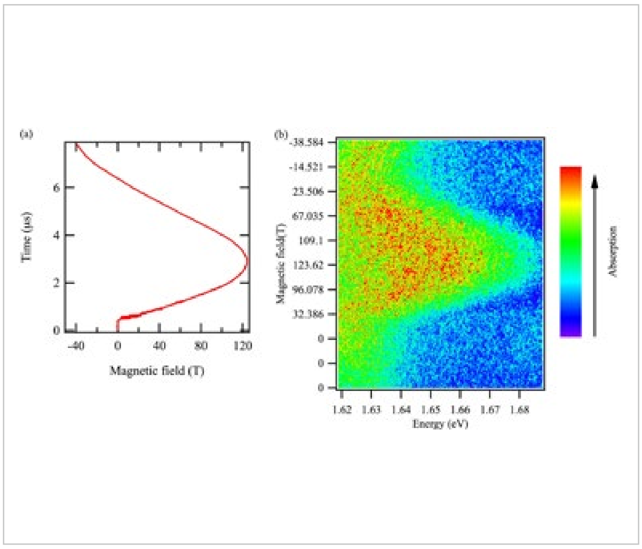
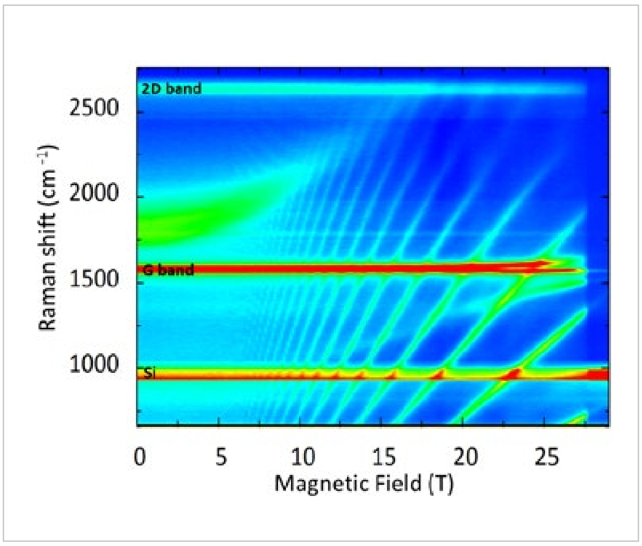
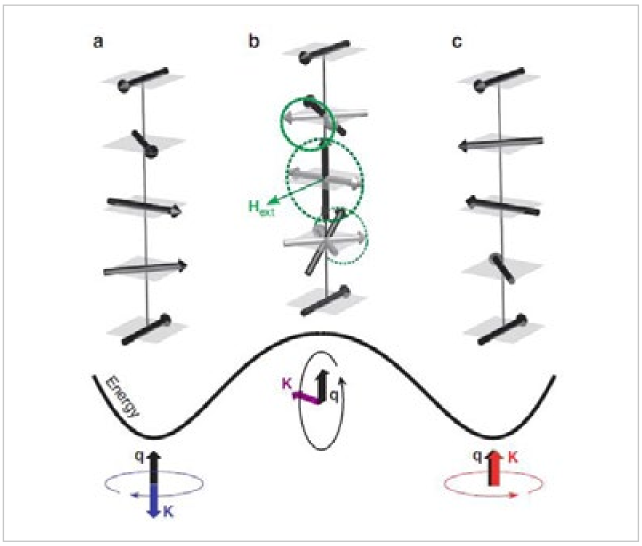
EMFL
European Magnetic Field Laboratory

EMFLNEWS

N°4 2016







CONTENTS

DEAR READER

First of all let me, on behalf of the entire EMFL staff, wish you a happy and prosperous 2017, with many Teslas and lots of great science.

The issue before you will show that 2016 was already a good year for high magnetic field science, with many exciting new scientific results pouring out of the EMFL facilities.

In view of the many promising projects going on within its walls, I am certain that EMFL will be able to contribute to making 2017 even better.

Geert Rikken
Director LNCMI, Chairman EMFL

MEET OUR PEOPLE

Matthias Hoffmann, HFML Nijmegen

„I studied IT and Mechanical Engineering at TU in Berlin, where I am originally from. Subsequently, I started working at the Helmholtz-Zentrum Berlin (HZB) in 2010, where I was in charge of the production and quality control of the hybrid-magnet project. Parts for this system were being designed, produced and assembled all over the world, in the USA, Switzerland and Italy. Eventually, the partially mounted system was transported to Berlin, where we finalized the hybrid magnet.

