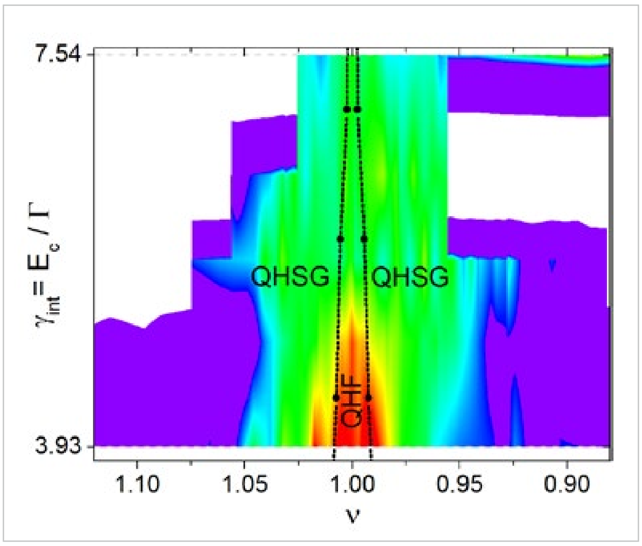
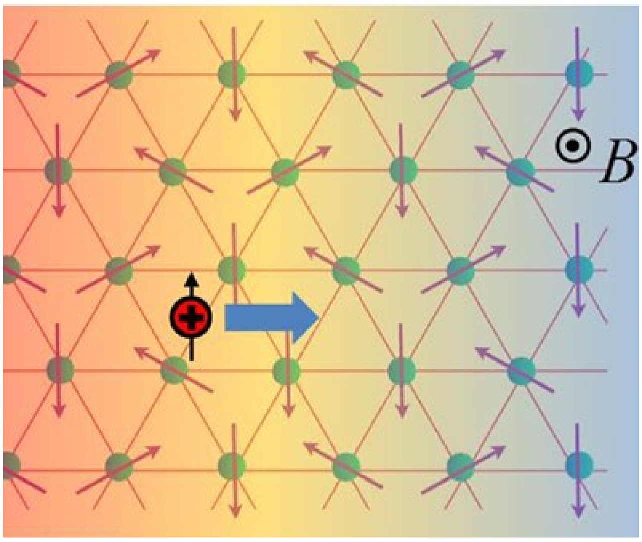
European Magnetic Field Laboratory

EMFLNEWS

N°1 2016





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www.emfl.eu

DEAR READER,

The EMFL has now gone into its second year of official existence. Its importance for the European research community has recently been recognized by the European Strategic Forum for Research Infrastructures (ESFRI), which has attributed the Landmark status to EMFL, and to 28 other large research infrastructures of pan-European interest. We are very proud to receive this label, and we will do our best to show ourselves worthy of it.

I profit from the occasion to invite you to the next EMFL User Meeting, taking place in Toulouse on 16th of June, where you will be informed of the latest developments and plans of the EMFL facilities, and where you can exchange with facility staff and other users on high field science and instrumentation. You can find the preliminary program on page 8 in this issue.

Of course exciting new scientific results keep on pouring out of the EMFL facilities, as you will see further on in this issue.
Looking forward to seeing you all in Toulouse!

Geert Rikken
Director LNCMI-CNRS
Chairman EMFL Board

MEET OUR PEOPLE

Cécile Alix, Catherine Knödlseder, Séverine Bories

We are three people working in the LNCMI Toulouse administration office: Cécile Alix who works in the office since 2011, Séverine Bories present since 2005 and Catherine Knödlseder who arrived in 2014 and is in charge of the office. We coordinate the budget and the payments of the laboratory together with a number of research contracts.

We interact with many different people, the staff of LNCMI, the staff of the local CNRS administration and our partner organizations UPS and INSA. We also interact with our colleagues from LNCMI Grenoble and the other laboratories of the EMFL.

We have the task of welcoming international visitors who use the LNCMI Toulouse high magnetic field facility. We help them to prepare their travel and to find accommodation in Toulouse in either a hotel or an apartment. During their visit we are available to facilitate their stay in Toulouse.

