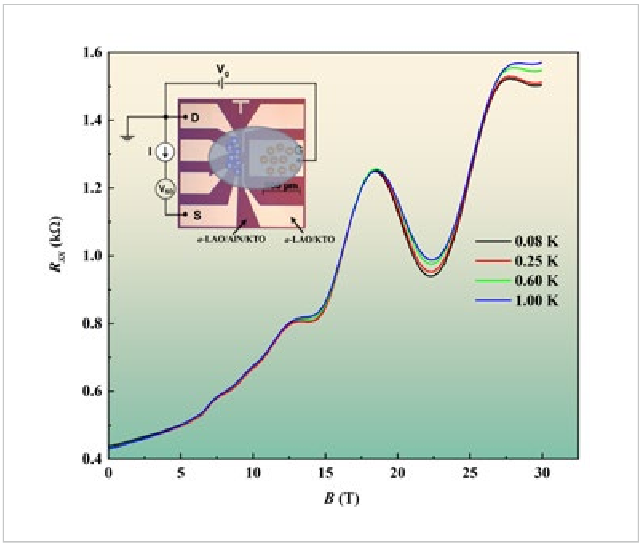
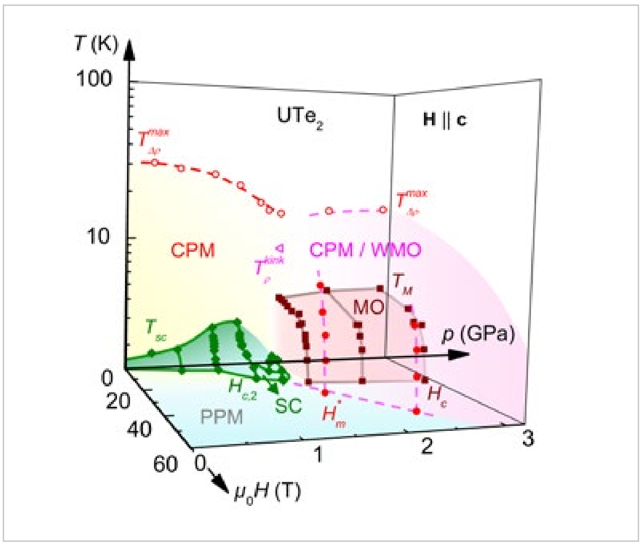
EMFL

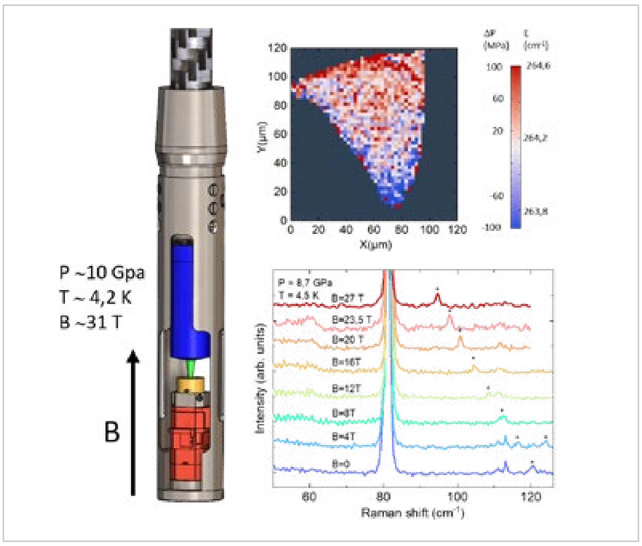
European Magnetic Field Laboratory

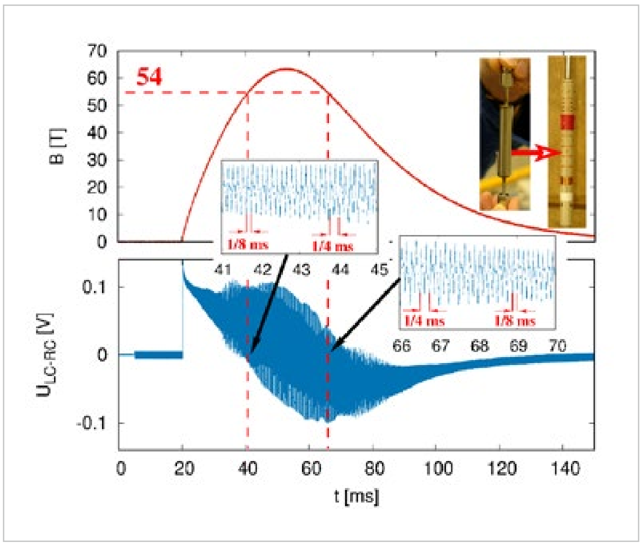
# EMFLNEWS

**N°4** 2021




**CONTENTS**



www.emfl.eu

# DEAR READER

Let me first wish you a prosperous and healthy New Year on behalf of the entire EMFL staff. Unfortunately, we still suffer from the consequences of the Corona pandemic, but the good news is that all EMFL facilities are in operation, and that there is hope that the restrictions for traveling will become less severe in the near future. We are, therefore, looking forward to an exciting year, in which we can frequently meet each other in person: in the laboratories for experiments, but also at conferences, workshops, and schools for much-needed discussions.

