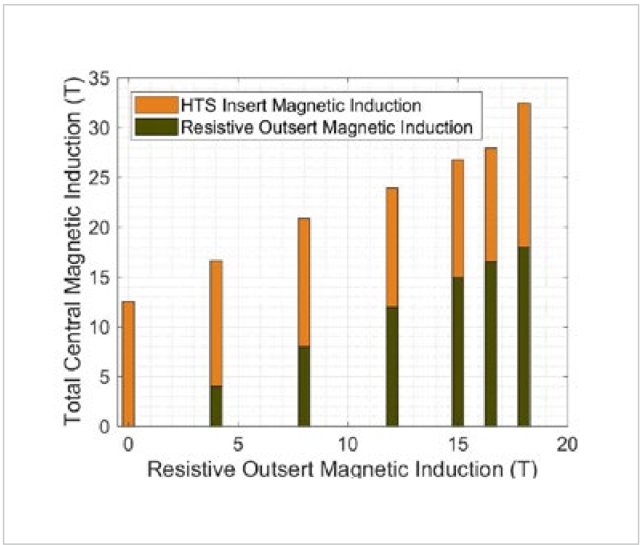
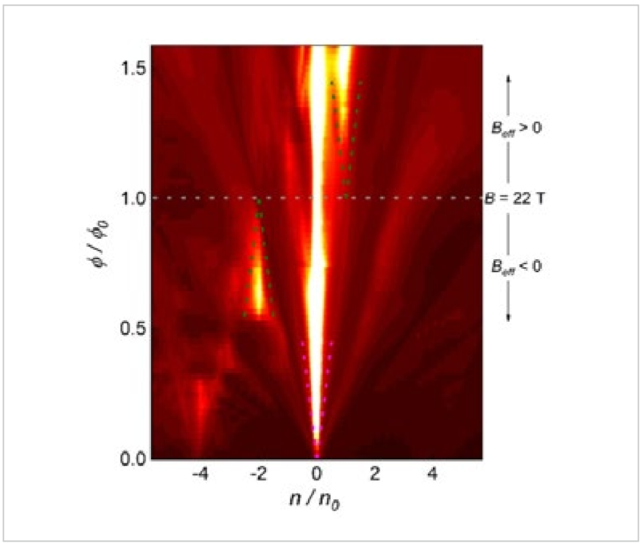
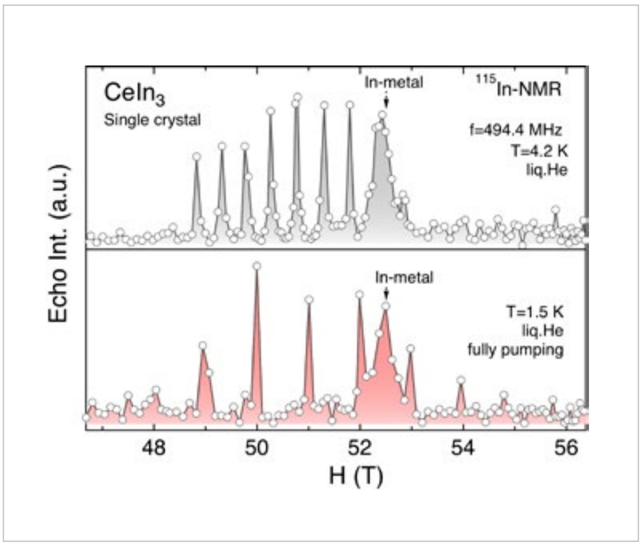
European Magnetic Field Laboratory