This year will be a particularly busy one for us as we are organizing the EMFL User Meeting on the 16th of June, followed by the Selection Committee (SelCom) on the 17th of June. Séverine Bories is responsible for the organization of these two days and you should contact her if you have any questions. The invitations have already been sent. You are reminded that you can register for this event here:
www.emfl.eu/meetings-and-events/emfl-meetings.html

The next EMFL days will take place from 14th to 16th of September in Königstein (Taunus) in Germany and will be an occasion to forge stronger links with the EMFL community.
The website of the laboratory can be consulted here:
www.toulouse.lncmi.cnrs.fr
If you would like further information please do not hesitate to contact us.

› Contact: secretariat.toulouse@lncmi.cnrs.fr

› Cécile Alix, Catherine Knödlseder, Séverine Bories (from right to left)

MAGNETOELECTRIC EFFECT AND PHASE TRANSITIONS IN CuO IN EXTERNAL MAGNETIC FIELDS

Zhaosheng Wang, HLD Dresden and Vassil Skumryev, ICREA Barcelona

Apart from being so far the only known binary multiferroic compound, CuO has a much higher transition temperature into the multiferroic state, 230 K, than any other known material in which the electric polarization is induced by spontaneous magnetic order, typically lower than 100 K. Although the magnetically induced ferroelectricity of CuO is firmly established, no magnetoelectric effect has been observed so far as direct crosstalk between bulk magnetization and electric polarization counterparts, prompting to call CuO a material with persistent multiferroicity without magnetoelectric effects.

By synergistic use of a number of experimental techniques combined with high magnetic fields – single-crystal neutron diffraction, electric polarization, ultrasound, magnetization, capacitance and magnetostriction measurements at the European facilities (HLD-EMFL at HZDR in Dresden and ILL in Grenoble) – researchers from Dresden and Barcelona, in collaboration with colleagues from Grenoble and Moscow, were able to shed light on the puzzling magnetoelectric nature of CuO.

The results show that sufficiently high magnetic fields of about 50 T are able to suppress the helical modulation of the magnetic moments in the multiferroic phase and dramatically affect the electric polarization. Furthermore, just below the spontaneous transition from commensurate (paraelectric) to incommensurate (ferroelectric) magnetic structures at 213 K, even modest magnetic fields induce a transition into the incommensurate structure and then suppress it at higher fields, causing remarkable polarization changes. Thus, hidden magnetoelectric features are uncovered, establishing CuO as a prototype multiferroic with abundance of competitive magnetic interactions. The magnetoelectric phase diagram of this multiferroic is sketched in the figure.