When the hybrid-magnet project was finished, the HFML magnet-development team visited us in Berlin and asked me to join their team. I knew that I would like to build a hybrid magnet again, so I was very happy with the offer and recently moved to Nijmegen with my family. Opposite to the situation in Berlin, there is a development unit with multiple engineers here at the HFML, which makes my job easier.

Since high-field magnets are pretty rare, you don't gain any experience with them during engineering school. Actually, I only saw my first superconducting magnet - the one in Tallahassee - when I was already working in Berlin for one year! A few years later, I think I can say that I feel already pretty specialized in the engineering of hybrid systems.

My first major task at HFML was to test the current leads of the hybrid system. In the component testing phase, which ended in the autumn of 2016, we built various parts such as a superconducting jumper to interconnect the two current leads and set up a test cryostat. Currently, my focus has gradually shifted to other elements of the system such as the superconducting bus between the current leads and the outsert magnet. The thing about hybrid magnets is that you don't know whether the system works, until it works. Therefore, the most exciting moment in the upcoming years will be when we turn on the superconductor for the first time…"

› Matthias Hoffmann, Mechanical Engineer at the HFML

ELECTRONS IN FLAT BANDS

Clement Faugeras, LNCMI-Grenoble

Layered materials can realize different stackings of their individual planes, different polytypes, to compose three-dimensional structures. ABA-stacked graphite is the most stable form of graphite at ambient conditions and the study of thin layers of this material have revealed many interesting phenomena related to the change of the nature of quasiparticles when adding layers one by one. Graphite can also exist in the so-called rhombohedral stacking or ABC stacking, which is less abundant. As a result, studies of this polytype are today limited to its simplest form, the ABC trilayer. Tight-binding models show that a pair of electron bands at zero energy with flat dispersion develops when increasing the number of layers and that the wave functions associated with the flat bands are spatially located on the top and bottom surfaces while other gapped subbands are confined in the bulk of a crystal. This is in clear analogy with crystalline topological insulators. These flat bands are expected to host, yet unexplored, exotic electronic ground states.

We have successfully produced thick layers (~15 layers) of ABC-stacked graphite by mechanical exfoliation of bulk graphite and we have identified their Raman-scattering signatures. Applying a magnetic field perpendicular to the plane of our crystal, induces Landau quantization in the electronic system, a phenomenon directly observable in our magneto-Raman scattering spectra (Figure). Indeed, many magnetic-field-dependent Raman scattering peaks appear and these electronic excitations can be grouped into two families: one arising from the flat bands which evolve linearly with magnetic field, but with a negative energy intercept at B = 0, and another one with negative dispersion with magnetic field arising from the gapped subbands in the bulk. Besides showing that this material exists we have presented its (magneto-)Raman scattering signatures. This work serves as an impetus for further studies on gated structures in order to be able to tune the position of the Fermi level and to place it right in the middle of the flat band.

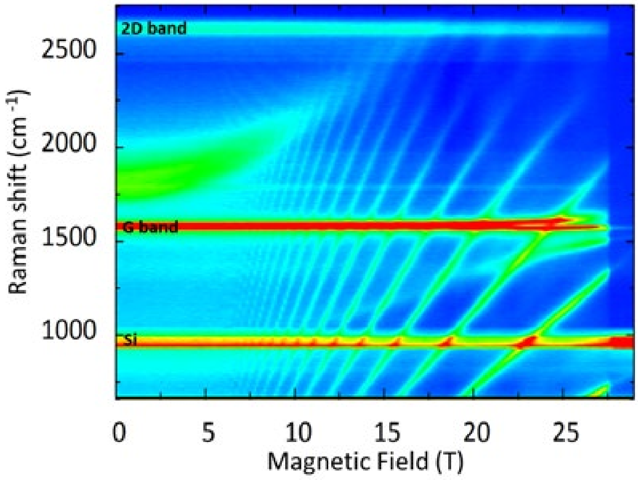


Figure: False color map of the magneto-Raman scattering response of 15 ABC-stacked graphene layers showing electronic excitations within an electronic band with flat dispersion.

Rhombohedral multilayer graphene: A magneto-Raman scattering study, Y. Henni, H. P. Ojeda Collado, K. Nogajewski, M. R. Molas, G. Usaj, C. A. Balseiro, M. Orlita, M. Potemski, and C. Faugeras, NanoLetters **16**, 3710 (2016).

