with a bore of 34 mm in diameter. This achievement, the fruit of many years of dedicated work, means that the LNCMI joins the podium of the world's laboratories offering fields of more than 40 T, alongside with the US laboratory in Tallahassee and the Chinese laboratory in Hefei. Experiments with around 45 T in boreholes with a diameter of 32 mm are possible there.

The Grenoble magnet will be open to users of the EMFL in a few months' time in the usual biannual frame of open calls for projects. It will enable research teams in the need for very high magnetic fields to carry out their experiments. Today, such strong magnetic fields are essential for studying advanced materials in the fields of information technology, magnetic resonance imaging, energy materials (batteries, solar panels, etc.), and quantum technologies.

Optimized to reduce its carbon footprint, this hybrid magnet uses a superconducting part with an internal diameter of 1100 mm (8.5 T) and a resistive part (33.5 T). The resistive magnet benefits from the long-standing expertise at LNCMI, in particular in power supply, which is unique in the world because of its ability to operate for very long durations, as well as in magnetic cooling in terms of hybrid magnets cooled with pressurized superfluid helium.

European partners took part in the project, including CEA Saclay (design of the superconducting part, protection system for the superconducting coil), the French companies SDMS and CRYO DIFFUSION (production of the cryostat and cryogenic lines), and the German companies BRUKER and BILFINGER (production of the superconducting cable and the superconducting coil).



P. Pugnat, LNCMI

› Insertion of the superconducting coil of the hybrid magnet in its cryostat at LNCMI-Grenoble.

EMFL AT TRADE FAIRS AND INDUSTRIAL EVENTS

Members of the European Magnetic Field Laboratory went to various trade fairs and events in 2024 to meet our current and make contacts to future industrial partners. In July, we sponsored the workshop "Cryogenic Operations" (Cryo-Ops) in Grenoble. This three-day event welcomed around 80 participants. We were able to meet many of the cryogenics experts from around the world as well as to present our own expertise in this research area. We further used the opportunity to invite the participants to visit the Laboratoire National des Champs Magnétiques Intenses in Grenoble.

October 2024 was a busy month, with EMFL being part in two large trade fairs, one in Trieste, Italy, and one in Paris, France.

Every two years, the "Big Science Business Forum" (BSBF) takes place. The third edition in Trieste, from October 1 to 4, welcomed over 1300 participants from 500 organizations. During this event, 245 exhibitors and 14 national pavilions from thirty-two countries presented their science-related expertise in 163 stands. The EMFL had a stand, where the Industrial Liaison Officer and ISABEL project manager, Inès Dupon-Lahitte, and SuperEMFL project manager, Eleonora Sartori, were able to represent the EMFL and answer the questions of interested participants. BSBF 2024 also offered a platform to allow its participants to have business-to-business (B2B) meetings. Thanks to this, it was possible to showcase the EMFL in detail to numerous Big Science actors.

Finally, the EMFL was also present at this year's edition of the Rendez-vous Carnot in Massy, France. This event welcomed 1300 participants and, thanks to the B2B platform, allowed for more than 4000 meetings.

Such fairs and events are always a great opportunity to meet new potential industry partners, but also to consolidate already existing and discuss future collaborations. In March 2025, EMFL will be present at the International Metrology Congress (CIM2025) in Lyon.

Inès Dupon-Lahitte, EMFL Industrial Liaison Officer and ISABEL project manager

UPCOMING EVENTS

Panoramic view of the city of Montreal from Mount Royal

1 DPG Spring Meeting of the Condensed Matter Section, Regensburg, Germany, March 16 - 21, 2025.
https://regensburg25.dpg-tagungen.de/

2 Joint March Meeting and April Meeting (APS Global Physics Summit), Anaheim, USA, March 16 - 21, 2025.
https://summit.aps.org/

3 10th International Conference on Superconductivity and Magnetism (ICSM2025) & 3rd International Conference on Quantum Materials and Technologies (ICQMT2025), Ölüdeniz-Fethiye, Turkey, April 26 - May 3, 2025.
https://icsmforever.org/

4 13th International Conference on Highly Frustrated Magnetism, Toronto, Canada, May 25 - 30, 2025.
https://conference.physics.utoronto.ca/event/18/

5 International Conference on Magnet Technology (MT29), Boston, USA, July 1 - 6, 2025.
https://mt29-conf.org/

6 International Conference on Strongly Correlated Electron Systems (SCES 2025), Montréal, Canada, July 6 - 11, 2025.
https://sces2025.org

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

8 50th International Conference on Infrared, Millimeter, and Terahertz Waves (IRMMW-THz 2025), Espoo, Finland, August 17 - 22, 2025.
https://www.irmmw-thz.org/venue/

9 Joint European Magnetic Symposia (JEMS), Frankfurt, Germany, August 24 - 29, 2025.
https://magnetism.eu/264-jems2025.htm

10 17th European Conference on Applied Superconductivity, Porto, Portugal, September 21 - 25, 2025.
https://eucas2025.esas.org/

11 16th International Symposium on Crystalline Organic Metals, Superconductors and Magnets (ISCOM 2025), Toyohashi/Okazaki, Japan, September 28 - October 3, 2025.
https://registration.ims.ac.jp/iscom2025/home

HFML-FELIX || RESEARCH

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

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