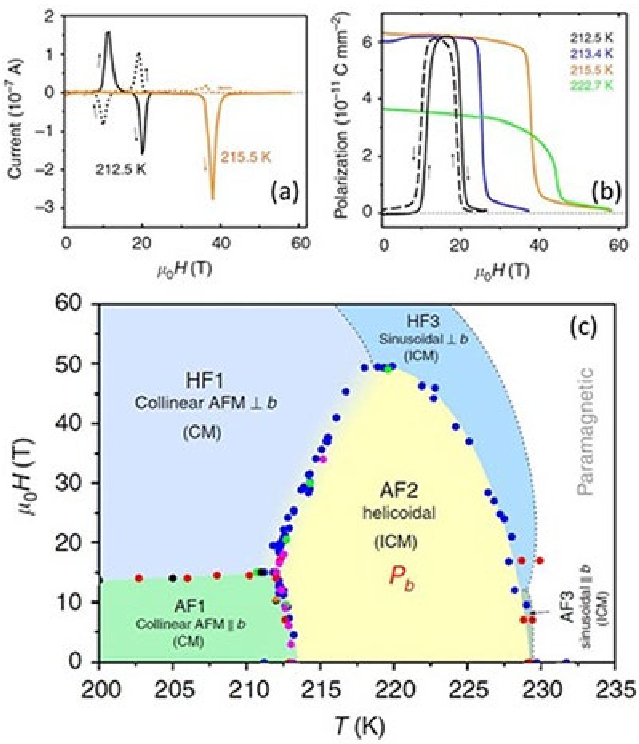

Figure: Electric polarization measurement results and the magnetoelectric phase diagrams of CuO. (a) Pyrocurrent as a function of magnetic field applied along the b axis at two selected temperatures (slightly below 213 K and in the incommensurate phase above it). (b) Electric polarization along the b axis at some selected temperatures, vs. magnetic field applied along the b axis. (c) Magnetic-field-temperature phase diagram for H || b, based on pyrocurrent (blue dots), capacitance (green dots), magnetostriction (pink dots), sound velocity (red dots) and bulk magnetization data (black dots).

Magnetoelectric effect and phase transitions in CuO in external magnetic fields, Z. Wang, N. Qureshi, S. Yasin, A. Mukhin, E. Resouche, S. Zherlitsyn, Y. Skourski, J. Geshev, V. Ivanov, M. Gospodinov, and V. Skumryev, Nature Communications **7**, 10295 (2016).

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DISORDER-INDUCED STABILIZATION OF THE QUANTUM HALL FERROMAGNET

Benjamin Piot, LNCMI Grenoble

The quantum Hall ferromagnet (QHF) is a fascinating ground state of two-dimensional (2D) electrons in a magnetic field where exchange interactions can establish a long-range ferromagnetic order. In strong magnetic fields, electrons are "squeezed" close together, and thus experience strong Coulomb interactions creating a large energy gap which protects the QHF. Despite this large gap, the spin polarization P of the system, which should be complete (P = 1) in the QHF state, may be reduced due to the appearance of peculiar spin textures known as Skyrmions, which can form as soon as charge is added or removed from the system. In practice, a fully polarized QHF is rarely observed, and recent experiments have shown a surprising fragility of the spin polarization which drops below 1 in the presence of charge fluctuations of about 0.1 % or at temperatures of a few hundred millikelvin.

Our recent work gives an explanation for such fragility by showing that an optimal amount of disorder actually "protects" the QHF against depolarization. In simple words, a slightly dirty QHF is stronger than a clean one. When the amount of disorder is too high, however, the QHF, like other quantum Hall states, is eventually destroyed. This defines a small pocket in the disorder / interaction (magnetic field) / carrier density phase diagram of the 2D electron gas where the fully spin polarized state is stabilized. Our conclusions are reached by using state-of-the-art "frequency-pulsed-resistively-detected-NMR", enabling us to measure the electron spin polarization in an absolute way at very low temperatures as a function of the electron density and the magnetic field (see Figure), close to the complete filling of the lowest Landau level.

These findings explain why the QHF is so fragile in very clean (high-mobility) 2D systems, but also open ways to improve our control of the degree of spin polarization of collective 2D states.

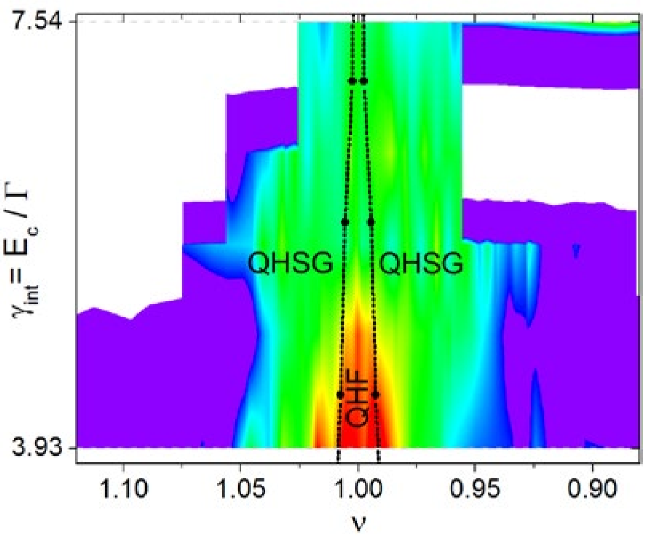

Figure: Color map of the electron spin polarization P as a function of the filling factor (number of filled Landau levels) and the interaction parameter γ_{int} which corresponds to the ratio between the Coulomb interaction E_c (tuned by applying a large magnetic field), and the sample disorder Γ. P < 0.7 (purple), P = 0.7 (blue) to P = 1 (red). Outside the theoretical narrow QHF region, delimited by the black-dotted lines, the QHF is destabilized with respect to the formation of Skyrmions (QHSG).