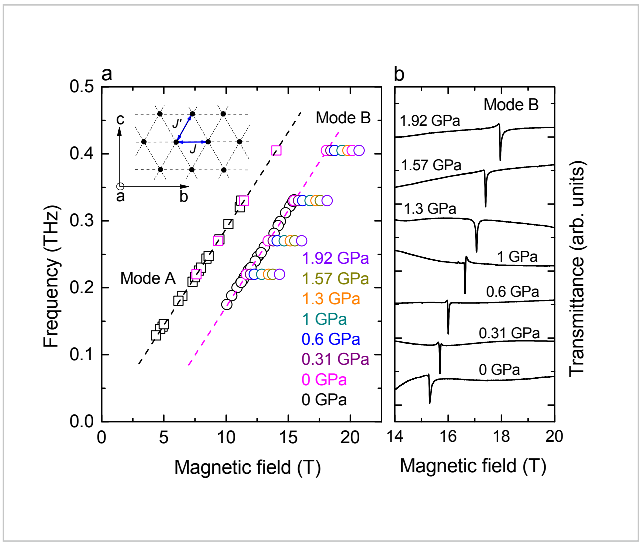
EMFLNEWS

N°1 2019









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www.emfl.eu

DEAR READER

The EMFL has started its fifth year of legal existence and, according to the statutes, a new chairman had to be elected. For this reason, it is now my pleasure to chair EMFL for the next two years. I would like to take this opportunity to thank Jochen Wosnitza for his excellent chairmanship during the last two years.

This is the first EMFL Newsletter of 2019, which is again full of scientific and technical highlights that illustrate the good shape the European high-field research is in. You will also find the announcement of the annual EMFL User Meeting, that this time will be organized in Warsaw on June 25th. This meeting is an opportunity to learn about ongoing and planned EMFL developments, and to give your own vision on how EMFL should evolve in the future. We are looking forward to your participation.

Geert Rikken
Director LNCMI
Chairman EMFL

MEET OUR PEOPLE

Olivier Jay – LNCMI Grenoble

After a Master's degree in chemistry and materials science at the University of Evry Val d'Essonne near Paris, I had the opportunity to do a PhD in materials science co-supervised by the Materials and Processes Science and Engineering Laboratory (SIMaP) in Grenoble and the Multi-Scale Additive Manufacturing Lab (MSAM) at the University of Waterloo (Canada). During my PhD work, I have aimed at finding the key parameters to adapt the microstructure of a MgCa alloy in the frame of biodegradable implants. It is from this experience that I have acquired a taste for microstructural engineering to provide macro properties to a metal.

I joined the LNCMI team at the beginning of 2017 in order to participate in the R&D of the materials for the resistive magnets. I am in contact with industrial partners and academic collaborators for experiments and characterizations. The goal is to find the proper metallurgy to enhance the properties of the materials in view of their application. Thus, the levers range from the choice of the alloy to the thermomechanical treatments to be applied during the manufacturing steps. I am also interested in the monitoring and the modeling of the resistive parts of the magnets.

Working at the LNCMI is particularly enriching due to the international dimension of the environment and the multidisciplinary of the people who all have their own background. I also like the stimulation that is leading us to overcome the challenges that we encounter, all of this being made in order to provide high-performance and user-friendly installations for scientific research.
Thank you for your time! And see you soon!

Olivier Jay

THE HIGH FIELD HTS INSERT NOUGAT REACHED A RECORD FIELD OF 32.5 T

Jung-bin Song, X. Chaud, F. Debray, LNCMI-Grenoble and P. Fazilleau, T. Lécrevisse, CEA Saclay

The High Temperature Superconductor (HTS) team at LNCMI has set a new world record by producing a magnetic field of 32.5 T for a period of several minutes. With this, EMFL is paving the way for the production of a very intense magnetic field - from 30 to 50 T - continuously, by devices that are completely superconducting and, therefore, particularly energy efficient. In the frame of EMFL, the development of HTS inserts aims at enabling long-duration experiments above 23 T at a much lower cost. Many areas of research will benefit: NMR spectroscopy, thermonuclear fusion, magnetic levitation, etc.

To produce very intense magnetic fields - up to 45 T - it is currently necessary to combine an external superconducting magnet with an internal copper coil. With a power consumption of several tens of megawatts, these hybrid devices are very energy intensive. Moreover, the duration of experiments are limited to a few hours. To overcome these two problems, the solution would be to use a central superconducting winding, just like the external winding. The use of „classical" superconductors is unfortunately excluded. When the magnetic field exceeds 23 T, these materials become normal. The solution is to use materials such as cuprates, hereby called HTS, which remain superconducting up to magnetic fields of tens of teslas.

Developed in the CNRS / LNCMI laboratory in Grenoble, the HTS insert Nougat is the result of a CEA-CNRS collaboration, funded by the French Research Agency ANR. The use of the innovative technique „Metal-as-Insulation" made it possible to ensure stable operation and eliminates any risk of irreversible damage in the event of an incident [1]. By co-winding the HTS tape with a metal ribbon, without isolation and without impregnation, allows the redistribution of the current between the winding turns in case of local HTS failures with excellent protection against excessive overheating, and provides the additional mechanical reinforcement necessary to counteract the very high magnetic forces at these field values.

