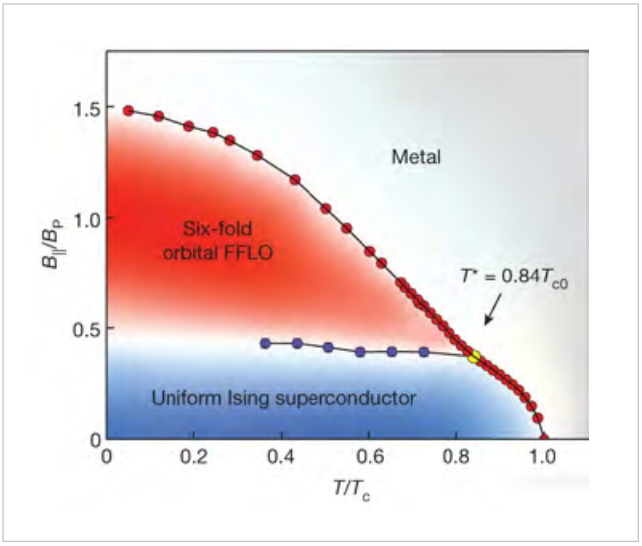
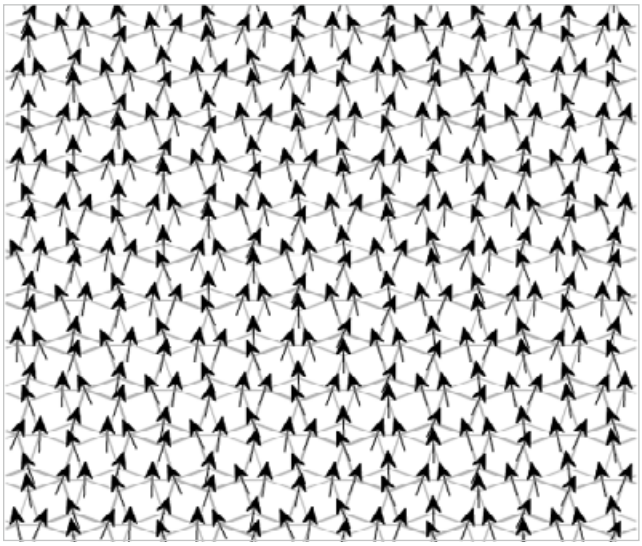
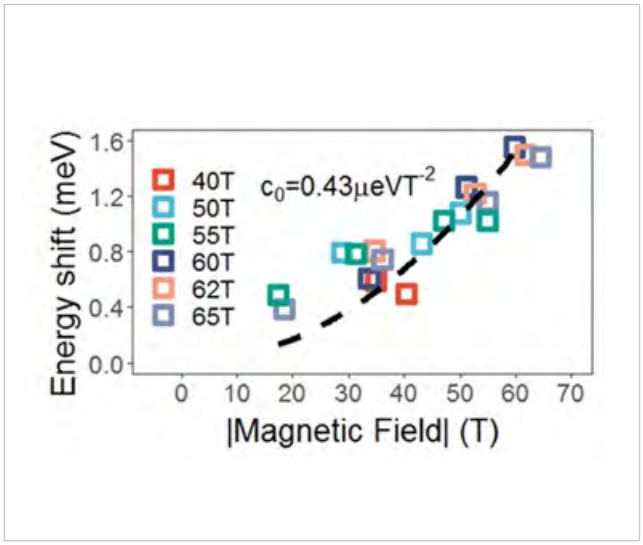
European Magnetic Field Laboratory

EMFLNEWS

N°2 2023







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DEAR READER

This issue of EMFLNews is once again an opportunity to share recent news with you. At the annual council meeting with our members, they congratulated us on our excellent scientific results for 2022. Indeed, after the COVID years which had a major impact on travel and, therefore, on the use of our research infrastructures, 2022 saw a resumption of sustained activity similar to that prior to 2020.

In 2023, new difficulties appeared with the European supply crisis of energy in general and electricity in particular. We reacted very quickly and recently secured funding for a European research program (FlexRICAN). This program, piloted by ESS (European Spallation Source) and ELI (Extreme Ligth Infrastructure), is looking into the systematic use of the flexibility of our resistive installations to adapt to the supply and demand of electricity grids. It is also dealing with the optimization of energy resources in general.