Disorder-induced stabilization of the quantum Hall ferromagnet, B. A. Piot, W. Desrat, D. K. Maude, D. Kazazis, A. Cavanna, and U. Gennser, Phys. Rev. Lett. **116**, 106801 (2016).

Contact: benjamin.piot@lncmi.cnrs.fr

MAGNETIC-FIELD SUPPRESSION OF THERMOELECTRICITY IN A METALLIC FRUSTRATED MAGNET

Stevan Arsenijevič, HLD-HZDR Dresden and Nigel E. Hussey, HFML Nijmegen

The thermoelectric effect (TE) in metals occurs as a voltage difference – accumulated charge – when a thermal gradient is applied. This property can be used to convert heat into electrical energy in power generation and in temperature sensing. Among several scattering mechanisms, the TE depends on how the charge carriers interact with any underlying magnetic structure. In a publication in Physical Review Letters, scientists at the HFML and Radboud University, together with colleagues from POSTECH in Korea, have demonstrated that the TE in a metallic frustrated magnet can be completely suppressed by applying high magnetic fields of 30 T.

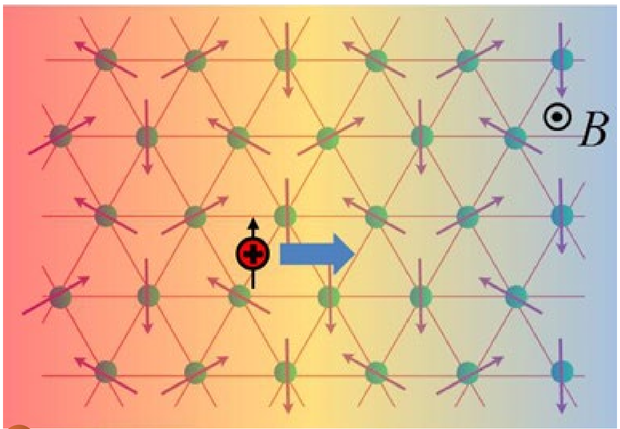

Figure 1: When a thermal gradient is applied, the electron's movement is affected by the interaction with the underlying magnetic lattice. The question is how the applied magnetic field changes this process?

The investigated material $PdCrO_2$ consists of alternating layers of conducting and magnetic ions whose interactions can lead to novel phenomena (Figure 1). At high temperatures, the charge carriers scatter principally off quantized waves called magnons which are created by thermally exciting the spins on the magnetic ions. This mechanism is strongly suppressed by a magnetic field, leading to the reduction in the thermoelectric voltage (Figure 2). With lowering temperature, this 'frustrated' magnetic structure becomes stiffer. Finally, it orders in a compromising manner with an angle of 120° between its moments to satisfy the underlying triangular lattice. The magnetic order leads to the TE being more resilient to an applied field.

The observed phenomena are evidence of an interesting symbiosis between the spin and charge excitations in this system and suggests that magnetic-field tuning of the TE coefficient in certain frustrated magnets could lead to improvements in the thermal management of electronic and magnetic devices.