In this EMFLNews issue, you will find some of the EMFL scientific and technological highlights, as well as an overview of the most recent developments. It includes a report of the very fruitful ISABEL and SuperEMFL consortium meetings, which took place last November in Grenoble, with both on-line and on-site presence of the participants. We also continue with the introduction of our regional and industrial partners, this time featuring the Spintronics and Nanomagnetism Laboratory at the University of Salento in Lecce and the magnetic pulse-welding company Bmax based in Toulouse.

Finally, we are extremely happy to report that, in principle, the renewal of the UK membership of the EMFL has been approved by the Engineering & Physical Sciences Research Council (EPSRC). The renewal extends the current membership to 31 March 2027.

Peter Christianen
Director HFML
Chairman EMFL

# MEET OUR PEOPLE

*Aimée Savourey, new ILO officer for ISABEL*

Hi. I'm Aimée Savourey. I started my one-year contract with CNRS at the beginning of 2022 as an Industrial Liaison Officer for the ISABEL European Project. I'm based in LNCMI-Toulouse. Before that, I was an R&D engineer in different industrial research centers. After my PhD in magneto-optics in the University Paris XI, I continued my career in materials science and namely in thin-film growth by different techniques, such as PVD, PECVD, ALD, etc. Now, I start a very new experience for me that consists in construction of a solid liaison between EMFL and the world of industry. I understand the importance of my role and will do my best to succeed. I hope my previous experience will be beneficial for this job and I really count on you to support me! Only together we can create this important interaction.


› *Aimée Savourey*

# SPATIALLY RESOLVED OPTICAL SPECTROSCOPY IN AN EXTREME ENVIRONMENT OF LOW TEMPERATURE, HIGH MAGNETIC FIELDS, AND HIGH PRESSURE

*Ivan Breslavetz and Clément Faugeras, LNCMI Grenoble*

To flesh out the phase diagrams of novel material systems, researchers must examine these materials under extreme conditions. We have designed an experimental setup for optical spectroscopy that simultaneously offers three extremes: low temperature, a strong magnetic field, and high pressure imposed by using a diamond anvil cell. The setup provides these extreme conditions while maintaining micrometer scale spatial resolution for optical spectroscopy, which can be used to study exotic phases of microstructures.

We now have a powerful tool to investigate the electronic and magnetic properties of solids at hand, working in combined extreme conditions necessary for studying the occurrence of certain classes of exotic electronic phases. From its unique perspective, optical spectroscopy can shed special light on such electronic phases.

We have recently performed the first experiments in such environments with bulk layered iron phosphorus trisulfide. The results presented in the figure show that this setup permits independent tuning of the three thermodynamic parameters. Consequently, this setup can be used to investigate phase diagrams for different systems and probe their properties with optical spectroscopy. Thanks to the spatial resolution, tiny structures or specific locations on large samples can be investigated by optical spectroscopy (Raman scattering, photoluminescence, reflectivity). This setup will be particularly useful in the field of layered materials for which pressure allows for a tuning of the interlayer distance and the related interaction effects.

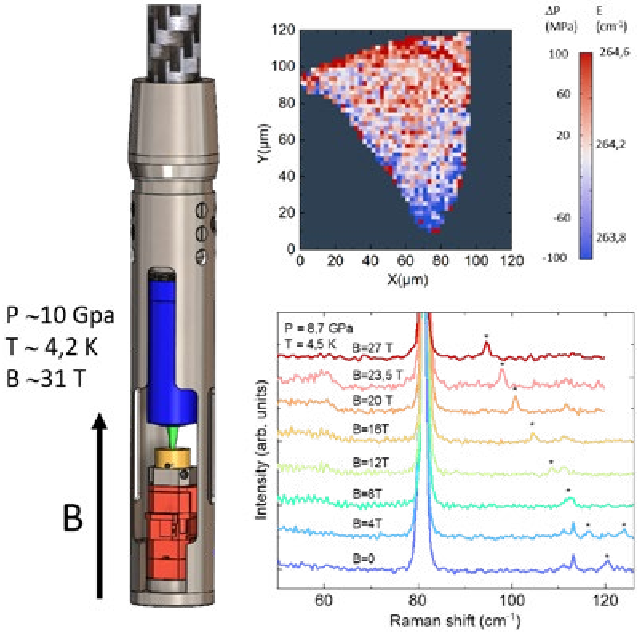



Figure: (Left) Schematic drawing of the optical probe including an optical objective (blue), a diamond anvil cell (orange), and piezo positioners (red). (Top right) spatial map of the Raman-scattering response of $FePS_3$ pressurized at 0.9 GPa. (Bottom right) Raman-scattering response of bulk $FePS_3$ at P = 8.7 GPa, including the magnon excitation, indicated by a star in the spectra, for different values of the magnetic field.