Further, we are pleased to announce that Italy will become a new EMFL member soon. We extend a warm welcome to all our Italian users. Indeed, we are planning the next user meeting to be organized in Italy in June 2024. During the EMFL user meeting, held this year in Nijmegen, we awarded the EMFL prize to Jake Ayres, whom I would like to congratulate once again for reflecting so well the high quality of our young users.

The outcome of the June 2023 call for projects is very positive, with many new experimental proposals submitted. The call for secondments in May 2023 was also highly competitive. We will soon announce a new call for secondments.

This issue is also an opportunity to present our partnership with Oxford Instrument.

I wish you all a nice summer,

Charles Simon
Director LNCMI
Chairman EMFL

MEET OUR PEOPLE

Thierry Lemaire, LNCMI Toulouse

I am currently assistant engineer in the pulsed-field generator team at LNCMI Toulouse.

I studied at the Déodat-de-Séverac high school in Toulouse electrotechnique achieving a BTS (brevet de technicien supérieur) diploma.

Within large industrial companies, such as Vinci, Clemessy, and Spie, I have spent part of my career as a technician in the Airbus Industries test-facility laboratory, carrying out curative and preventive maintenance studies and implementation. I was involved in works on improvements of industrial systems, then as industrial maintenance manager on the ATR Toulouse site, and for the transport of the A380 sections at the Langon and Toulouse sites. I also worked on the means of handling at the Airbus site in Saint Eloi.

I joined the LNCMI in April 2019 in the pulsed-field generator team, under the responsibility of Jêrome Beard. My main activities are the study and the production of plans, the implementation of new works, the maintenance and the retrofit of the 1 MJ, 3 MJ, and 21 MJ generators in the field of electrical engineering.

Our team received the CNRS collective crystal medal in 2022 for the renovation and modernization of the 14 MJ generator. This prize recognizes women and men of the research-support staff, who, through their creativity, technical mastery and sense of innovation, contribute alongside researchers to the advancement of knowledge and to the excellence of EMFL research.

› *Thierry Lemaire*

ORBITAL HIGH-FIELD FFLO STATE IN ISING SUPERCONDUCTOR

Oleksandr Zheliuk, HFML Nijmegen

Scientists from the University of Groningen, together with colleagues from HFML Nijmegen, the University of Twente, and the Harbin Institute of Technology (China), have discovered the existence of a superconducting state that was first predicted in 2017. In particular, they present evidence for a special variant of the so-called Fulde–Ferrell–Larkin–Ovchinnikov (FFLO) superconducting state, a discovery that could have significant applications in the field of superconducting electronics.

To create the FFLO state – with a real-space variation in the pairing gap – in a conventional superconductor, a strong magnetic field is needed. But, the role played by the magnetic field needs careful tweaking. Typically, the FFLO state relies on the Zeeman effect that separates electrons in Cooper pairs based on the direction of their spins (magnetic moment). The orbital effect - the other role that normally destroys superconductivity – has previously thought to play no substantive role for the observation of an FFLO state.

In an Ising superconductor with strong spin-orbit coupling, however, the Zeeman effect is suppressed and the in-plane upper critical field B_{c2} will be determined in principle by orbital effects. This work provides a first clear fingerprint of an orbitally driven FFLO state in an Ising superconductor. The FFLO state in conventional superconductors requires low temperatures and a very strong magnetic field, which makes it difficult to create. However, in an Ising superconductor, the state is reached with a weaker magnetic field and at higher temperatures. The high magnetic fields at HFML-EMFL were nevertheless important to enable researchers to establish the full phase diagram of this novel phenomenon.

This new superconducting state still needs further investigation, however. For example, how does the kinetic momentum influence the physical parameters? Studying this state will provide new insights into superconductivity and may ultimately allow to control this state in devices such as transistors.

Apart from its scientific importance, this work is also a nice example of an efficient international collaboration at an EMFL laboratory. State-of-the art devices processed in Groningen were brought to the high-field installation in Nijmegen, which allowed the researchers to explore the peculiar phase diagram of this superconductor at magnetic fields above 20 T, where the superconductivity is destroyed, providing convincing proof for the existence of FFLO state in the absence of strong Zeeman effects.

Finally, the findings of this work, namely that the presence of Ising spin-orbit coupling in combination with an in-plane magnetic field shifts the transition to the FFLO state closer to the critical temperature and lower fields, may allow easier access to this exotic state for other experimental groups.