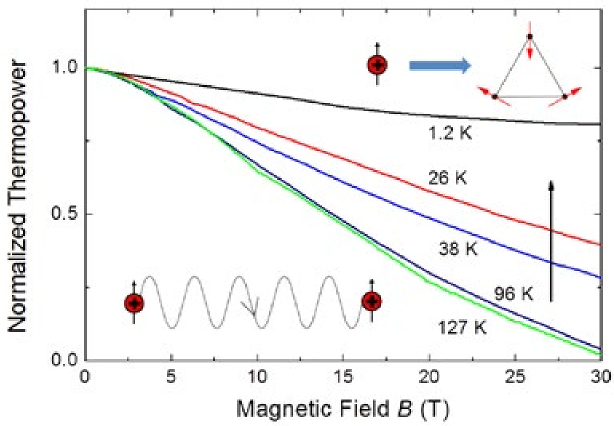

Figure 2: The suppression of the TE in $PdCrO_2$ by the magnetic field at high temperature is driven by the electron-magnon interaction. As the magnetic lattice orders, scattering of electrons with this order prevails.

Anomalous magnetothermopower in a metallic frustrated antiferromagnet,
S. Arsenijevič, J.-M. Ok, P. Robinson, S. Ghannadzadeh, M. I. Katsnelson, J.-S. Kim, and N. E. Hussey,
Phys. Rev. Lett. **116**, 087202 (2016).

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PSEUDOGAP QUANTUM PHASE TRANSITION IN HIGH-T_c CUPRATES

Cyril Proust, LNCMI Toulouse and Louis Taillefer, Sherbrooke University

The microscopic origin of high-temperature superconductivity in the cuprates, despite its long history, is still under fierce debate. There is a conjecture that the so-called pseudogap phase, and in particular the critical fluctuations associated with it, are the underlying cause for high-T_c superconductivity. However, the existence of other phases, such as a spin density wave and a charge density phase complicate the picture considerably.

By performing high-field Hall effect measurements up to 88 T in the low-temperature normal state of high-quality $YBa_2Cu_3O_y$ samples at different doping levels (Figure 1), a team of Canadian and French researchers working at the EMFL in Toulouse has found that the onset of pseudogap and CDW order occurs at two distinct and well-separated critical dopings. Above the critical doping where the CDW order disappears, they were able to study the pseudogap phase and they have observed a sharp drop in the number of charge carriers exactly where the pseudogap phase sets in (Figure 2). This proves that the pseudogap state is accompanied by a transformation of the Fermi surface such that its volume suddenly shrinks by one hole per Cu atom.

Lying centrally in the phase diagram where superconductivity is strongest and other properties are the most remarkable, this quantum phase transition at the pseudogap critical point is emerging as a key organizing principle of cuprates. In fact, the team hypothesizes that whatever is taking place at this critical point is probably the cause of high-temperature superconductivity.

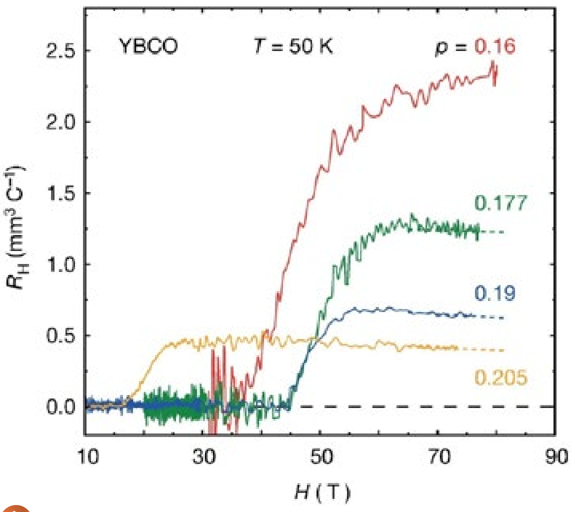

Figure 1: Hall effect measurements for samples with different doping level p in pulsed magnetic fields. Note the huge increase in the value of R_H at H = 80 T by a factor 5.7, when going from p = 0.205 to 0.16.