**Spatially resolved optical spectroscopy in extreme environment of low temperature, high magnetic fields and high pressure**, I. Breslavetz, A. Delhomme, T. Pelini, A. Pawbake, D. Vaclavkova, M. Orlita, M. Potemski, M.-A. Measson, and C. Faugeras, Rev. Sci. Instrum. **92**, 123909 (2021).

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# QUANTUM OSCILLATIONS IN A 5d-OXIDE INTERFACE

*Km Rubi and Uli Zeitler, HFML Nijmegen and Walter Escoffier, LNCMI Toulouse*

A team of researchers from HFML-Nijmegen, LNCMI-Toulouse, and the National University of Singapore investigated the electronic properties of the quasi-two-dimensional electron gas (2DEG) at a new 5d-oxide heterointerface, $LaAlO_3/KTaO_3$. The team induced high-mobility carriers at the interface by implementing an ionic-liquid gating process at room temperature. In addition to the detailed information about the band structure of the 2DEG in $KTaO_3$, this study paves a way to create a high-mobility 2DEG based on other 5d oxides for which constructing an epitaxial heterointerface is hardly possible.

Discovered in 2004, the 2DEG at the interface between two insulators, $LaAlO_3$ and $SrTiO_3$, has developed into an intense research topic in fundamental condensed-matter physics with promising application perspectives. Exceptional findings in this system, such as superconductivity, magnetism, large Rashba spin-orbit interaction, and aperiodic quantum oscillations call for investigations on other related systems. Indeed, $KTaO_3$ for which the conduction band is made up of Ta-5d orbitals instead of 3d orbitals in $SrTiO_3$ is such a system with improved specific properties. For example, $KTaO_3$-based 2DEGs exhibit a higher spin-orbit interaction, weaker electron correlation, higher mobility of the electrons, and a higher critical temperature of superconductivity.

To investigate these novel systems experimentally, the team performed quantum-transport measurements on $LaAlO_3/KTaO_3$ heterostructures in high magnetic fields (continuous fields up to 30 T at HFML and pulsed fields up to 55 T at LNCMI) and at temperatures down to 80 mK. These extreme conditions are essential to resolve the quantum oscillations associated with narrowly spaced energy levels (figure). The oscillations in the magnetoresistance, measured in different field orientations, reveal confinement of the majority of electrons within a few atomic layers of $KTaO_3$ from the interface. The oscillations of multiple frequencies and their temperature dependence evidence the occupancy of electrons in small-energy spaced light (0.2 electron masses) and heavy (0.5 electron masses) subbands originated from the Ta-$t_{2g}$ orbitals. Overall, the inferred subband properties are in good agreement with angle-resolved photoemission spectroscopy and band-structure calculations.

The additional observation of magnetoresistance fluctuations in the low-density regime, which most likely originate from the quantum interference of electrons, demonstrates a prospect of oxide-based quantum electronic devices and a platform to investigate quantum-coherence transport in a correlated two-dimensional electron system.

**Electronic subbands in the *a*–$LaAlO_3/KTaO_3$ interface revealed by quantum oscillations in high magnetic fields**, K. Rubi, S. Zeng, F. Bangma, M. Goiran, A. Ariando, W. Escoffier, and U. Zeitler, Phys. Rev. Research **3**, 033234 (2021).

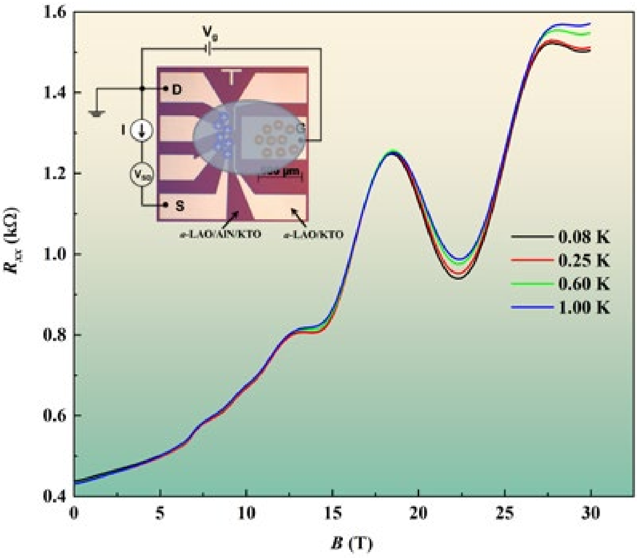


Figure: Quantum oscillations in the magnetoresistance of an ionic-liquid gated α-$LaAlO_3/KTaO_3$ device measured down to 80 mK. The inset includes an optical microscope image of a Hall-bar-patterned sample, a circuit diagram used for the ionic-liquid gating at room temperature, and a schematic of the gating process.