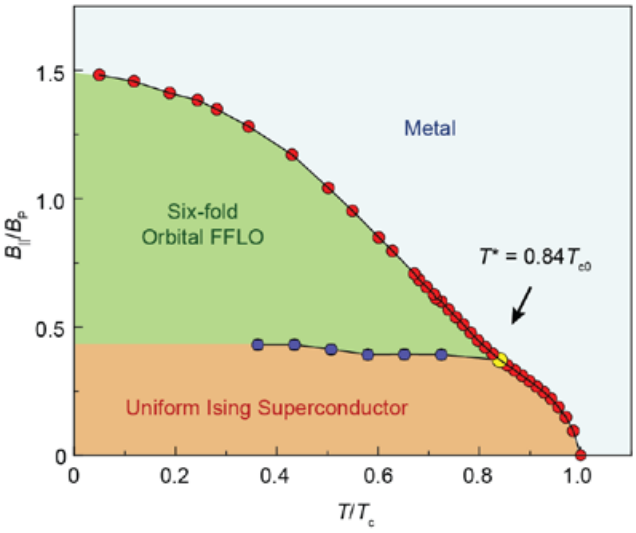

Figure: Phase diagram of the orbital FFLO state as determined from the temperature and field dependence of B_{c2} in a parallel magnetic field.

Orbital Fulde–Ferrell–Larkin–Ovchinnikov state in an Ising superconductor, P. Wan, O. Zheliuk, N. F. Q. Yuan, X. Peng, L. Zhang, M. Liang, U. Zeitler, S. Wiedmann, N. E. Hussey, T. T. M. Palstra, and J. Ye, Nature **619**, 46 (2023).

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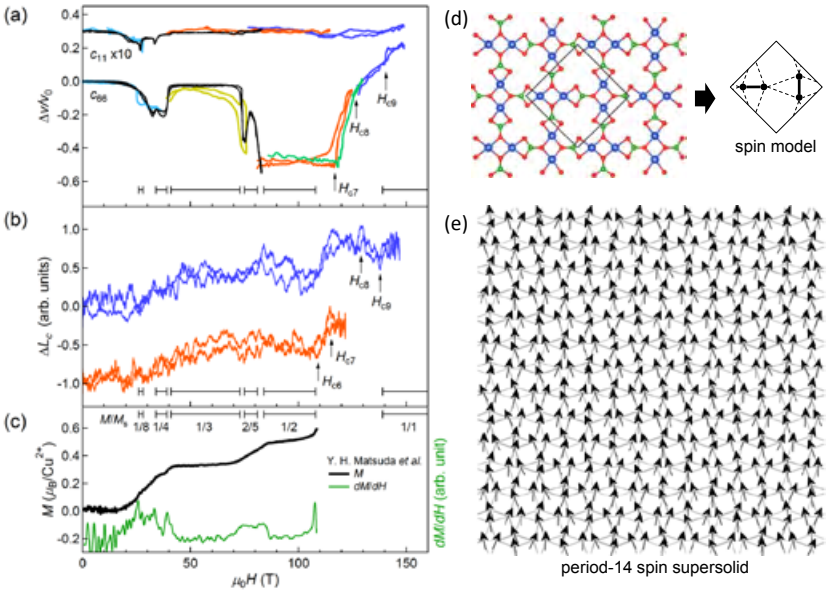
UNVEILING NEW QUANTUM PHASES IN THE SHASTRY-SUTHERLAND COMPOUND $SrCu_2(BO_3)_2$

Sergei Zherlitsyn, HLD Dresden

By investigating the Shastry-Sutherland compound $SrCu_2(BO_3)_2$ up to the saturation magnetic field of 140 T and beyond, researchers from Japan, the Netherlands, and Switzerland together with scientists from the HLD have succeeded in identifying several spin-supersolid phases (SSPs) between the 1/2 magnetization plateau and saturation (1/1 plateau). The SSPs simultaneously break translational symmetry and the U(1) symmetry associated with the total S_z conservation. They all exhibit a diagonal stripe pattern with a certain period.

The spin-lattice coupling plays an important role for the high-field properties of $SrCu_2(BO_3)_2$. In this study, the researchers performed ultrasound and magnetostriction experiments, combined with the advanced high-magnetic-field generation equipment at the HLD-EMFL and at the ISSP of the University of Tokyo. They further supported their experimental data by extensive tensor-network calculations. They detected multiple anomalies in their experiments (Figure 1). Quite remarkably, the sound velocity of the 1/2 plateau exhibits a drastic decrease of -50 % (Figure 1a), related to a tetragonal-to-orthorhombic instability of the checkerboard-type magnon crystal. The magnetostriction results exhibit features similar to those of the magnetization; both start to increase when the spin gap closes (~ 25 T) and stay approximately constant in the plateau phases (Figures 1b and 1c).