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MAGNETO-OPTICS OF MONOLAYER TUNGSTEN DISULFIDE

Peter Christianen, HFML Nijmegen

Single-layer transition-metal dichalcogenides, such as MoS_2, $MoSe_2$, WS_2, WSe_2, are two-dimensional semiconductors with a honeycomb lattice. Their band structures show a pair of inequivalent valleys (local extrema) at the +K and -K points of the Brillouin zone. The valleys in the conduction and valence bands are separated by a direct band gap in the visible spectral range, resulting in efficient light absorption and emission. The charge carriers in these valleys have, in addition to their real spin, an extra property called pseudospin, accompanied by a magnetic moment.

In a collaboration between the Universities of Regensburg and Münster and the High Field Magnet Laboratory Nijmegen the magneto-optical properties of monolayer WS_2 have been determined. The photoluminescence emission is dominated by neutral and charged electron-hole pairs (excitons). Two distinct types of charged excitons (trions), singlets (X_S^-) and triplets (X_T^-), have been observed, just below the emission line of the neutral exciton X (Figure 1). The magnetic field-induced valley polarization effects shed light onto the exciton and trion dispersion relations in reciprocal space.

A remarkable magnetic-field-induced rotation of the polarized light emission of neutral excitons has been observed (Figure 2). A field-induced valley Zeeman splitting causes a rotation of the emission polarization with respect to the excitation by up to 35° and reduces the linear polarization degree by up to 16%. From these results it is deduced that coherent light emission from the valleys decays with a time constant of 260 fs.

These remarkable properties pave the way to study and utilize valley-dependent phenomena ("valleytronics") by optical means, which is very promising for novel opto-electronic applications.

Magnetic-field-induced rotation of polarized light emission from monolayer WS_2, R. Schmidt, A. Arora, G. Plechinger, P. Nagler, A. Granados del Águila, M.V. Ballottin, P. C. M. Christianen, S. Michaelis de Vasconcellos, C. Schüller, T. Korn, and R. Bratschitsch, Phys. Rev. Lett. **117**, 077402 (2016).

Trion fine structure and coupled spin–valley dynamics in monolayer tungsten disulfide, G. Plechinger, P. Nagler, A. Arora, R. Schmidt, A. Chernikov, A. Granados del Águila, P. C. M. Christianen, R. Bratschitsch, C. Schüller, and T. Korn, Nat. Commun. **7**, 12715 (2016).

Excitonic valley effects in monolayer WS_2 under high magnetic fields, G. Plechinger, P. Nagler, A. Arora, A. Granados del Águila, M.V. Ballottin, T. Frank, P. Steinleitner, M. Gmitra, Jaroslav Fabian, P. C. M. Christianen, R. Bratschitsch, C. Schüller, and T. Korn, Nano Letters **16**, 7899 (2016).

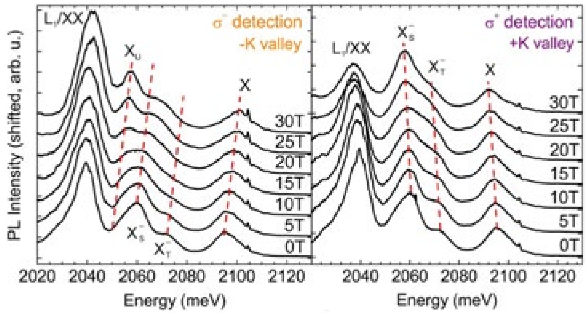

Figure 1: Left (σ−, left panel) and right (σ+, right panel) circularly polarized emission from monolayer WS_2 at 4.2 K and different magnetic fields. Neutral excitons (X) as well as different charged excitons, singlets (X_S^-) and triplets (X_T^-), can be distinguished.