Construction and Test of a 7 T Metal-as-Insulation HTS Insert Under a 20 T High Background Magnetic Field at 4.2 K, Jung-Bin Song , Xavier Chaud , Benjamin Borgnic , François Debray, Philippe Fazilleau, and Thibault Lécrevisse,
IEEE Trans. Appl. Supercond. **29**, 4601705 (2019).

The test campaign of the high-field HTS Nougat insert was successfully conducted at the CNRS / LNCMI in Grenoble. The insert reached twice its nominal operating point of 30 T, of which 12 T were generated by the superconducting magnet alone. The insert operated more than 6 minutes above this value with dwells at 31 T, then 32 T and a new world record was set for a superconducting insert of this size (useful diameter of 38 mm) with a central magnetic field of 32.5 T of which 14.5 T are produced by the superconducting magnet only. This result demonstrates that the „Metal-as-Insulation" technology is now mature. A magnet generating magnetic fields greater than 30 T with an HTS insert is now feasible. This work also paves the way for significant energy savings, as it partially can replace experiments on multi-megawatt resistive installations of a few tens of kilowatts with superconducting magnets.

Figure 1: The HTS insert NOUGAT after assembling of its 9 double pancakes and overbanding, ready to be instrumented and mounted.

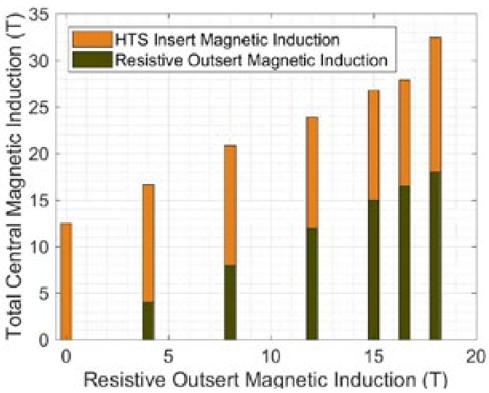

Figure 2: Representation of several operating points reached as a function of external background field.

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INSULATING STATES OF REPLICA DIRAC FERMIONS IN GRAPHENE SUPERLATTICES

Sergio Pezzini, Steffen Wiedmann, Uli Zeitler, HFML Nijmegen

Two-dimensional layers of graphene and hexagonal boron nitride (hBN) both have a honeycomb atomic structure, with a slight lattice mismatch of 1.8 %. When placing graphene on top of hBN one forms a so-called moiré pattern, with a large periodicity of $\lambda \approx 15$ nm in case of perfect crystallographic alignment (Figure (a)). Subjecting these moiré superlattices to high magnetic fields creates a fractal energy spectrum in the two-dimensional electron system, the so-called Hofstadter butterfly. More specifically, every time that rational values of flux quanta $\phi_0 = h/e$ thread the superlattice unit cell, replica of the original Dirac fermions are created. At $\phi/\phi_0 = 1$, these new particles behave as if subjected to an effective magnetic field $B_{eff} = B - 22$ T.

Researchers from HFML-RU/FOM in Nijmegen, in collaboration with colleagues from the University of Manchester, have investigated the Landau quantization of these replica Dirac fermions using temperature-dependent magnetotransport experiments in magnetic fields up to 35 T. The study revealed that the replica Dirac particles form field-induced insulating states, with an energy gap for both the bulk and edge excitations, reminiscent of that of the "original" ones. In Figure (b) one can observe such states as bright areas in the color-map of the two-terminal resistance, corresponding to regions of low (effective) filling factor. The insulating states were characterized quantitatively by determining the field dependence of their energy gaps, estimated from temperature activation of the four-terminal resistance. Combining these data with a simple theoretical model, the researchers realized that the replica particles created at 22 T have reduced Fermi velocity and a gap at the Dirac point. These results open the possibility of using magnetic fields with tuned two-dimensional superlattices to create Dirac fermions with on-demand Fermi velocity and gap size.