The unveiled nature of this paradigmatic quantum system is a new milestone for exploring exotic quantum states of matter emerging under extreme conditions. The very good agreement between theory and experiment regarding the saturation field and other critical fields demonstrates how these cutting-edge studies contribute to our better understanding of complex quantum systems. This establishes the combination of ultrasound and magnetostriction measurements with pulsed fields up to 150 T as a rather unique source of information in a field range scarcely explored so far. This opens very interesting perspectives for the study of other quantum magnets and, more generally, of other strongly correlated materials with exotic magnetic properties at ultrahigh magnetic fields.



› Figure: Ultrahigh-field data (H // c) obtained in $SrCu_2(BO_3)_2$: (a) sound velocity, (b) magnetostriction, and (c) magnetization. (d) Crystal structure in the ab plane with the dimer configuration built by Cu^{2+} ions with spin S = 1/2. (e) Spin pattern of the spin-supersolid state between H_{c8} and H_{c9}, just below saturation. The bars represent the regions of magnetization plateaus.

Unveiling new quantum phases in the Shastry-Sutherland compound $SrCu_2(BO_3)_2$ up to the saturation magnetic field, T. Nomura, P. Corboz, A. Miyata, S. Zherlitsyn, Y. Ishii, Y. Kohama, Y. H. Matsuda, A. Ikeda, C. Zhong, H. Kageyama, and F. Mila, Nat. Commun. **14**, 3769 (2023).

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LAYERED BiOI SINGLE CRYSTALS CAPABLE OF DETECTING LOW DOSE RATES OF X-RAYS

Robert A. Jagt, Bartomeu Monserrat, Judith L. MacManus-Driscoll, Robert L. Z. Hoye, University of Cambridge, UK and Paulina Płochocka, LNCMI Toulouse

Modern advances in x-ray imaging have greatly improved the quality of medical care. The ability to detect low doses of x-rays is critical to the development of safe radiological tools, but available absorber materials have their limitations. Reducing the x-ray dose would not only minimize harm to patients, but also enable innovative applications such as x-ray video techniques.

The ideal material for x-ray absorption should have a high effective atomic mass (Z) and mass density, a long charge-carrier drift length, and a low and stable dark-current density. Recently, metal-halide perovskites have shown promising properties for x-ray detection. However, lead-halide perovskites suffer from ion migration and contain toxic lead. Bismuth-based double perovskites, on the other hand, suffer from low charge-carrier drift lengths due to an exciton self-trapping effect.

In this work, we demonstrated the enormous potential of bismuth oxyiodide (BiOI) for x-ray detection. Bismuth oxyiodides are two-dimensional layered crystals in which slabs of [I–Bi–O–Bi–I] are connected by van der Waals forces (Figure 1a). This material has a high effective Z number and density, resulting in strong x-ray attenuation. Extensive spectroscopic and magneto-optical measurements, as well as first-principles calculations, allow us to elucidate why this material also exhibits a significant drift length, which is essential for x-ray detectors. While photoexcited charge carriers structurally deform the lattice, they form delocalized large polarons instead of self-capturing excitons or small polarons common in other halide compounds.

To study the radial expansion of the exciton, we performed transmission experiments in the presence of strong magnetic fields of up to 65 T. By analyzing the shift of the absorption edge as a function of the magnetic field, we determined the coefficient for the diamagnetic shift and derived the radial expansion of the 1-s exciton (Figure 1b). This gave a diamagnetic shift coefficient of 0.43 μeVT^{-2}, resulting in an r.m.s. radius of the 1-s exciton of 15.3 Å. These values are comparable to those of other layered materials (e.g., WS_2) and support the two-dimensional Wannier exciton nature, which span multiple unit cells within the plane. The photophysical principles discussed in this study provide novel design opportunities for materials containing heavy elements and low-dimensional electronic structures for x-ray detectors.

