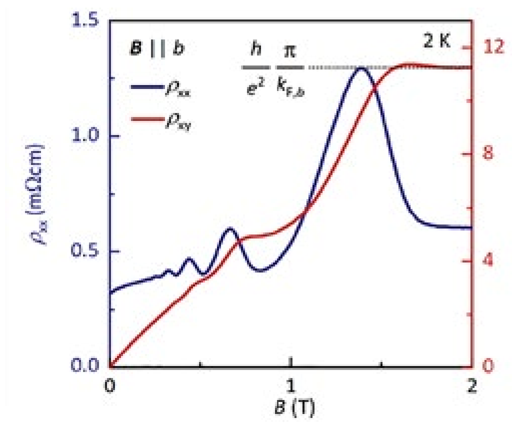
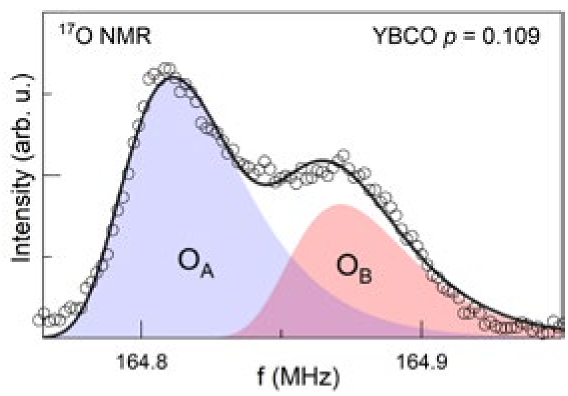
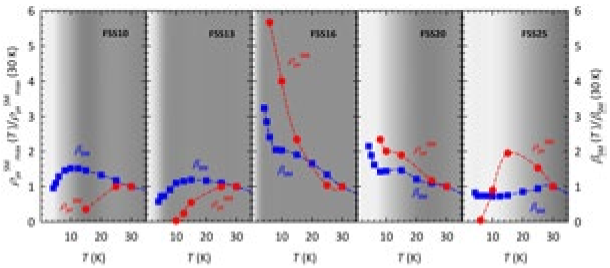
European Magnetic Field Laboratory

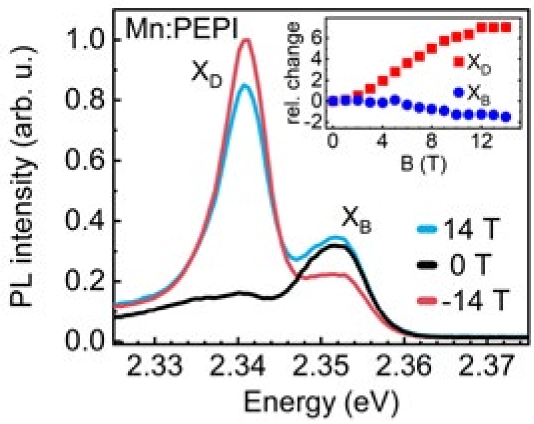
EMFLNEWS

N°2 2021









CONTENTS

DEAR READER

Due to the effects of the Corona pandemic, the 2021 EMFL User Meeting was held on-line, organized by the HLD team in Dresden. With a record number of more than 140 participants the meeting was a big success, with many very high-quality presentations of EMFL users, the presentation of the EU projects ISABEL and SuperEMFL and a well-attended user-committee meeting. And, of course, the EMFL prize attribution, which this year went to Denis Gorbunov (HLD Dresden) for his outstanding high-field work on novel magnetic materials using a variety of experimental techniques. I want to thank the entire HLD team for the excellent organization.

The next User Meeting will be organized by the LNCMI in Grenoble around mid-June 2022, where we will aim to combine the best features of both in-person and on-line meetings.

Many activities within the ISABEL and SuperEMFL projects are in full progress. Please do not forget to fill in the survey on the novel access modes and to consider the submission of a proposal in our new secondment program (deadline September 30th).

Also in this issue of EMFLNews, the presentation of one of our new regional partners: the University of Nottingham Magnetic Levitation Laboratory.

We wish you all a good holiday season and we hope to see you soon at one of the EMFL facilities.

Peter Christianen
Director HFML
Chairman EMFL

MEET OUR PEOPLE

Eleonora SARTORI, LNCMI Grenoble

I was hired by CNRS at the beginning of 2021, as European Project Manager in charge of SuperEMFL, a Horizon2020 project coordinated by LNCMI. Since I arrived in Grenoble from Milan in 2015, I have worked in similar positions, in the public as well as the private sector.