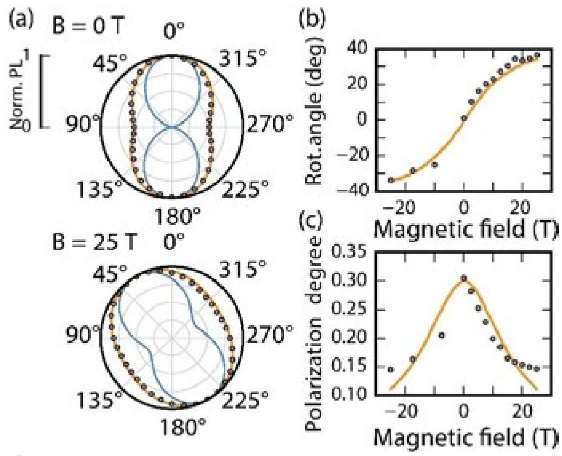

Figure 2: (a) Measured normalized photoluminescence intensity (circles) for monolayer WS_2 as a function of the analyzer angle, under linearly polarized excitation for 0 and 25 T. The blue and orange lines indicate the polarization patterns obtained from different models. (b) Relative rotation angle between the excitation and emission polarization for different magnetic fields. c) Linear polarization degree of the emission as a function of the magnetic field. The orange lines show the global fit to the data using a model taking into account exciton-valley coherence.

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BROADBAND SPECTROSCOPY AT EXTREME MAGNETIC FIELDS: FIRST RESULTS

Alessandro Surrente, Atsuhiko Miyata, Oliver Portugall, and Paulina Plochocka, LNCMI-Toulouse

Magnetic fields exceeding 100 T can be obtained only by semi-destructive methods. In one approach, the magnetic field is generated by a single-turn coil, which explodes during the pulse leaving the cryostat where the sample is mounted intact. Very high magnetic fields can be generated, up to 350 T, at the expense of the pulse duration of approximately 5 µs. In spite of this experimentally challenging environment, sensitive optical measurements can be performed. The first "Megagauss" magneto-spectroscopy setup at the LNCMI-Toulouse uses a monochromatic source and monitors the light transmitted through the sample during the magnetic pulse. During the magnetic field sweep, the optical transmission drops, due to the increased absorption when hitting resonances (e.g. interband Landau-level transitions).

The implementation of an experimental method which provides also spectral resolution is desirable. This can be achieved by using a streak camera equipped with a single scan unit. In this approach, the light transmitted through the sample is redirected to a streak camera, which is triggered to start its sweep just before the start of the magnetic field pulse. In the streak image, each horizontal line corresponds to a spectrum measured at a specific delay with respect to the trigger signal or, equivalently, to a spectrum measured at a different value of the magnetic field. Using a white-light source and such a streak camera, we have recently performed at Toulouse the first magneto transmission measurements of a thin film of methylammonium lead triiodide ($MAPbI_3$), a perovskite semiconductor intensively studied for photovoltaic applications. Preliminary results are shown in the Figure. In panel (a) we show the temporal profile of the magnetic field. In panel (b) we show the corresponding streak image measured at energies around the 1s absorption of $MAPbI_3$. The limit between the green and blue zones represents the 1s state of $MAPbI_3$, which follows the profile of the applied magnetic field.

By a proper choice of the monochromator parameters, the whole energy-magnetic field landscape of interest will now be available in one single field pulse. So far, this is limited to the UV-VIS range, but we are studying the possibility to extend this into the NIR and are looking forward to user proposals using this new setup.

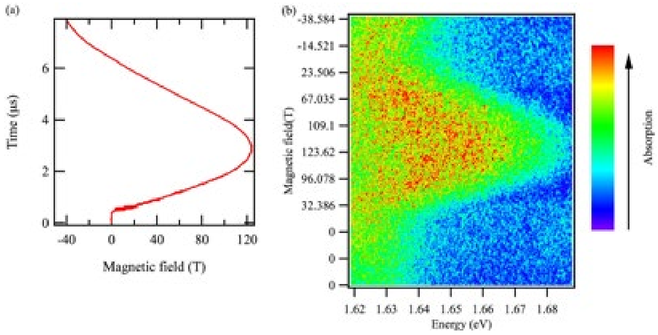

Figure: (a) Temporal profile of the magnetic field generated by the Megagauss installation. (b) Streak image measured during the pulse showing the field-dependent shift of the absorption edge of $MAPbI_3$ at 4 K.

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NON-COLLINEAR HEUSLER ANTIFERROMAGNET Pt_2MnGa

Yurii Skourski, HLD Dresden

Antiferromagnets (AFMs) have attracted increasing attention in state-of-the-art research. Their important role in enhancing the hardness of ferromagnetic electrodes through the exchange-bias effect in microelectronics, has been broadly extended by new perspectives in spintronic applications. AFMs also facilitate current-induced switching of their order parameter owing to the absence of shape anisotropy and action of spin torques through the entire volume. Additional non-trivial spintronic effects originating from a non-vanishing Berry phase might occur in non-collinear AFMs. Non-collinear planar AFMs without mirror symmetry are predicted to exhibit an anomalous Hall, Kerr, magnetic circular dichroism (MCD), and other effects, which were not encountered in AFMs so far.