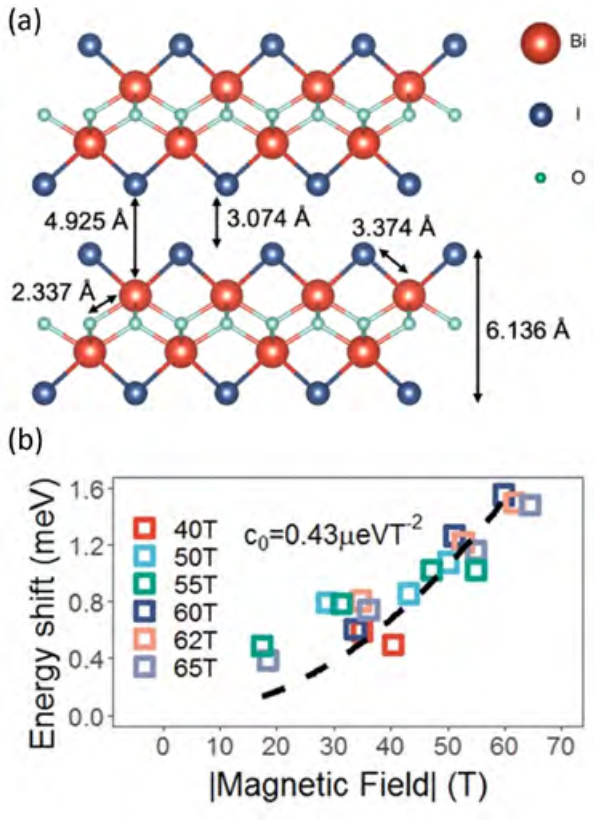

Figure: (a) BiOI lattice structure. (b) Change in absorption edge as a function of magnetic field strength.

Layered BiOI single crystals capable of detecting low dose rates of X-rays, R.A. Jagt, I. Bravić, L. Eyre, K. Gałkowski, J. Borowiec, K. Reddy Dudipala, M. Baranowski, M. Dyksik, T. W. J. van de Goor, T. Kreouzis, M. Xiao, A.Bevan, P. Płochocka, S. D. Stranks, F. Deschler, B. Monserrat, J. L. MacManus-Driscoll, and R. L. Z. Hoye, Nat. Commun. **14**, 2452 (2023).

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OUTCOME OF THE TWENTY-NINTH CALL FOR ACCESS

On 15 May 2023, the 29th call for access to the EMFL facilities ended. Mid June, the 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, supplemented by the necessary support from the scientific and technical staff on site.

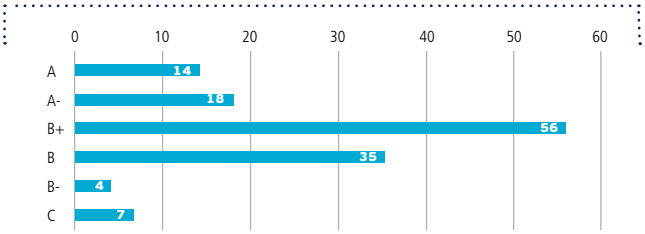
For this 29th call, 134 applications were submitted, of which 8 are proposals for dual access with regional partner laboratories, 10 for fast-track access, and 21 proposals for first-time access to the EMFL high-field facilities. These novel access procedures are introduced within the EMFL-ISABEL project.

The proposals came from 22 different countries and were evaluated by the EMFL Selection Committee on 13 June 2023. The Selection Committee consists of 18 specialists covering the following five scientific topics:

> Metals and Superconductors (46 applications),
> Magnetism (52 applications),
> Semiconductors (30 applications),
> Soft Matter and Magnetoscience (3 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: October 15, 2023
Deadline: November 15, 2023



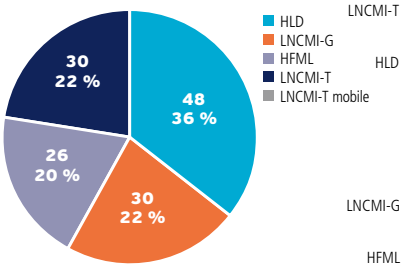
Evaluation of applications

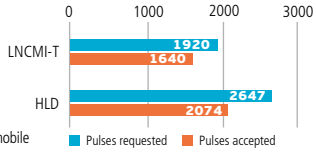
The proposals are ranked in three classes:

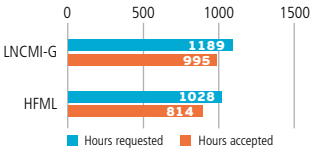
A (excellent proposal to be carried out),
B (should be performed but each facility has some freedom considering other constraints),
C (poorly crafted proposal, or one that does not need any of the four unique high-magnetic-field laboratories).