My background has been diverse and enriched by each experience I went through: From geography with a bachelor degree to urban planning with a master degree obtained in Milan. I ended my studies with an international cooperation master in Grenoble. Thanks to my proficiency level in three languages, English, French, and Italian, I could easily find a job in the international environment of European projects.

Being a project manager is like being an octopus. Coordination, administration, financial check, meeting organisation, communication, legal aspects, and editing reports. All of this is part of the job. Multitasking is a required skill to deal with consortium coordination and to guide partners in following European Commission rules and requirements and in reporting the project's scientific advancements. My everyday job is about to ensure, with the scientific coordinator, that partners work together on the research and also on non-scientific issues, like external communication about the project. I do not need to understand the scientific advancements and project's results, but I need to identify problems and help partners to solve them in order to meet European Commission obligations.

Everyone has his role to play in the project, everyone is important and I like to feel like the glue that holds the parts together. I can see collective intelligence at work in collaborative projects and I hope our project will end with a good success story!

Eleonora SARTORI, LNCMI Grenoble

STRANGE METAL TRANSPORT IN THE ELECTRONIC NEMATIC $FeSe_{1-x}S_x$

Matija Čulo, Salvatore Licciardello, and Nigel Hussey, HFML

Researchers from HFML, UK, USA, and Japan have carried out a detailed magnetotransport study of the electronic nematic superconductor $FeSe_{1-x}S_x$ that reveals key signatures of the so-called 'strange metal' behavior in vicinity of its nematic quantum critical point (QCP) $x_c \approx 0.17$. More importantly, the work points towards the co-existence of two distinct charge sectors in the normal (i.e., non-superconducting) state, a conventional (Fermi-liquid) component and a strange metal component.

The change in the electrical resistivity with temperature and magnetic field provides crucial information on the nature of charge transport within a material. In ordinary metals, resistivity scales as the square of both temperature and field. In strange metals, however, the resistivity shows a peculiar linear dependence in both quantities. The origin of this linear dependence is still not understood, though it appears to arise in metals close to a zero-temperature phase transition between ordered and disordered phases, i.e., a QCP. Until now, these two forms of magnetotransport behavior, standard quadratic and 'strange metallic' linear, have only been observed in isolation, never together, suggesting that they are associated with different limits, i.e., near or far from the QCP.

Here, the team measured both the high-field magnetoresistance and Hall response of iron chalcogenide $FeSe_{1-x}S_x$ which uniquely, as a function of sulfur doping, passes through a QCP of a pure electronic nematic origin (i.e., without accompanying magnetism). Their magnetoresistance study revealed the coexistence of both the quadratic and linear forms of the magnetoresistance; the latter evolving in a manner determined by the proximity to the nematic QCP (blue squares in figure). The Hall response was also found to comprise both the conventional and the strange component, the latter exhibiting a peculiar exponential decay at high fields and a 1/T divergence upon approach to the QCP (red circles in central panel of figure). This 1/T divergence of the Hall response provides a possible explanation for the phenomenon of (transport and Hall) lifetime separation observed in other strange metal candidates.

The combined study presents a new paradigm in the transport behavior of correlated electron systems by revealing, in contrast to common preconceptions, the possibility of the coexistence of conventional and strange charge sectors in such systems. The key step now is to understand how such dual character emerges.

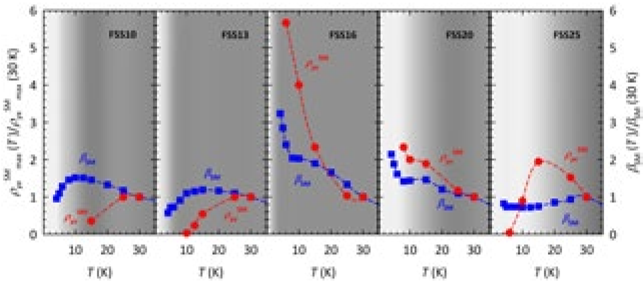


Figure: Magnetotransport properties of the strange metal (SM) component in $FeSe_{1-x}S_x$. Red circles show the T dependence of the maximum in the Hall resistivity ρ_{yx}^{SM} (H) normalized to its value at 30 K (left axis) and the blue squares represent β_{SM}, the slope of the field-linear magnetoresistance, similarly normalized (right axis). The greyscale schematically represents the exponent α in the T dependence of the resistivity $\rho(T) \propto T^{\alpha}$. Here, dark grey represents $\alpha = 1$, i.e., the 'strange metallic' linear T dependence, and white represents $\alpha = 2$, i.e., standard Fermi-liquid quadratic T dependence. Note, how both quantities peak upon approach to the nematic QCP where T-linear resistivity persists down to the lowest accessible temperatures.