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# MAGNETIC RESHUFFLING AND FEEDBACK ON SUPERCONDUCTIVITY IN $UTe_2$ UNDER PRESSURE

Michal Vališka, CEA-Grenoble and Charles University Prague, William Knafo, LNCMI Toulouse and Daniel Braithwaite, CEA-Grenoble

The discovery of superconductivity in the heavy-fermion paramagnet $UTe_2$ has attracted a lot of attention, particularly due to the reinforcement of superconductivity near quantum phase transitions induced by magnetic field and/or pressure. In this system, hydrostatic pressure induces an enhancement of the superconducting transition temperature by a factor of two, reaching about 3 K. The effect of magnetic field on the ambient-pressure superconductivity is also very unusual, with the superconducting critical field exceeding 60 T for certain field directions.

Here, we investigated the electrical resistivity of $UTe_2$ under pressures up to 3 GPa and pulsed magnetic fields up to 58 T along the hard magnetic crystallographic b and c direction. We constructed three-dimensional phase diagrams (figure) and showed that the application of pressure and magnetic field leads to extremely complex phases in $UTe_2$ with a complete reshuffling of the magnetic anisotropy and associated strong effects on superconductivity. Near the critical pressure, a field enhancement of superconductivity coincides with a boost of the effective mass related to the collapse of metamagnetic and critical fields at the boundaries of the correlated paramagnetic regime and magnetically ordered phase, respectively. Beyond the critical pressure, field-induced transitions precede the destruction of the magnetically ordered phase, suggesting an antiferromagnetic nature. By providing new elements about the interplay between magnetism and superconductivity, our paper appeals for microscopic theories describing the anisotropic properties of $UTe_2$ under pressure and magnetic field.

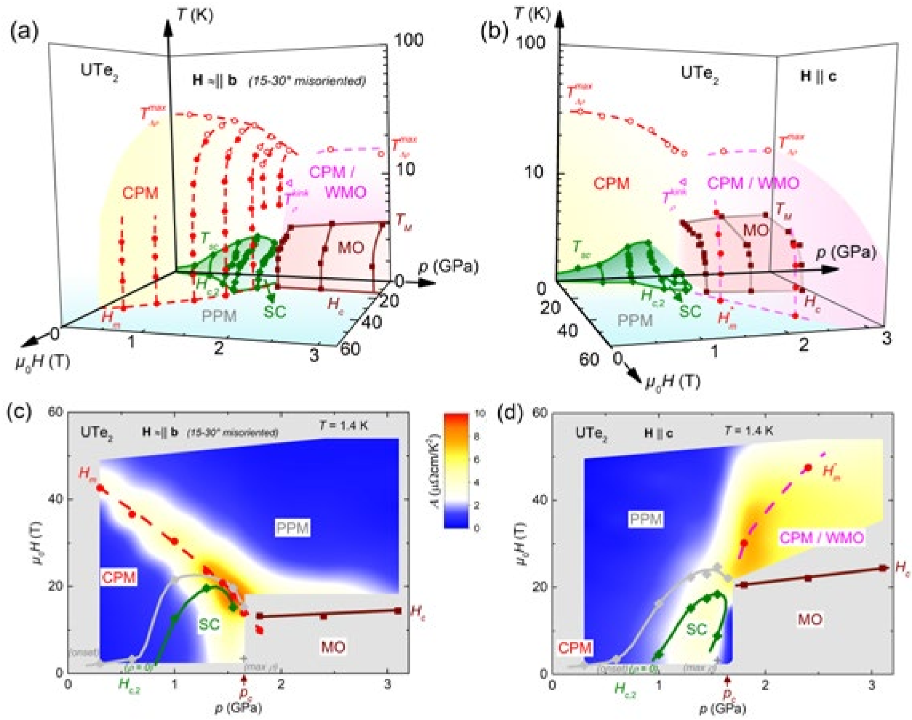


Figure: Three-dimensional (p,H,T) phase diagrams and evolution of the Fermi-liquid coefficient A in the low-temperature (p,H) planes of $UTe_2$ in magnetic fields applied along b and c.

**Magnetic reshuffling and feedback on superconductivity in $UTe_2$ under pressure**, M. Vališka, W. Knafo, G. Knebel, G. Lapertot, D. Aoki, and D. Braithwaite, Phys. Rev. B **104**, 214507 (2021).