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.

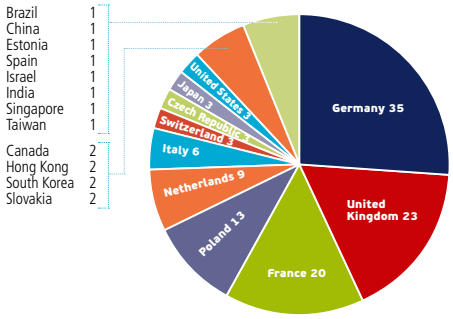
Distribution by facilities
Number of applications







Distribution by country of PI affiliation



CONFERENCES IN GRENOBLE: EP2DS-25 AND MSS-21

The 25th International Conference on the Electronic Properties of Two-Dimensional Systems (EP2DS-25) and the 21st International Conference on Modulated Semiconductor Structures (MSS-21) were held from 9 to 14 July in the World Trade Center in downtown Grenoble. The city is considered the cradle of the quantum Hall effect, typical of two-dimensional systems and discovered in 1980 at the high magnetic field laboratory in Grenoble (GHMFL), at the time a German-French cooperation between MPI-FKF (Max-Planck-Institut für Festkörperforschung in Stuttgart) and CNRS. The two conferences were jointly organized by colleagues from the LNCMI in Grenoble, with shared plenary and poster sessions. During the conferences, more than 340 scientists from 24 countries spent five days discussing the latest advances concerning our knowledge of 2D electronic systems. The rich and representative program covered progress of the fundamental understanding, as well as in synthesis, processing, characterization, and applications, of a broad range of low-dimensional electronic systems. These include semiconductor quantum wells/wires/dots, two-dimensional materials such as graphene, transition-metal dichalcogenides, magnetic and ferroelectric van der Waals materials, topological insulators, as well as hybrid systems.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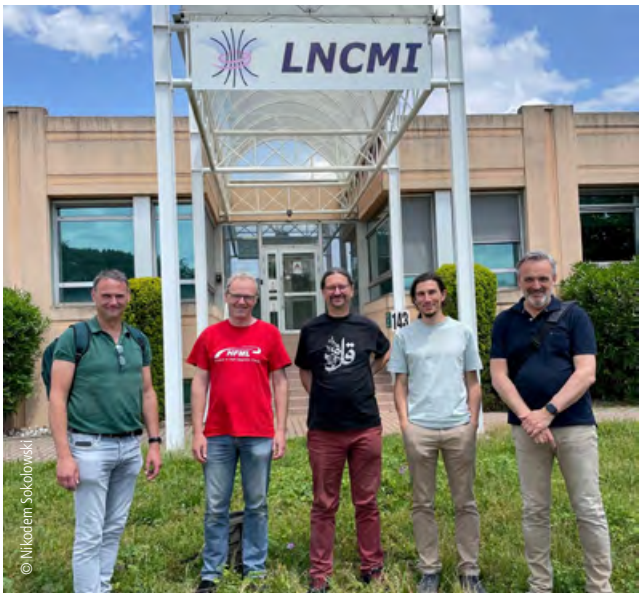
HFML EXCHANGE VISIT AT LNCMI-TOULOUSE

In May 2023, the HFML-FELIX technical user support group, Peter Albers, Lijnis Nelemans and Michel Peters, from Nijmegen visited the LNCMI pulsed-field facility in Toulouse. The aim was the exchange of knowledge on various magnet and measurement technologies between the two laboratories.

Scientists and engineers from the LNCMI warmly welcomed the Nijmegen team and enjoyed two days of intensive discussions with their colleagues. Topics included magnet and cryostat technology, materials science, manufacturing techniques, probes, optical measurement techniques, and data acquisition. It was a very successful and entertaining visit for both sides, allowing the exchange of innovative ideas.



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EMFL USER MEETING AND WORKSHOP 2023

Steffen Wiedmann and Uli Zeitler, HFML Nijmegen

Participants of the HFML-FELIX and EMFL user meeting in Nijmegen.

The EMFL User Meeting 2023, combined with the HFML-FELIX user meeting and a workshop on the combination of high magnetic fields and THz radiation took place in Nijmegen from 13-15 June 2023. The meeting started on Tuesday afternoon with an opening statement from HFML-FELIX director Britta Redlich and a plenary talk by Steen Brøndsted Nielsen (Aarhus University) addressed to the large group of both national and international attendees interested in research combining high magnetic fields and THz radiation.