Putative Hall response of the strange metal component in $FeSe_{1-x}S_x$, M. Čulo, M. Berben, Y.-T. Hsu, J. Ayres, R. D. H. Hinlopen, S. Kasahara, Y. Matsuda, T. Shibauchi, and N. E. Hussey, Phys. Rev. Research **3**, 023069 (2021).

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LOCALLY COMMENSURATE CHARGE-DENSITY WAVE WITH THREE-UNIT-CELL PERIODICITY IN $YBa_2Cu_3O_y$

Igor Vinograd and Marc-Henri Julien, LNCMI Grenoble

The ubiquity of charge-density waves (CDW) in cuprate superconductors is now well established, but the mechanism responsible for their formation remains debated. The generic aspects of the microscopic structure of the CDW are not settled yet.

In this work, we used ^{17}O nuclear magnetic resonance (NMR) to study the CDW order observed upon the application of a magnetic field in the superconducting state of $YBa_2Cu_3O_y$ (YBCO). Previous measurements have established that this CDW is long-range ordered in all three spatial dimensions ("3D") with a single propagation vector q ("unidirectional") along the crystallographic b axis (YBCO is an orthorhombic material). While x-ray scattering measurements have found that q is incommensurate, we show here that the CDW is actually commensurate at the local scale, as probed by NMR. We find a real-space periodicity of three unit cells (i.e., $\lambda = 3b$ and $q = 1/3$ in units of $2\pi/b$, where b is the lattice parameter along the b axis).

A similar dichotomy between a commensurate local and an incommensurate global propagation vector was previously reported in CDW systems such as dichalcogenides, manganites, and in a cuprate (Bi2212). The origin of this dichotomy generally lies in the presence of phase slips (so-called discommensurations) that result from the interplay between an incommensurate tendency at long length scale and a commensuration effect at short length scale. The former arises from properties of the Fermi surface and/or long-range Coulomb repulsion while the latter may be due to electron-electron interactions [as argued for Bi2212 in Mesaros et al. PNAS **113**, 12661 (2016)] or lock-in to the lattice as the different CDW periods for YBCO (three unit cells) and for Bi2212 (four unit cells) most naturally suggest.

Being devoid of disorder, magnetic ordering, and competition with superconductivity, the high-field CDW of YBCO is likely to represent the "ideal" cuprate CDW, which appears to be oxygen-centered, unidirectional, and globally incommensurate while locally locked to the lattice.

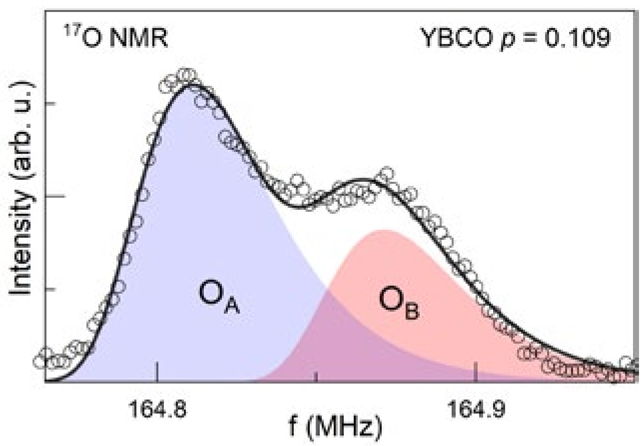

Figure: Second high-frequency satellite of O(2) sites in $YBa_2Cu_3O_{6.56}$ in the high-field CDW phase (T = 2 K, B_z = 27.1 T). Two asymmetric peaks, O_A and O_B, having 2:1 relative areas, consistent with a local CDW period of three unit cells, describe the line shape.