Contact: william.knafo@lncmi.cnrs.fr, michal.valiska@gmail.com, daniel.braithwaite@cea.fr

# LIQUID-RUBIDIUM ALFVÉN-WAVE EXPERIMENT IN PULSED MAGNETIC FIELDS

*Frank Stefani und Thomas Herrmannsdörfer, HZDR and HLD Dresden*

The heating of the Sun's corona to temperatures of several million kelvin is one of the major unsolved problems of solar physics. Although magnetic fields are unambiguously considered responsible for the "pot being hotter than the stove", it remains controversial whether the very heating mechanism is due to sudden reconnections of magnetic field lines or to the dampening of different types of waves in the solar plasma. A particularly important region in this respect is the so-called magnetic canopy below the corona, where sound and Alfvén waves have roughly the same speed and, therefore, can easily transform into each other. Yet, this "magic point" had remained inaccessible to experimenters until now: While in plasma experiments the Alfvén speed is typically much higher than the speed of sound, in all liquid-metal experiments to date it has been significantly lower. The reason for this was the limitation of available static magnetic fields, which do not produce sufficient magnetic tension for the Alfvén waves to travel with the same high speed as the sound.

The main idea of our experiment was to utilize the pulsed magnetic fields available at HLD to allow Alfvén waves to cross the "sound barrier", which appears at a reachable value of 54 T when using liquid rubidium. Due to the high chemical reactivity of this alkali metal, it had to be filled (in a glove box) into a sturdy stainless-steel container of 10 mm inner radius and 60 mm height (see the inset of Figure a). By injecting an alternating current at the bottom of the container and exposing it to the pulsed magnetic field of up to 63 T (Figure a), it was finally possible to generate Alfvén waves in the melt, whose upward motion had the expected speed, just as in many previous experiments. The novel result was that, while the frequency of the alternating current signal dominates all measurements up to the "magic point" of 54 T, exactly at this point a new signal with halved frequency appeared (insets of Figure b). This sudden period doubling is in perfect agreement with the theoretical predictions of a parametric resonance as described by Zaqarashvili and Roberts in 2006. Although we cannot yet explain all observed effects so easily, our work sheds light on an important mechanism related the Sun's corona heating. For the future, we are planning detailed numerical analyses of our results and further experiments

**Mode Conversion and Period Doubling in a Liquid Rubidium Alfvén-Wave Experiment with Coinciding Sound and Alfvén Speeds**,
F. Stefani, J. Forbriger, Th. Gundrum, T. Herrmannsdörfer, and J. Wosnitza, Phys. Rev. Lett. **127**, 275001 (2021).

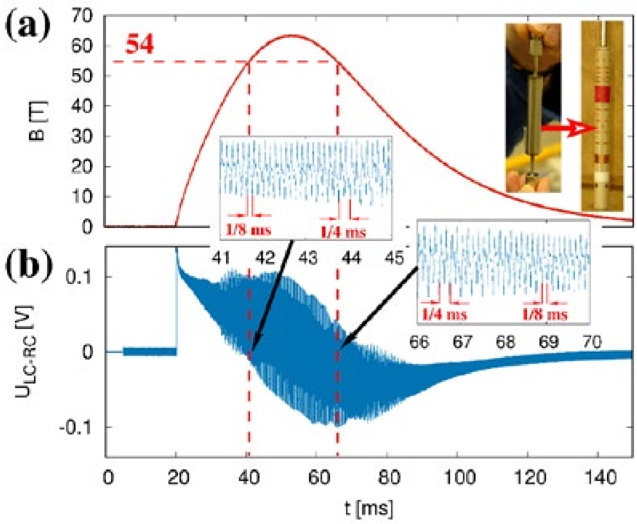


Figure: (a) Time dependence of the pulsed magnetic field and (b) of the voltage measurements at the lower contact. The red dashed lines indicate the instants where the critical field strength of 54 T is crossed. The two inset pictures in (a) show the stainless steel container filled with rubidium, and the holder with pick-up and compensation coils. The insets in (b) detail the two transition regions, where the double-period signal due to torsional Alfvén wave starts and ceases to exist.

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# RESULTS OF THE TWENTY-SIXTH CALL FOR ACCESS

On 15 November 2021, the 26th 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

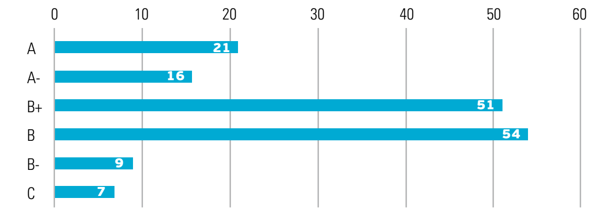
are open to users worldwide. EMFL operates a joint transnational access program, which grants full access to these installations and all associated scientific infrastructure to qualified external users, together with the necessary support from the scientific and technical staff on site.