Subsequently, Charles Simon (Chair of the Board of Directors of EMFL) opened the EMFL user meeting and presented an overview of recent developments at EMFL. The EMFL prize winner 2023, Jake Ayres (University of Bristol), gave the first scientific talk.

Further, eight researchers presented on Tuesday afternoon and Wednesday morning scientific talks covering a broad range of user work performed at the EMFL facilities. The users also discussed future scientific developments and possible new magnets that would be useful to have at the EMFL facilities.

During the user meeting on Tuesday afternoon, the User Committee chaired by Raivo Stern (NICPB, Tallinn, Estonia) critically discussed user-related issues of EMFL and reported back to the Board of Directors.

After the Wednesday morning session, both user groups from EMFL and HFML-FELIX joint again for the plenary talk by Ben Murdin (University of Surrey), who addressed the combination of high magnetic fields and THz radiation and presented some recent research examples. On Wednesday afternoon and Thursday morning, a dedicated workshop (supported by the ISABEL project) on the combination of high fields and THz radiation took place. Eight speakers stressed how such a unique combination provides our field with new research possibilities. In particular, the possibilities of the existing combination HFML-FELIX in Nijmegen and HLD-FELBE in Dresden were introduced. The workshop concluded with a general discussion on combined experiments, highlighting possibilities for future exciting collaborations.

Discussion session on the combination of high magnetic fields and THz radiation chaired by Ben Murdin.

EMFL PRIZE 2023 GOES TO JAKE AYRES

Since 2009, the EMFL Board of Directors announces annually the EMFL prize for exceptional achievements in science done in high magnetic fields. An award committee selects the prize winner from the nominations received.

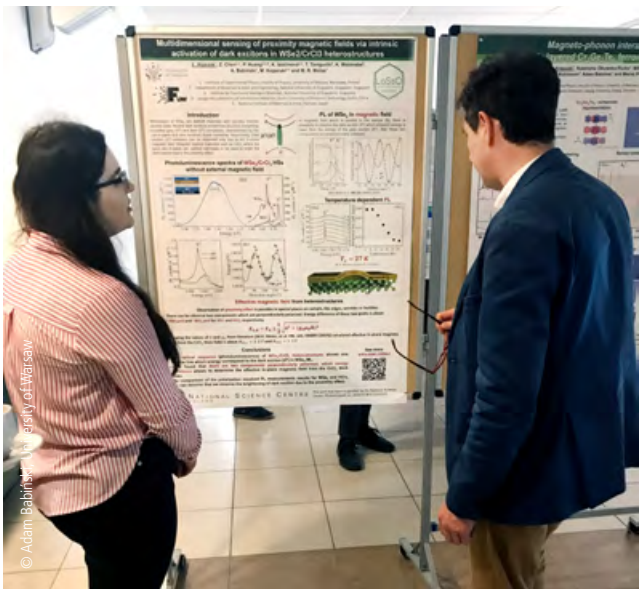
This year, the prize went to Dr. Jake Ayres, who currently holds a Leverhulme Early Career Fellowship at the University of Bristol, UK. During the user meeting in Nijmegen, Jochen Wosnitza, chair of the prize committee, had the honor of presenting the prize in a traditional small prize ceremony.

Jake Ayres, who performed his PhD work at HFML in Nijmegen, is a regular user of the EMFL facilities. His work is mainly focused on high-temperature superconductors. Significant results encompass his work on the in-plane magnetoresistance as well as the Hall effect under hydrostatic pressure of cuprate superconductors published in highly ranked journals. He further utilized the EMFL high magnetic fields to study the nematic iron-based superconductor FeSe and the nodal-line semimetal ZrSiS. In summary, Jake's substantial body of experimental work, performed at EMFL facilities, has made major advances in our understanding of unconventional superconductors.

WORKSHOP IN WROCŁAW

From 22 to 24 May 2023, the University of Warsaw and Wrocław University of Science and Technology organized the workshop „Magnetic Fields in Materials Research", with financial support from the ISABEL EU project. The meeting took place in Wrocław, Poland. The goal was to provide a forum to exchange knowledge between the Polish community of high magnetic field users involved in EMFL and other groups in Europe, both in terms of experimental opportunities and in-house research. The thematic areas covered were quite diverse including general information on the EMFL facilities but as well scientific highlights of research done using high magnetic fields, such as on two-dimensional semiconductors, topological insulators, magnetic materials, and heavy-fermion materials. Almost 30 invited speakers presented their research in a very lively atmosphere.