Locally commensurate charge-density wave with three-unit-cell periodicity in $YBa_2Cu_3O_y$, I. Vinograd, R. Zhou, M. Hirata, T. Wu, H. Mayaffre, S. Krämer, R. Liang, W. N. Hardy, D. A. Bonn, and M.-H. Julien, Nat. Commun. **12**, 3274 (2021).

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ENHANCED OPTO-SPINTRONIC FUNCTIONALITIES IN LAYERED HYBRID METAL-HALIDE PEROVSKITES

Timo Neumann, Felix Deschler, TU Munich and Mateusz Dyksik, Paulina Plochocka, LNCMI Toulouse

Hybrid metal-halide perovskites offer the opportunity for a novel control of spins in a high-performance semiconductor due to their exceptional tolerance to structural defects and impurities, combined with their production as polycrystalline thin films and nanostructures from simple scalable solution-processing techniques. Introducing a small number of magnetic dopants into the nominally non-magnetic perovskite lattice produces a dilute magnetic semiconductor, holding a great potential for creating novel opto-spintronic functionalities for information and communication technologies. The development of materials which are simultaneously magnetic and semiconducting, while retaining excellent opto-electronic properties and high luminescence yields, is a scientific challenge. Thus, the ability of perovskites to accept dopants without deteriorating the structural quality is highly appreciated.

We report on the successful introduction of manganese dopants into the crystal lattice of the layered perovskite $(PEA)_2PbI_4$ inducing paramagnetism to the diamagnetic host material. This was accomplished by adding small amounts of manganese salts to the precursor solution. The measured magnetization while sweeping the magnetic field does not show hysteretic behavior and follows the Brillouin function for noninteracting J = 5/2 spin systems, corresponding to a spin alignment of the high-spin Mn d^5 configuration in magnetic field.

Manganese doping for enhanced magnetic brightening and circular polarization control of dark excitons in paramagnetic layered hybrid metal-halide perovskites, T. Neumann, S. Feldmann, P. Moser, A. Delhomme, J. Zerhoch, T. van de Goor, S. Wang, M. Dyksik, T. Winkler, J. J. Finley, P. Plochocka, M. S. Brandt, C. Faugeras, A. V. Stier, and F. Deschler, Nat. Commun. **12**, 3489 (2021).

Photoluminescence (PL) measurements in magnetic field show the emergence of a new signal located at the low-energy side of the bright excitonic peak (Figure). We attribute this emission to the dark state brightened by magnetic coupling to the bright exciton in presence of a strong magnetic field. In contrast to the nonmagnetic variant, this emission shows a nonzero degree of circular polarization, reaching a value of 13 %, which we find to be directly proportional to the material's magnetization. Our findings constitute the first demonstration of magnetization control of exciton spin physics in a transition-metal-doped lead-halide perovskite and provide a first step towards future opto-spintronic functionalities of these materials.

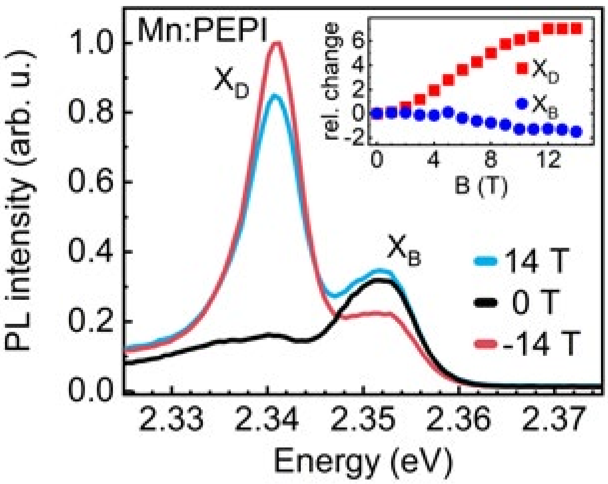

Figure: The circularly polarized PL spectra for Mn-doped PEPI $[(PEA)_2PbI_4]$. The inset shows the influence of magnetic field on the relative intensities of both dark (X_D) and bright (X_B) excitonic states.

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ORIGIN OF THE QUASI-QUANTIZED HALL EFFECT IN $ZrTe_5$

Stanislaw Galeski, MPI CPfS Dresden and Sergei Zherlitsyn, HLD Dresden

The quantum Hall effect (QHE) is traditionally considered to be a purely two-dimensional (2D) phenomenon. Recently, however, a three-dimensional (3D) version of the QHE was reported in the Dirac semimetal $ZrTe_5$. Researchers from Germany, USA, and Sweden have now succeeded in identifying the mechanism behind the quasi-quantization of the Hall effect (qQHE). A direct comparison of the experimental data with linear-response calculations based on an effective 3D Dirac Hamiltonian of $ZrTe_5$ suggests that the quasi-quantization of the observed Hall response emerges from the interplay of low charge-carrier density and the Dirac character of the charge carriers.