For this 26th call, 158 applications were submitted, of which 4 are proposals for dual access with regional partner laboratories. This novel access procedure is defined in the EMFL-ISABEL project and trialed for the second time at this call. The proposals came from 21 different countries and were evaluated by the EMFL selection committee until 15 December 2021. The Selection Committee consists of 18 specialists covering the following five scientific topics:

> Metals and Superconductors (52 applications),
> Magnetism (65 applications),
> Semiconductors (31 applications),
> Soft Matter and Magnetoscience (3 applications),
> Applied Superconductivity (7 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, 2022
Deadline: May 15, 2022



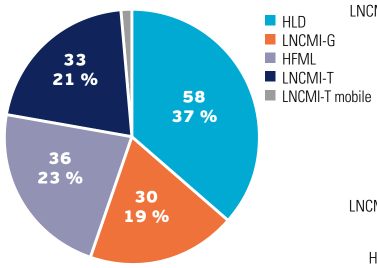

### Evaluation of applications

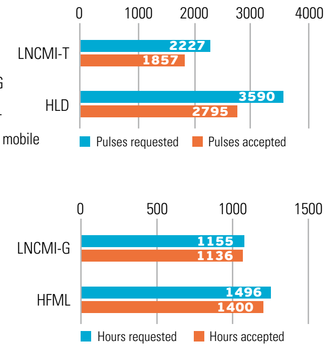
The proposals are ranked in three classes:

**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).

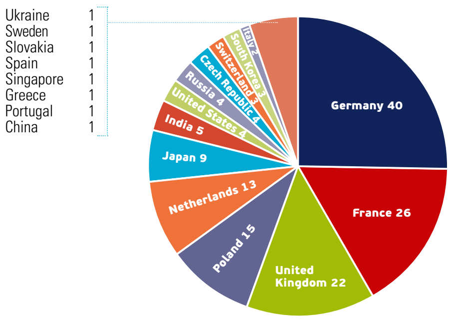
In the B category, the ranking + or - serves as a recommendation to the facility. This degree of freedom is necessary to allow the facilities to consider other aspects such as available capacity and equipment necessary for the successful outcome of a project.

**Distribution by facilities**
**Number of applications**




**Distribution by country of PI affiliation**



# VISIT OF ISABEL AND SUPEREMFL PARTNERS AT LNCMI FACILITY IN GRENOBLE

Between 29 and 30 November 2021, ISABEL and SuperEMFL partners met for the first time in a face-to-face meeting at the LNCMI facility in Grenoble. This was a great opportunity to see each other in person, to review the projects progress with the executive board members, and to anticipate the coming actions and challenges with the ISABEL Council and SuperEMFL governing board. On the second day, the ISABEL and SuperEMFL coordination teams shared a joint meeting and discussed the synergy and implementation of their common actions.

After the meetings, the participants had the opportunity to visit the infrastructure of the Grenoble facility. It was a moment of sharing experience and knowledge on large-scale magnet installations with the staff of Grenoble. The ISABEL and SuperEMFL partners thank the Grenoble staff for hosting the event and the participants for the fruitful discussions. We are all looking forward to new opportunities for more face-to-face meetings during the coming years.


© Eva Bezgousko

# RENEWAL OF UK MEMBERSHIP OF EMFL APPROVED BY EPSRC

UKRI Engineering and Physical Sciences Research Council

The renewal of the UK membership of the European Magnetic Field Laboratory (EMFL) has been approved, in principle, by the Engineering and Physical Sciences Research Council (EPSRC), the main funding body for engineering and physical sciences research in the UK. The renewal extends the current membership to 31 March 2027 and allows to continue and expand the well-established successful cooperation.

The EMFL, consisting of the Laboratoire National des Champs Magnétiques Intenses (LNCMI) with sites in Grenoble and Toulouse, the High Field Magnet Laboratory (HFML - Nijmegen) and the Hochfeld-Magnetlabor (HLD - Dresden), provides access to the highest continuous and pulsed magnetic fields in Europe. The UK membership of the EMFL will enable the UK users the free access to these installations and of all available auxiliary equipment, expert support from the local staff, as well as funding for travel and subsistence.

Calls for proposals are launched by the EMFL twice a year (with deadlines in May and November) inviting proposals for research requiring access to one of the installations of the EMFL. Users may submit proposals for access to any of these installations by an on-line form, which can be found on the EMFL website (www.emfl.eu „apply for magnet time"). The proposals are evaluated by an international Selection Committee and are ranked based on scientific quality, justification of the need for high magnetic fields, and technical feasibility of the project.

Each year, the EMFL organizes a user meeting for those who have used or would like to use the EMFL. The purpose of this meeting is to bring users together to report on their experiments and exchange information about the opportunities offered by the EMFL. Also, UK as well as other users are invited to inform the EMFL on the specific needs in terms of new equipment or facility developments they may have in the future.

# MAGNETOFORMING COILS WITH A LONG LIFE-TIME: LNCMI TO CEMENT TIES WITH Bmax

Since 2013, the LNCMI is collaborating with the Toulouse company Bmax / I Cube Research to design magnetoforming coils with long lifetime. Durability is a crucial issue for using electromagnets at an industrial scale, requiring the production of parts in large quantities with extreme precision and at controlled cost.