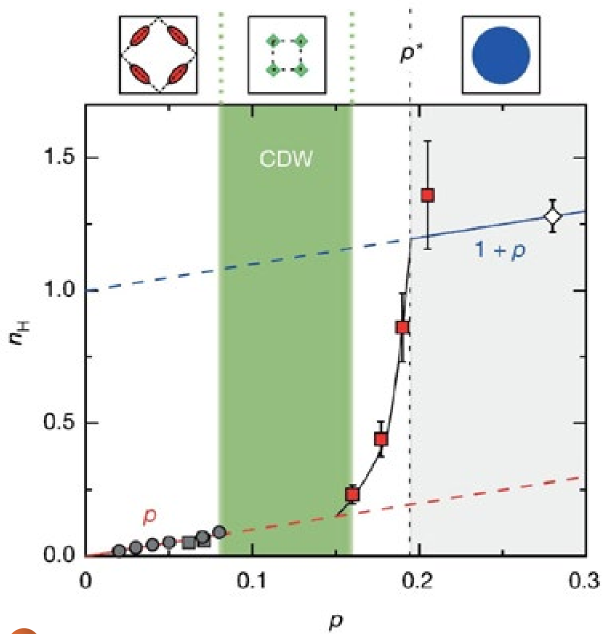

Figure 2: Doping dependence of the Hall number, $n_H = V/(eR_H)$, in hole-doped cuprates, measured in the normal state at 50 K. The region where the Fermi-surface reconstruction due to CDW order occurs in YBCO is marked as a green band. The charge carrier density (per Cu atom) drops from 1 + p to p at the pseudogap critical point p*.

Change of carrier density at the pseudogap critical point of a cuprate superconductor, S. Badoux W. Tabis, F. Laliberté, G. Grissonnanche, B. Vignolle, D. Vignolles, J. Béard, D. A. Bonn, W. N. Hardy, R. Liang, N. Doiron-Leyraud, L. Taillefer, and C. Proust, Nature **531**, 210 (2016).

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OPENING OF THE FIFTEENTH CALL FOR ACCESS

The 15th call for proposals has been launched in April, 2016 inviting researchers worldwide to apply for access to one of the large installations for high magnetic fields collaborating within EMFL.

The four facilities

- LNCMI - Grenoble - France: Static magnetic fields up to 36 T
- HFML - Nijmegen - the Netherlands: Static magnetic fields up to 37,5 T
- HLD - Dresden - Germany: Pulsed magnetic fields to beyond 90 T
- LNCMI - Toulouse - France: Pulsed magnetic fields of long duration to beyond 80 T and on the microsecond scale to beyond 180 T

run a joint proposal program, which allows full access to their installations and all accompanying scientific infrastructure to qualified external users, together with the necessary support from their scientific and technical staff.

Users may submit proposals for access to any of these installations by a unified procedure. The online form for these proposals can be found on the EMFL website (www.emfl.eu/user).

The next deadline for proposals for magnet time is May 16, 2016.

The proposals will be evaluated by a Selection Committee. Selection criteria are scientific quality (originality and soundness), justification of the need for high fields (are there good reasons to expect new results) and feasibility of the project (is it technically possible and are the necessary preparations done). It is strongly recommended to contact the local staff at the facilities to prepare a sound proposal and ideally indicate a local contact. There is no support from the EU available anymore. Therefore, only occasional travel and subsistence support may be provided for users. If such a support is necessary, users are requested to contact the facility.

- You may find more information on the available infrastructures for user experiments on the facility websites.

www.hzdr.de/hld
www.lncmi.cnrs.fr
www.ru.nl/hfml

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

EMFL
European Magnetic Field Laboratory

EMFL USER MEETING IN TOULOUSE

On June 16, 2016 the EMFL organizes its next User Meeting in Toulouse. The purpose of this meeting is to bring together users of the DC installations in Grenoble (LNCMI-G) and Nijmegen (HFML) as well as of the pulsed-field installations in Toulouse (LNCMI-T) and Dresden (HLD) to report on their experiments and exchange information about the opportunities offered by the EMFL facilities.

You may **register online until May 2, 2016** at this address:
usermeeting-2016.lncmi.cnrs.fr

To receive feedback from our users, the User Committee has made a web feedback form which you are kindly requested to fill in at the EMFL website. The results will be discussed during this User Meeting.