From previous charge-transport experiments, the 3D QHE was hypothetically proposed to arise from a magnetic-field-driven Fermi-surface instability with gapping of the Fermi surface and appearing of charge-density waves (CDW) in the quantum limit of $ZrTe_5$. In our comprehensive study, we combined magnetization, ultrasound, magneto-transport, scanning-tunneling, and Raman spectroscopy experiments with advanced high-magnetic-field generation. Our investigations show no signatures of a Fermi-surface instability. Our results indicate that the state underlying the emergence of Hall plateaus in the quantum limit of $ZrTe_5$ is, in fact, gapless and exhibits the behavior of a Fermi sea of a Landau-quantized 3D Dirac semimetal.

Our findings establish the Hall effect in $ZrTe_5$ as a truly three-dimensional relative of the quantum Hall effect in 2D systems, and a prime candidate for the observation of relativistic chiral surface states.

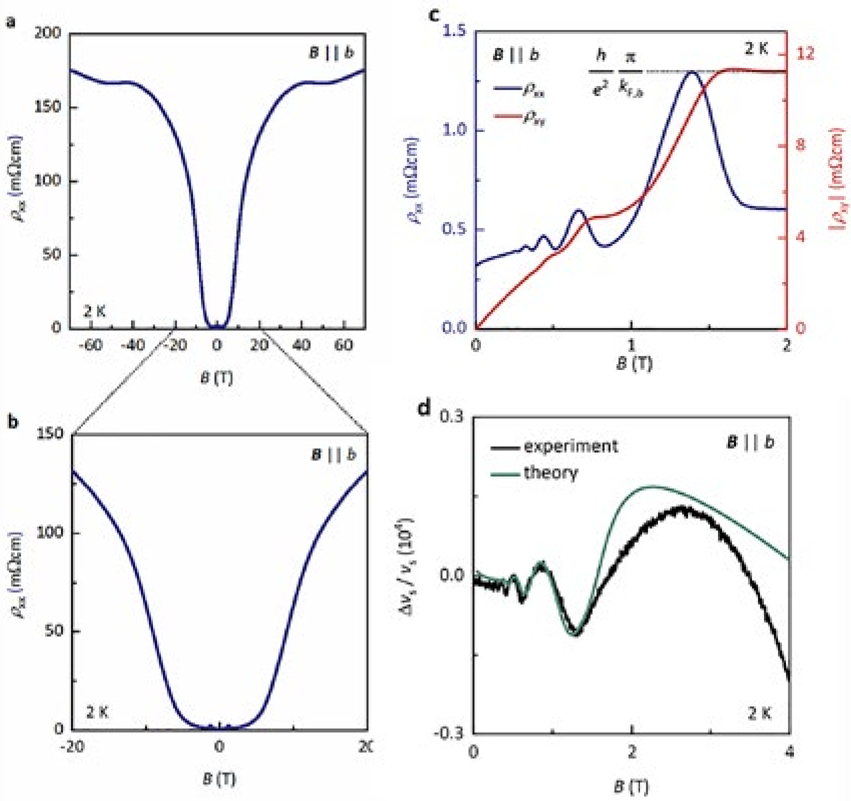

Figure: Longitudinal electrical resistivity at 2 K as a function of magnetic field B applied along the b axis of the crystal (a) up to ±70 T and (b) up to ±20 T. (c) Low-field longitudinal and transversal Hall resistivity revealing a quasi-quantized Hall effect in $ZrTe_5$. (d) Comparison between measured and calculated sound velocity in $ZrTe_5$.

Origin of the quasi-quantized Hall effect in $ZrTe_5$, S. Galeski, T. Ehmcke, R. Wawrzyńczak, P. M. Lozano, K. Cho, A. Sharma, S. Das, F. Küster, P. Sessi, M. Brando, R. Küchler, A. Markou, M. König, P. Swekis, C. Felser, Y. Sassa, Q. Li, G. Gu, M. v. Zimmermann, O. Ivashko, D. I. Gorbunov, S. Zherlitsyn, T. Förster, S. S. P. Parkin, J. Wosnitza, T. Meng, and J. Gooth, Nat. Commun. **12**, 3197 (2021).