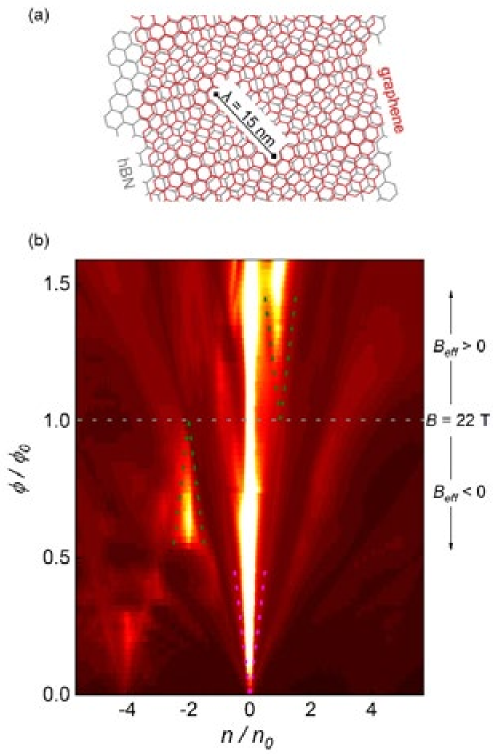

Figure: (a) Sketch of single-layer graphene aligned on top of hBN. The lattice periodicities and mismatch are exaggerated to allow easier visualization of the moiré superstructure. (b) Color plot of the two-terminal resistance measured at 1.5 K on an aligned graphene/hBN Hall-bar device (fabricated at University of Manchester). The x-axis (y-axis) indicates the number of electrons (flux quanta) per superlattice unit cell. The dashed magenta (green) lines delineate the regions of (effective) filling factor less than 1 investigated for the original (replica) Dirac particles.

Field-induced insulating states in a graphene superlattice, S. Pezzini, S. Wiedmann, A. Mishchenko, M. Holwill, R. Gorbachev, D. Ghazaryan, K. S. Novoselov, and U. Zeitler, Phys. Rev. B **99**, 045440 (2019).

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PULSED-FIELD NMR STUDY OF $CeIn_3$ UP TO 56 T

Yo Tokunaga, JAEA Tokai, Nicolas Bruyant, LNCMI-Toulouse, and Ilya Sheikin, LNCMI-Grenoble

Heavy-fermion materials exhibit a diverse range of fascinating phenomena including quantum phase transition (QPTs), non-Fermi-liquid behavior, and novel states of matter such as unconventional superconductivity. The application of high magnetic fields often induces additional phase transitions, such as metamagnetic and Lifshitz transitions. In many cases, however, the exact origin of field-induced phase transitions in heavy-fermion compounds remains poorly understood.

$CeIn_3$ is one of the simplest and best-studied heavy-fermion compounds. At ambient pressure and zero magnetic field, it exhibits antiferromagnetic (AFM) order below 10 K. A small dome of superconductivity emerges around a pressure-induced QPT from the AFM to paramagnetic (PM) phase. The AFM order can be also suppressed by a magnetic field, in which a field-induced QPT occurs at the critical field H_c, which varies from 60 to 80 T, depending on the field orientation. However, a QPT is not the only feature induced in $CeIn_3$ by high magnetic fields. Indeed, a clear anomaly was discovered in tunnel diode oscillator measurements at $H^* \approx 45$ T, well below H_c. The physical origin of this transition, or crossover, is at present obscure. A possible explanation for this feature is a field-induced change of the magnetic and/or crystal structure.

In order to shed more light on the origin of the high-field anomaly in $CeIn_3$, researchers from Grenoble and Toulouse, together with Japanese colleagues, performed a high-magnetic-field NMR study using a pulsed magnet. This was the first successful pulsed-field NMR experiment in a heavy-fermion compound. A clear change in the NMR spectrum between 4.2 K and 1.5 K (Figure) confirms that a magnetic phase transition from PM to AFM states occurs between the two temperatures. This in turn ensures that the metallic crystal in the pumped ^4He cryostat stayed well below ~4 K despite possible heating due to the high-field pulse. No visible change was detected in pulsed-field NMR spectra across H*. Thus, the 45 T anomaly in $CeIn_3$ cannot be simply ascribed to a field-induced change of magnetic or crystal structure at H*.