Preliminary program for the User Meeting on June 16

8h30 - 9h00	Welcome, coffee
9h00 - 9h30	Overview status EMFL
9h30 - 10h30	Presentation of progress and plans at the facilities
10h30 - 11h00	Coffee break
11h00 - 12h00	3 presentations of 20 minutes by users
12h00 - 13h30	Lunch buffet, poster session
13h30 - 14h30	3 presentations of 20 minutes by users
14h30 - 15h30	User Committee meeting
15h30 - 16h00	Coffee break
16h00 - 16h30	User Committee report
16h30 - 16h45	Discussions and closure
16h45 - 17h30	Tour of the new LNCMI building for those interested

Figure: New LNCMI building.

EMFL RECEIVES ESFRI LANDMARK STATUS

The European Strategy Forum on Research Infrastructures (ESFRI) has awarded the European Magnetic Field Laboratory (EMFL) the "Landmark" status in the new ESFRI Roadmap list. EMFL is now one of the 29 Landmarks: pan-European research infrastructures which ensure that scientists in Europe have access to world-class facilities, enabling them to do cutting-edge research. The status represents full recognition of the established EMFL, with the formation of the EMFL AISBL legal entity, the incorporation of the Engineering and Physical Sciences Research Council (EPSRC) as a new member and an overall growth in the high field scientific domain.

The EMFL mission for the four high field facilities in Europe (LNCMI Grenoble & Toulouse, HFML and HLD) is to develop and operate world class high magnetic field facilities and to use them for excellent research by both in-house and external users. High magnetic fields are one of the most powerful tools available to scientists for the study, the modification and the control of the state of matter. EMFL provides the highest possible fields (both continuous and pulsed) for its researchers.

The founding members of the EMFL are the French Centre National de la Recherche Scientifique (CNRS), the German research center Helmholtz-Zentrum Dresden-Rossendorf (HZDR) and the Dutch collaboration between Radboud University Nijmegen and the Foundation for Fundamental Research on Matter (FOM).

Nigel Hussey (Director of the HFML and member of the EMFL Board): "Receiving the Landmark status by ESFRI underlines the success of the long-term cooperation among the EMFL partners, initiated by my predecessor Jan Kees Maan. Within the FP6 framework, this cooperation has evolved into the founding of EMFL during the FP7 project. EMFL is a clear example that a distributed network of research infrastructures, providing access to high quality experimental facilities through a single access point and selection committee, can be extremely beneficial for the researchers."

NEW CRYO-MECHANICAL DESIGN FOR THE 43 T GRENOBLE HYBRID MAGNET

Pierre Pugnat, LNCMI Grenoble

A new hybrid magnet aiming for continuous fields of 43 T and more is being built at the EMFL site in Grenoble. This ambitious project will be realized through a close collaboration between the Centre National de la Recherche Scientifique (CNRS) and the French Alternative Energies and Atomic Energy Commission (CEA).

By combining a resistive insert, made out of Bitter and polyhelix coils, with a large-bore superconducting outsert, an overall continuous magnetic field of at least 43 T is aimed at being produced in a 34 mm warm bore aperture. The various hybrid magnet configurations that will be available for the scientific community are given in the Table. The superconducting coil relies on the novel development of a Nb-Ti/Cu Rutherford Cable On Conduit Conductor (RCOCC) cooled down to 1.8 K by a bath of superfluid helium at atmospheric pressure and will produce a nominal magnetic field of 8.5 T in a 1.1 m cold bore diameter. The first cool-down and the commissioning phase are planned for the end of 2018.

During the final design review, which was held at Grenoble in February 2016, the members of the Technical Advisory Committee gave constructive recommendations: namely Krzysztof Brodzinski (CERN), Andries den Ouden (HFML-EMFL), Alain Hervé (Chairman, University of Wisconsin-Madison), Hans J. Schneider-Muntau (Former Chief Technology Officer of the NHMFL), and Andrzej Siemko (CERN).