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RESULTS OF THE TWENTY-FIFTH CALL FOR ACCESS

On 15. May 2021, the 25th call for access ended. After that, the ranking of the proposals for research activities requiring access to the large-scale high magnetic field facilities collaborating within EMFL started 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

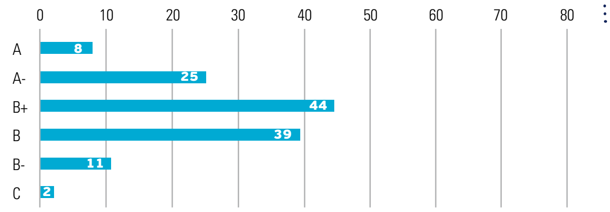
are open to users worldwide. EMFL operates a joint transnational access program, which grants full access to these installations and all associated scientific infrastructure to qualified external users, together with the necessary support from the scientific and technical staff on site.

For this 25th call, 129 applications were submitted, of which 5 are proposals for dual access with regional partner laboratories. This novel access procedure is defined in the EMFL-ISABEL project and trialed for the first time at this call. The proposals came from 18 different countries and were evaluated by the EMFL selection committee until 15. June 2021. The Selection Committee consists of 18 specialists covering the following five scientific topics:

- Metals and Superconductors (36 applications),
- Magnetism (48 applications),
- Semiconductors (35 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: October 15, 2021
Deadline: November 15, 2021



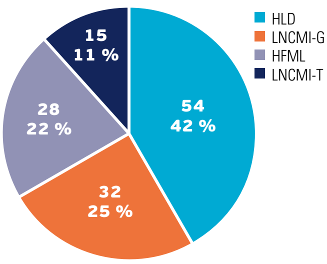
Evaluation of applications

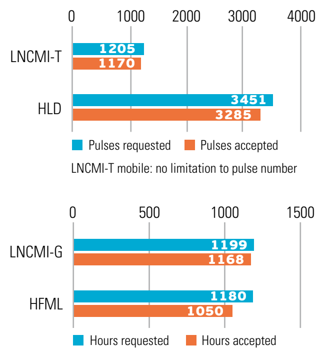
The proposals are ranked in three classes:

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).

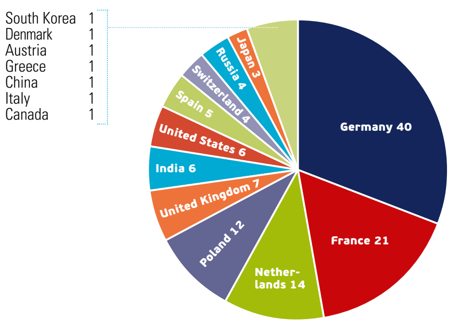
In the B category, the ranking + or - serves as a recommendation to the facility. This degree of freedom is necessary to allow the facilities to consider other aspects such as available capacity and equipment necessary for the successful outcome of a project.