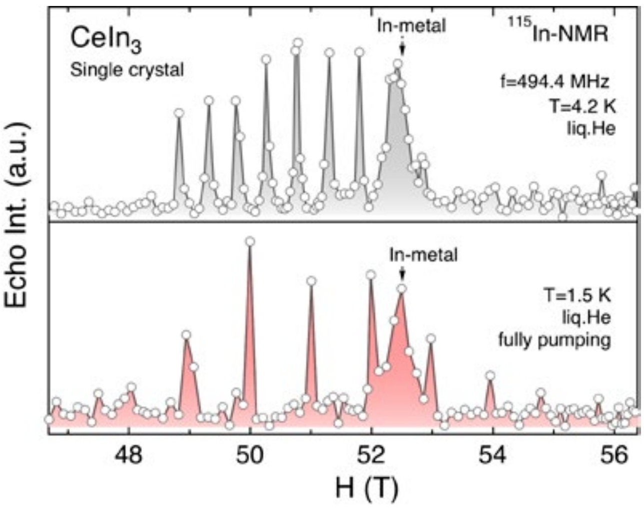

Figure: Field-swept NMR spectra obtained at two temperatures in a pulsed magnet with a fixed NMR frequency of 494.4 MHz.

High-field phase diagram of the heavy-fermion metal $CeIn_3$: Pulsed-field NMR study on single crystals up to 56 T, Y. Tokunaga, A. Orlova, N. Bruyant, D. Aoki, H. Mayaffre, S. Krämer, M.-H. Julien, C. Berthier, M. Horvatić, N. Higa, T. Hattori, H. Sakai, S. Kambe, and I. Sheikin, Phys. Rev. B **99**, 085142 (2019).

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PRESSURE TUNING OF EXCHANGE COUPLINGS IN A FRUSTRATED MAGNET

Sergei Zvyagin, HLD Dresden

Spin-1/2 triangular-lattice Heisenberg antiferromagnets represent one of the most important classes of frustrated quantum magnets, demonstrating a complex interplay between geometrical frustration, quantum fluctuations, and magnetic order. In spite of their simple magnetic structures (Figure, inset), they possess highly unusual magnetic properties and a very rich – and not fully understood – phase diagram. One major obstacle in this area of research is the lack of materials with appropriate, ideally tuned, magnetic parameters. Using Cs_2CuCl_4 as a model system, we demonstrate an alternative approach, where, instead of the chemical composition, the spin Hamiltonian is altered by hydrostatic pressure. The approach combines high-pressure high-field electron spin resonance (ESR), performed at the Tohoku University in Sendai, Japan, and magnetization measurements, done at the National High Magnetic Laboratory in Tallahassee, USA. The results allowed us not only to quasi-continuously tune the exchange parameters, but also to accurately monitor them by measuring the pressure-dependent shift of the ESR lines (Figure). The application of a pressure of up to about 2 GPa increases the exchange-coupling parameters in this compound by up to 70%, triggering, at the same time, a cascade of new low-temperature field-induced phase transitions, absent at zero pressure.

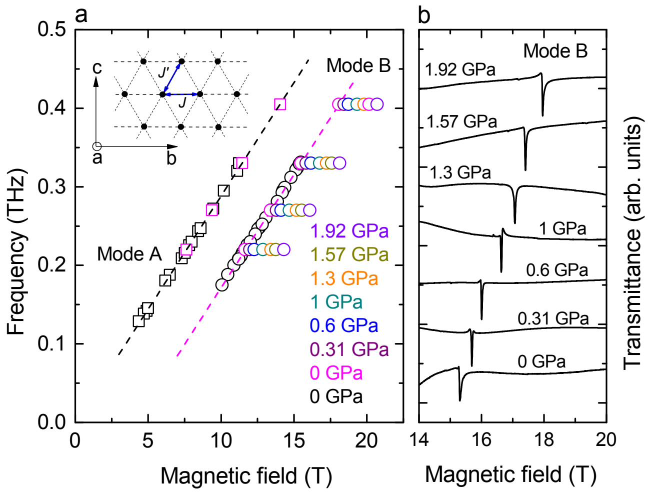

Figure: Pressure dependence of ESR in Cs_2CuCl_4 at 1.9 K. a) Frequency-field diagram of magnetic excitations at different pressures, i.e., acoustic (mode A) and optical (mode B) magnon. The inset shows a schematic picture of magnetic sites and exchange couplings in a triangular layer of Cs_2CuCl_4. b) ESR spectra of the optical magnons taken at a frequency of 330 GHz at different pressures (the spectra are offset for clarity).