Magnet configuration	Power (MW)	Warm bore dia. (mm)	DC Field (T)
Hybrid-1	24 + 1.3 [a]	34	43
Hybrid-2	12 + 0.8 [a]	34	34
Hybrid-3	18 + 1 [a]	170	27
Hybrid-4	12 + 0.8 [a]	376	17.5
Super-conducting	0.3 [b]	800	8.5

[a] Electrical consumption of magnet powering, water cooling pumps and cryoplant
[b] Electrical consumption of the cryoplant alone

Table: Modularity of the LNCMI hybrid magnet user platform

This project is funded by the CNRS, the French Ministry of Higher Education and Research in the framework of the "Investissements pour l'avenir" LaSUP (Large Superconducting User Platform), the European Funds for Regional Development (FEDER) and the Rhône-Alpes region.

Figure: Members of the review committee, of the team of the hybrid magnet project, and of the LNCMI management in front of the first single pancake prototype of the superconducting wire. The assembly of the 12 km of RCOCC will start in April this year at LNCMI Grenoble after a thorough R&D phase.

Status of the 43-T Hybrid Magnet of LNCMI Grenoble, P. Pugnat, R. Barbier, C. Berriaud, R. Berthier, G. Caplanne, F. Debray, P. Fazilleau, P. Hanoux, B. Hervieu, P. Manil, F. Molinié, C. Pes, R. Pfister, Y. Queinec, M. Pissard, L. Ronayette, C. Trophime, and B. Vincent, IEEE Transactions on Applied Superconductivity **26**, 4302405 (2016).

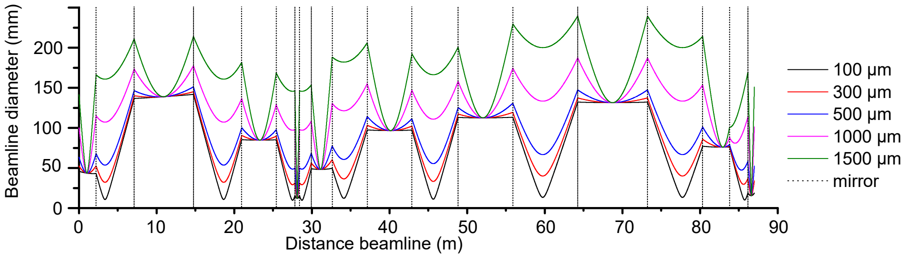
Contact: pierre.pugnat@lncmi.cnrs.fr

HFML MAGNET COMBINED WITH FELIX TERAHERTZ LASER

Since October 2015, the High Field Magnet Laboratory (HFML) in Nijmegen is functionally connected to its neighbor, the FELIX Laboratory which houses free-electron lasers for infrared experiments. The established beamline travels an 86 meter aligned optical path from FELIX to HFML, and is guided by 41 gold coated mirrors.

The combination of FELIX's radiation in the infrared region and the continuous high magnetic fields at HFML offers local and visiting scientists the possibility to study matter and materials in conditions that cannot be found anywhere else in the world.

FELIX's radiation energies match magnetic excitations such as cyclotron and spin resonances in high magnetic fields. Furthermore excitations in solids - like the superconducting gap and antiferromagnetic resonances - are at the same energy. A joint FELIX-HFML research group exploits these possibilities.



Visualization of the 80 meter beamline between FELIX and HFML. Every vertical stripe represents a mirror. © HFML

EMFL ANNUAL REPORT 2015

Becoming a legal entity and welcoming a new EMFL partner with the Engineering and Physical Sciences Research Council (EPSRC) from the UK were just two highlights of the year 2015. For an extensive review of this eventful year for the European Magnetic Field Laboratory the EMFL Annual Report has now been published.

You may download the report at the EMFL website:
www.emfl.eu/outreach/annual-report

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Publisher:
Helmholtz-Zentrum Dresden-Rossendorf
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Printing:
reprogress GmbH

Layout:
Pfefferkorn & Friends, www.pfefferkornundfriends.de

EMFL News, the newsletter of the European Magnetic Field Laboratory, is published quarterly. Contact: contact@emfl.eu

printed on FSC-certified paper

ISSN 2196-0909
1/2016, published: April 2016
www.emfl.eu