Distribution by facilities
Number of applications





Distribution by country of PI affiliation



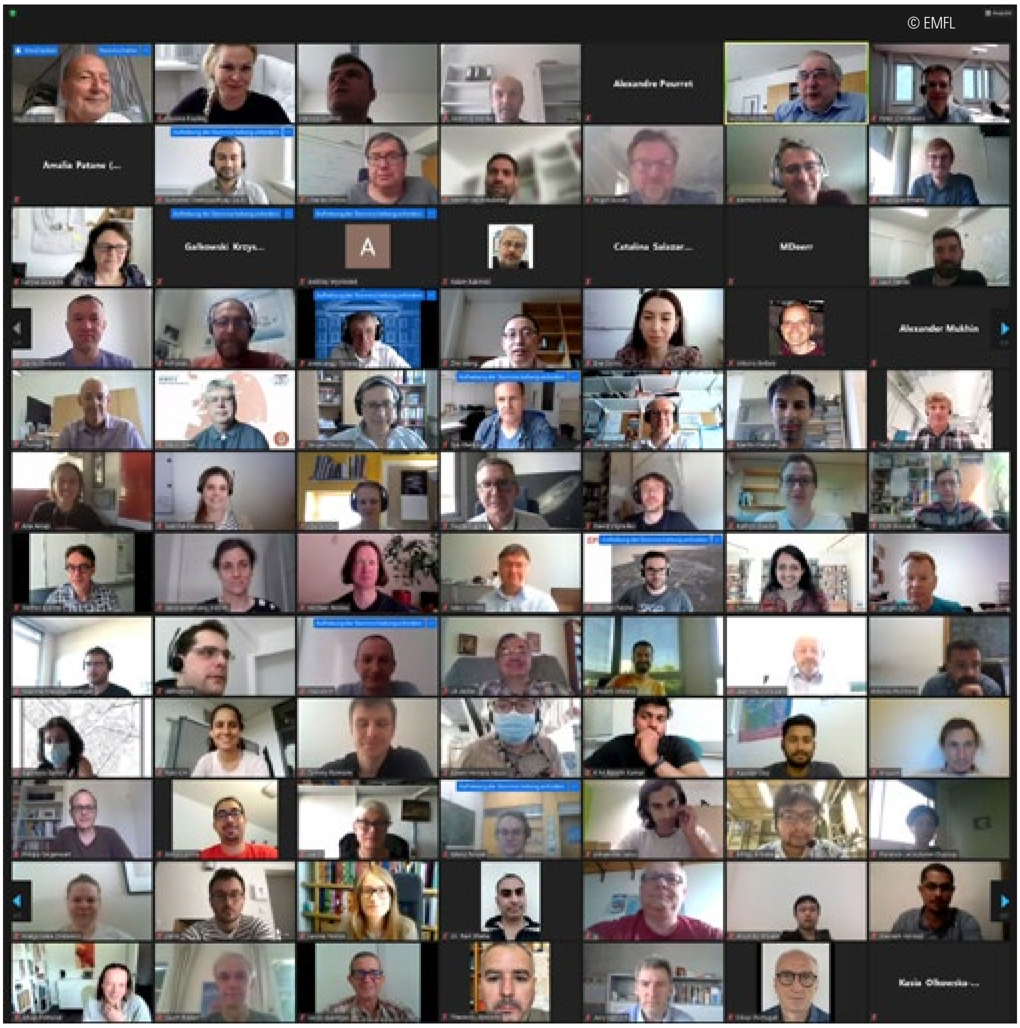
USER MEETING OF THE EUROPEAN MAGNETIC FIELD LABORATORIES

After the cancellation of the user meeting in 2020, the EMFL Board of Directors undertook a fresh start this year. Organized by HLD, the twelfth user meeting of the European magnetic field laboratories took place on June 15, 2021 in video format. With up to 140 participants of the high-field community logged in to join the virtual venue, it was exceptionally well attended.

The aim of the meeting was to exchange ideas and experiences, to present scientific results, and to discuss about possibilities for improving the facilities' attractiveness. The meeting started with a warm welcome by Peter Christianen, chair of the EMFL Board of Directors and director of the HFML. After the announcement of and presentation by the EMFL prize winner (see separate article on the next page) the audience enjoyed eight excellent invited talks from selected users reporting on recent scientific highlights done at EMFL facilities. Further, there were introductory talks on the EU-funded projects ISABEL by Geert Rikken and SuperEMFL by Xavier Chaud, important for the future development of EMFL.

As usual, the EMFL User Committee met during the meeting. Raivo Stern (NICPB, Tallinn, Estonia) chaired this part and reported afterwards on the outcome of the meeting and on suggestions of the Committee back to the Board of Directors.

The virtual user meeting ran very smoothly and was well received by the participants. However, the common coffee breaks, chats with colleagues, tours through the lab, and direct interactions were missing. We very much hope that the next user meeting will take place in person in Grenoble next June. We plan to provide remote access to this meeting.



LAUNCH OF THE SURVEY ON NOVEL ACCESS MODES

Within the framework of the ISABEL project, EMFL wants to test novel user access modes to its facilities. Thereby, EMFL will offer an extended and tailored range of new access procedures to our users.

After introducing the dual-access mode in the recent call for magnet-time proposals, we plan to provide further access modes in the course of 2021, such as first-time, fast-track, long-term, and industrial-user access.

With a recently launched survey, we would like to ask for your kind feedback and specific user needs. It will take less than two minutes to answer the question: Would you use these access modes within the next years?

In order to reply to our survey, please follow the link: **https://enquete.grenoble.cnrs.fr/698444?lang=en**. We thank you very much for your feedback!