Numerous posters added to the relevance of the meeting and provided a unique opportunity for young researchers to discuss their results with their more experienced colleagues.



OXFORD INSTRUMENTS PROFILE

Oxford Instruments NanoScience, Tubney Wood, Abingdon, UK

Oxford Instruments plc is a leading provider of high-technology products and services to the world's leading industrial companies and scientific research communities. Our core purpose is to support our customers to address some of the globally most pressing challenges, enabling a greener economy, increased connectivity, improved health, and leaps in scientific understanding.

The Oxford Instruments NanoScience business division leverages our core technologies in low and ultra-low temperatures, high magnetic fields and system integration to provide research tools in physical science and scalable cryogenic platforms for quantum technologies. Our customers range from universities and national research facilities to quantum start-ups and global commercial entities. As such, superconducting magnet technology and the creation of high-quality and accessible high magnetic field systems continue to be an important factor.

Oxford Instruments was founded in 1959 by Sir Martin Wood to commercialize superconducting magnets and, very shortly after, dilution refrigerators. These themes of innovation continue today, as new magnet technology is developed to deliver compact magnets up to 20 Tesla and wide-angle split-pair magnets for beamlines, together with our Proteox cryogen-free dilution-refrigerator family. For example, recent magnet systems delivered include 20 T with 100 mm magnet bore for advanced low-temperature STM, 12 T/320 mm bore for axion dark-matter detection, and 15 T/250 mm bore magnets as "outserts" for a new generation of LTS/HTS all-superconducting magnets up to 32 T.

For the future, high-temperature superconductors (HTS) offer routes to compact research magnets beyond 20 T that can be accessible outside of large facilities, and Oxford Instruments recently announced a collaboration with the National MagLab's (Tallahassee, FL) Applied Superconductivity Center (ASC) for the development of high-field magnet technology directed at quantum materials discovery. Further, Oxford Instruments is a partner in the EU Horizon2020 "ISABEL" and "SuperEMFL" programs to increase access to very high-field magnets throughout Europe, and to develop the technologies for up to 40 T all-superconducting magnets. These collaborations enable the development of new analysis tools as well as the materials themselves, providing key stepping stones to new high magnetic field capability and access for physics, quantum science, and materials research.

www.oxford-instruments.com

32 T all-superconducting magnet system; image courtesy of National MagLab (NHMFL)

Cryofree® dilution-refrigerator assembly

UPCOMING EVENTS

1 Joint European Magnetic Symposia (JEMS), Madrid, Spain, August 27 – September 1, 2023.
https://www.jems2023.es/

2 16th European Conference on Applied Superconductivity, Bologna, Italy, September 3-7, 2023.
https://eucas2023.esas.org/

3 International Conference on Magnet Technology (MT-28), Aix-en-Provence, France, September 10-15, 2023.
https://mt28.aoscongres.com/

4 48th International Conference on Infrared, Millimeter, and Terahertz Waves (IRMMW-THz 2023), Montreal, Canada, September 17-22, 2023.
https://www.irmmw-thz.org/conference/

5 Magnetic Resonance of Correlated Electron Materials, Dresden, Germany, September 17-23, 2023.
https://www.ifw-dresden.de/ifw-institutes/iff/events/international-conference-on-magnetic-resonance-of-correlated-electron-materials

6 68th Annual Conference on Magnetism and Magnetic Materials (MMM 2023), Dallas, USA, October 30 - November 3, 2023.
https://magnetism.org/

7 12th International Conference on Highly Frustrated Magnetism 2024 (HFM24), Madras, India, January 8 - 13, 2024.
https://ge.iitm.ac.in/HFM-2024/

8 APS March Meeting, Minneapolis, USA, March 4-8, 2024.

9 DPG Spring Meeting of the Condensed Matter Section, Berlin, Germany, March 17-22, 2024.

10 International Conference on Magnetism (ICM2024), Bologna, Italy, June 30 - July 5, 2024.
https://www.icm2024.org/

11 International Conference on the Physics of Semiconductors (ICPS 2024), Ottawa, Canada, July 28 - August 2, 2024.

› Minneapolis

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