Pressure-tuning the quantum spin Hamiltonian of the triangular lattice antiferromagnet Cs_2CuCl_4, S. A. Zvyagin, D. Graf, T. Sakurai, S. Kimura, H. Nojiri, J. Wosnitza, H. Ohta, T. Ono, and H. Tanaka, Nat. Commun. **10**, 1064 (2019).

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OPENING OF THE CALL FOR ACCESS NO. 21

The 21st call for proposals has been launched on April 15th 2019 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 up to 99 T and on the microsecond scale up to 200 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

Please note that each experiment carried out on our high magnetic field installations must be followed up by a progress report and your publication record filled out online on the EMFL website. Please be aware that this information will also be made available to the Selection Committee.

To further improve our user program your feedback to the user committee is highly appreciated.
Please find the form on the EMFL website.
https://emfl.eu/SelCom/UserCommittee/feedbackform.php

The next deadline for proposals for magnet time is May 15, 2019.
Proposals received after the deadline, that are considered of sufficient urgency, may be handled as they arrive and fit into any available time.

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.

Please do acknowledge any support under this scheme in all resulting publications with „We acknowledge the support of the HFML-RU/FOM (or HLD-HZDR or LNCMI-CNRS), member of the European Magnetic Field Laboratory (EMFL)." UK users should, in addition, add "A portion of this work was supported by the Engineering and Physical Sciences Research Council (grant no. EP/K016709/1)."

> 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

EMFL
European Magnetic Field Laboratory

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

2.5 MILLION ERC ADVANCED GRANT TO STUDY SUPERCONDUCTIVITY UNDER EXTREME CONDITIONS

Nigel Hussey, HFML Nijmegen

Experimental physicist Nigel Hussey has received a prestigious € 2.5 million grant from the European Research Council (ERC) to study the flow of charge in exotic metals and superconductors under extreme conditions. The ultimate goal is to understand superconductivity and create a pathway towards room-temperature superconductors.

Nigel Hussey

Hussey: "This is very challenging. We want to understand how superconductivity works, but nature keeps playing games with us. In order to understand a superconductor, you also need to destroy it and here at our EMFL facility in Nijmegen we use extreme conditions to study the behavior of electrons in the metallic state."

Hussey is interested in how a good metal becomes bad and 'breaks down' all of a sudden. He will use his ERC funding to test his idea that while high-temperature superconductivity is initially borne out of the interaction that causes the electrons to pair up in the superconducting state, it is ultimately destroyed by it, since the scattering becomes so strong that the electronic states required to form the superconductor are themselves destroyed. "With this grant, I have the unique opportunity to set up my own research group dedicated to this task. By exposing exotic metals to extreme conditions like the high magnetic fields at HFML, the intense radiation of the free-electron lasers at the FELIX Laboratory, high pressures, and very low temperatures I hope to find out what exactly happens."

"The scientists that judged my proposal called it controversial, highly ambitious, and on the edge. It's high risk, high gain. But even if my idea is proven wrong, we will nonetheless be one step closer to identifying the physics behind strange-metal behavior. It will be an important key step in the development of a coherent theory for high-temperature superconductivity, which in turn may provide key guiding principles in our quest for materials with ever higher transition temperatures."

HFML-FELIX CONNECTED – HIGH FIELDS AND FREE-ELECTRON LASERS

Users that have visited the EMFL facility in Nijmegen the past year have witnessed the construction of new offices and meeting rooms between HFML and the adjacent FELIX Laboratory. When this EMFL news comes out, all the work is done and HFML is coupled to FELIX. If you now visit HFML, you can use the new joined entrance that is located in the middle part. All HFML and FELIX staff is now housed in the new building. Combining the radiation of the FELIX lasers with the continuous high magnetic fields of the HFML creates exciting new opportunities. Do you want to do a unique experiment that requires both laser beamtime and magnet time? Contact your local contact at HFML or FELIX to discuss the possibilities.

On the photo HFML-FELIX is still under construction. In the middle the connecting building is already visible.