EMFL PRIZE WINNER 2020: DENIS GORBUNOV

We are still in the middle of the Corona pandemic, but this year´s EMFL award ceremony took place already a little bit more festive than last year. This time, Dr. Denis Gorbunov, staff member and local contact at the Dresden High Magnetic Field Laboratory (HLD-EMFL), had the honor to receive the prize, at the occasion of the EMFL user meeting. Due to the unusual circumstances, given the virtual ambience of the event, Jochen Wosnitza, director of the HLD-EMFL, was forced to hand over the award directly through the screen.

Dr. Denis Gorbunov received the award for his pioneering work in the field of magnetism, in particular for his research on rare-earth transition-metal compounds using a broad suite of experimental techniques, including x-ray experiments at very high, pulsed magnetic fields.

Since 2009, the EMFL members award annually the EMFL prize for exceptional achievements in science done in high magnetic fields.

The EMFL Prize winner 2021, Denis Gorbunov.

INTRODUCING OUR REGIONAL PARTNER FACILITIES

University of Nottingham Magnetic Levitation Laboratory

The Nottingham magnetic levitation laboratory is a relatively small facility hosted by the School of Physics and Astronomy at the University of Nottingham, UK.

The lab houses two superconducting magnets, reaching fields of up to 18.3 Tesla. Both magnets have been custom-built to perform experiments using the technique of diamagnetic levitation to mimic weightlessness and novel 'differential gravity' environments.

The areas of research normally pursued in this laboratory include studies of fluid and granular physics in pseudo-weightless conditions, and investigations of biological responses to weightlessness.

Both magnets have relatively wide (50 mm and 59 mm diameter), vertical, room-temperature bores. Their design allows convenient access to the high field-gradient region of the magnets, where the diamagnetic forces on organic liquids, water, plastics, and biological material can be harnessed to counteract the force of gravity at the molecular level.

These magnets can be run for extended periods at maximum magnetic field, allowing long-duration (up to several days) 'microgravity' experiments to be performed, an expensive and often impossible feat using comparable alternatives: space and parabolic flights and drop towers.

The continuous running mode allows experimental methods to be improved and expanded iteratively, and extensive testing, before translating to the shorter duration experiments typically undertaken in the high-field facilities of EMFL.

Researchers interested in undertaking experiments at this laboratory under the Dual Access scheme can obtain further details by contacting Richard Hill.

Contact: richard.hill@nottingham.ac.uk

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UPCOMING EVENTS

1. EAPPC-BEAMS-MEGAGAUSS 2021, Biarritz, France, August 29-September 2, 2021. **HYBRID**
http://eappc-beams2020.org/

2. IRMMW-THz 2021, International Conference on Infrared, Millimeter, and Terahertz Waves, Chengdu, China, August 29-September 3, 2021. **HYBRID**
https://irmmw-thz2021.org/

3. European Conference on Applied Superconductivity (EUCAS) 2021, Moscow, Russia, September 5-8, 2021. **VIRTUAL**
https://www.eucas2021.org/

4. DPG Meeting of the Condensed Matter Section, Berlin, Germany, September 27-October 1, 2021. **VIRTUAL**
https://www.dpg-physik.de/aktivitaeten-und-programme/tagungen/fruehjahrstagungen/herbst_2021

5. International Conference on Strongly Correlated Electron Systems (SCES), Guarujá, Brazil, September 27-October 2, 2021. **HYBRID**
https://sces2020.org/

6. International Conference on Magnet Technology (MT27), Fukuoka, Japan, November 15-19, 2021. **HYBRID**
http://csj.or.jp/conference/MT27/

7. Joint Conference on Magnetism and Magnetic Materials (MMM) and the IEEE International Magnetics Conference (INTERMAG). New Orleans, USA, January 10-14, 2022. **HYBRID**
https://magnetism.org/

8. APS March Meeting, Chicago, USA, March 14-18, 2022.
https://bit.ly/3w9xdfz

9. International Conference on Magnetism (ICM), Shanghai, China, July 3-8, 2022.
http://www.icm2021.com/

10. International Conference on the Physics of Semiconductors (ICPS), Sydney, Australia, June 26- July 1, 2022.
https://www.icps2022.org/

11. International Conference on Low Temperature Physics (LT29), Sapporo, Japan, August 18-24, 2022.
http://www.lt29.jp

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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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