To generate very strong magnetic fields, it is necessary to use conductors that combine good electrical conductivity with very high mechanical strength. In addition to the magnet production, the LNCMI has its own wire-drawing workshop and is able to manufacture the conductors necessary for the fabrication of coils which can resist long-lasting magnetic fields (several tens of milliseconds) up to the 100 T range. It is this expertise that attracted Bmax / I Cube Research, a specialist in magnetoforming.

Magnetoforming is a technique that makes it possible to manufacture precise parts with shapes that cannot be obtained by other methods at reasonable costs. The pulsed electromagnets that are designed for this purpose generate very short and strong magnetic field pulses, which induce a current in the metal part to be molded. The part is then projected at very high speed onto a mold, which gives it the desired form. This technique is called direct, as opposed to indirect, magnetoforming where a punch is set in motion by magnetic forces, hits the material to be modeled and projects it to the mold. The operation takes place in a few tens of microseconds, and offers a level of precision in the shape of the parts that meets the expectations of very demanding sectors such as luxury, aeronautics, and automotive industry.

However, the pulsed electric currents that make this process possible impose enormous magnetic, mechanical, and thermal stresses on the electromagnet. The challenge is, therefore, to produce coils with conductive materials that are sufficiently resistant to sustain these stresses in order to use them on industrial production lines without the need of frequent replacement. Starting with a few hundred pulses realized a few years ago, the LNCMI, therefore, has optimized the electromagnets to withstand more than 30,000 pulses, which corresponds to a 50-times longer lifetime. Based on this success Bmax / I Cube Research is now in a position to extend its magnetoforming applications and to conquer new markets. Initially financed by funds of Bmax / I Cube Research, the partnership with the LNCMI was recognized institutionally and has been sponsored as part of local (NEXTMAG, LABEX NEXT), regional (MAG-IC, Région Occitanie), national (SIgMA, ANR), and European (ISABEL, H2020) projects.



Figure: Magnetoforming coil

**Further information:**
**https://www.bmax.com/technology/magnetic-pulse-forming/**

# INTRODUCING OUR REGIONAL PARTNER FACILITIES

*The Spintronics and NanoMagnetism Laboratory in Lecce*

The Spintronics and NanoMagnetism Laboratory in Lecce is a joint facility involving three different institutions: the Università del Salento, Consiglio Nazionale delle Ricerche, and Istituto Nazionale di Fisica Nucleare. The research is funded by EU, national, and regional projects.

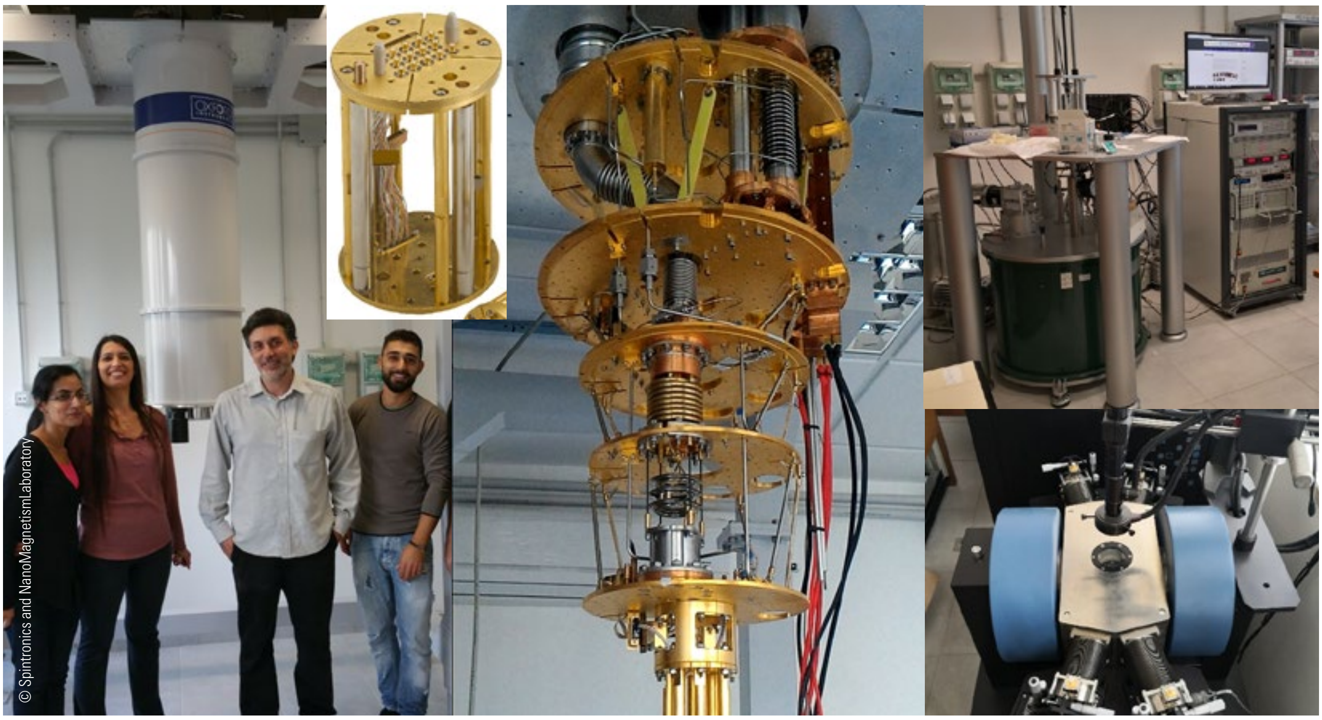
Research activities are multidisciplinary and span from spintronics and magnonics to quantum sciences and technologies, sensing, and material sciences. Results, achievements, and concepts are disseminated to the general public within the frame of European Researchers' Night initiatives, including exhibits and hand-on experiments on magnetism (i.e., superconducting levitation on a Möbius band). Major equipment includes:

- An Oxford superconducting vector magnet (6 T/1 T/1 T) with dilution refrigerator reaching temperatures down to 10 mK and equipped for DC magnetotransport, RF spectroscopy, and ferromagnetic-resonance measurements.
- A Cryogenic Ltd superconducting magnet (10.5 T, 0.3-300 K) equipped for variable-temperature magnetotransport, magnetometry, and ac-susceptibility measurements.
- A Lakeshore cryogenic probe station for DC and RF (up to 20 GHz) measurements in moderate field.
- An Oxford superconducting magnet (8 T) with a custom-built optical cryostat for magneto-optical experiments.

Notably, the infrastructure further includes a fully equipped clean room for nanofabrication and material growth as well as nanochemistry, photonics, and biology facilities providing an ideal location for multidisciplinary and applied research for in-house and visiting researchers before translating the experiments to the high-field facilities of EMFL, when required. In particular, service can be offered for magnetotransport, RF and magneto-optical spectroscopy, characterization/optimization of novel sensors, nanomagnetism, and novel functional magnetic materials (such as multiferroics).

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

Contact: giuseppe.maruccio@unisalento.it



# UPCOMING EVENTS

**1.** APS March Meeting, Chicago, USA, March 14-18, 2022. HYBRID
**https://march.aps.org/**

**2.** International Conference on the Physics of Semiconductors (ICPS), Sydney, Australia, June 27-June 30, 2022.
**https://www.icps2022.org/**

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

**4.** 13th International Conference on Materials and Mechanisms of Superconductivity & High Temperature Superconductors (M2S-2022), Vancouver, Canada, July 17-22, 2022.
**https://www.m2s-2022.com/**

**5.** Joint European Magnetic Symposia (JEMS), Warsaw, Poland, July 24-29, 2022. HYBRID
**https://jems2022.pl/**

Are you missing a conference? Let us know!

**6.** International Conference on Strongly Correlated Electron Systems (SCES 2022), Amsterdam, The Netherlands, July 24-29, 2022.
**https://www.sces2022.org/**

**7.** 29th International Conference on Low Temperature Physics (LT29), Sapporo, Japan, August 18-24, 2022. HYBRID
**http://www.lt29.jp**

**8.** IRMMW-THz 2022, 47th International Conference on Infrared, Millimeter, and Terahertz Waves, Delft, The Netherlands, August 28-September 2, 2022. HYBRID
**https://www.irmmw-thz2022.tudelft.nl/**

**9.** DPG Spring Meeting of the Condensed Matter Section, Regensburg, Germany, September 4-9, 2022. SHIFTED
**https://www.dpg-physik.de/aktivitaeten-und-programme/tagungen/fruehjahrstagungen/2022**

**10.** Spectroscopies of Novel Superconductors (SNS) 2022, Bangalore, India, December 12-16, 2022.
**https://snsbangalore.iisc.ac.in/**


› Vancouver Convention Centre

# SAVE THE DATE

The EMFL Board of Directors is happy to announce that the next user meeting of the European high-magnetic-field facilities for

- continuous fields (LNCMI Grenoble and HFML Nijmegen) and
- pulsed magnetic fields (HLD Dresden and LNCMI Toulouse)

will take place on **Wednesday, June 15, 2022**. We hope to welcome you in Grenoble, but due to the circumstances, a hybrid meeting will be organized.

Further details will be sent out to the user community by email and will be given in the next issue of EMFLNews as well as on the EMFL website **https://emfl.eu**.

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www.ru.nl/hfml

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**Helmholtz-Zentrum Dresden-Rossendorf (HZDR)**
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The ISABEL and SuperEMFL projects have received funding from the European Union's Horizon 2020 research and innovation programme under grant agreements No 871106 and No 951714, respectively.

## IMPRINT

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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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