USER MEETING 2019 IN WARSAW

The yearly 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 be hosted by Prof. Adam Babiński (The University of Warsaw, Poland) and will take place on Tuesday, June 25, 2019 in the faculty of Physics of the University of Warsaw. The aim of the meeting is to exchange ideas and experiences, to present scientific results, and to discuss about possibilities for improving the facilities' attractiveness.

Registration is free of charge.
https://emfl.eu/user-meeting-2019-in-warsaw/

We would like to involve you, our users, in the process of defining the meeting's agenda; please inform us of the specific needs in terms of new equipment or facility developments you have today or may have in the future, so that we can provide you with the corresponding information during the meeting. Do not hesitate to suggest themes that you would like to discuss during the meeting.

The user committee has an online feedback form for all users **https://emfl.eu/SelCom/UserCommittee/feedbackform.php**

Also, users can contact the user committee directly via e-mail: **raivo.stern@kbfi.ee**

The User Committee meeting will be chaired by Prof. Raivo Stern (National Institute of Chemical Physics & Biophysics, Tallinn, Estonia). During this day, several talks will be given about the scientific and technical developments in high magnetic fields and all users are invited to present their scientific work during the poster presentation.

LES HOUCHES HERAEUS SCHOOL – "FERMI SURFACE AND NOVEL PHASES IN STRONGLY CORRELATED ELECTRON SYSTEMS" - FERMI SCES

Les Houches, France, October 13th – 18th, 2019

The aim of the school is to deepen the understanding of the physics of correlated electron materials. The lectures will address materials growth, measurements, theory, computation, and general understanding. A comprehensive overview of the fundamental ideas, current status, recent developments, and perspective future directions in the field will be attempted.

This school is addressed to graduate students and young researchers in the field of correlated-electron materials. The participants will be selected according to their scientific qualification and their previous knowledge.

The confirmed lecturers and speakers are: Ernst Bauer, Silke Biermann, Antony Carrington, Alexander X. Gray, Elena Hassinger, Maria Hermanns, Cornelius Krellner, Matthieu LeTacon, Jochen Mannhart, Peter Oppeneer, Stephane Raymond, Lucia Reining, Peter Riseborough, and Denis Vyalikh.

The school fee of 400 EUR covers meals and accommodation. A large number of grants are available reducing the registration fee to 100 EUR for most of the participants (formal application for this grant is required when registering). The number of participants is limited to 50.

For further information about topics, speakers, and venue and on how to apply, please see:

http://fermi-sces.grenoble.cnrs.fr/

For the organizers: Sebastien Burdin, Christoph Geibel, Claudine Lacroix, Pierre Rodiere, Gertrud Zwicknagl
Deadline for applications: April 30th, 2019; acceptance will be communicated before May 10th.

UPCOMING EVENTS

1. Gordon Research Conference: Superconducting Materials and Phenomena, Les Diablerets, Switzerland, May 12-17, 2019.
https://www.grc.org/superconductivity-conference/2019/

2. Superstripes 2019, Ischia, Italy, June 23-29, 2019.
https://www.superstripes.net/

3. Joint European Magnetic Symposia (JEMS) 2019, Uppsala, Sweden, August 26-30, 2019.
https://jems2019.se/

4. IRMMW-THz 2019, 44th International Conference on Infrared, Millimeter, and Terahertz Waves, Paris, France, September 1-6, 2019.
https://irmmw-thz2019.org/

5. EASTMAG-2019, VII Euro-Asian Symposium "Trends in Magnetism", Ekaterinenburg, Russia, September 8-13, 2019
http://eastmag2019.imp.uran.ru/

6. MT26, International Conference on Magnet Technology, Vancouver, Canada, September 22-27, 2019.
http://mt26.triumf.ca/

7. SCES 2019, International Conference of Strongly Correlated Electron Systems, Okayama, Japan, Sep. 23-28, 2019.
http://sces2019.org

8. EMFL 2019 User Meeting, Poland, June 25, 2019
https://emfl.eu/user-meeting-2019-in-warsaw/

9. Les Houches Heraeus School – "Fermi Surface and Novel Phases In strongly correlated electron systems"
Les Houches, France, October 13th – 18th, 2019
http://fermi-sces.grenoble.cnrs.fr/

10. Flatlands beyond Graphene 2019
2 – 6 September 2019, Toulouse, France
https://www.hfml.ru.nl/flatlands2019/

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