Scientists from the Max Planck Institute for Chemical Physics of Solids, Dresden, the ILL in Grenoble, and the HLD have studied the new room-temperature tetragonal non-collinear Heusler AFM Pt_2MnGa. Low-field magnetization measurements exhibit a non-saturating (almost linear) increase up to 7 T (Figure 1, left), similar to antiferromagnetic or paramagnetic materials. Only a narrow hysteresis at 2 K (inset in Figure 1) indicates a very weak ferromagnetic component at low temperature. To probe the magnetic response in very high fields, we applied magnetic-field pulses of 60 T. The corresponding magnetization data at 257 and 1.5 K (Figure 1, right) increase monotonically and do not saturate. Only a broadened step-like feature is observed at 1.5 K indicating a metamagnetic transition close to 14 T.

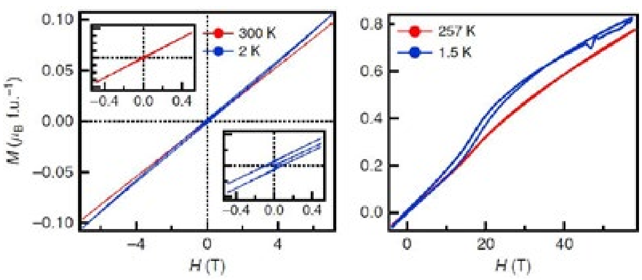

Figure 1: Magnetization of Pt_2MnGa. Field-dependent magnetization hysteresis loops (left) up to 7 T at 2 (blue) and 300 K (red) and (right) up to 60 T at 1.5 K (blue) and 257 K (red). The insets in the left panel show the low-field data in enlarged scale.

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The detailed magnetic structure was determined by neutron-diffraction experiments. The results suggest that the magnetic order is a spiral in the Mn sublattices. Owing to the inversion symmetry, the left- and right-handed spirals are equally stable. The large energy barrier between left- and right-handed spirals can efficiently be overcome via a precessional reorientation of magnetization, induced by magnetic-field pulses perpendicular to the spiral axis (Figure 2). This suggests Pt_2MnGa as a convenient candidate for a non-volatile magnetic memory based on the helicity vector as a bit of information.

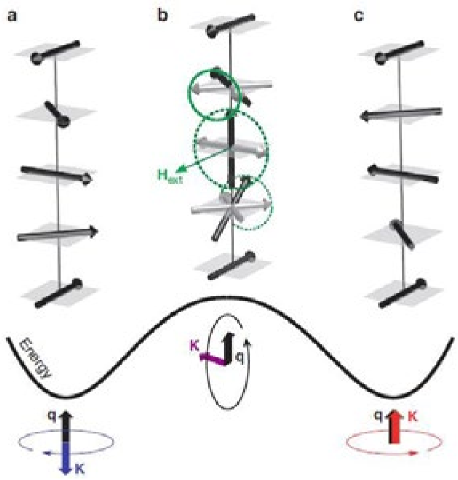


Figure 2: Switching of the magnetic helicity. The application of an external magnetic-field pulse H_{ext} (indicated by the green arrow) perpendicular to the spiral wave vector q causes the precession of local moments (rotating along the dashed green curves), which changes the helicity of a spiral from a left-handed screw (a), through the intermediate cycloidal state (b), finally to the right-handed screw (c).

Room-temperature tetragonal non-collinear Heusler antiferromagnet Pt_2MnGa, S. Singh, S. W. D'Souza, J. Nayak, E. Suard, L. Chapon, A. Senyshyn, V. Petricek, Y. Skourski, M. Nicklas, C. Felser, and S. Chadov, Nat. Commun. **7**, 12671 (2016).

RESULTS OF THE SIXTEENTH CALL FOR ACCESS

On November 15th, 2016, the 16th call for access ended inviting proposals for research requiring access to the large installations for high magnetic fields collaborating within EMFL.

The four facilities

> LNCMI - Grenoble - France: Static magnetic fields to 36 T
> HFML - Nijmegen - the Netherlands: Static magnetic fields to 37.5 T
> HLD - Dresden - Germany: Pulsed magnetic fields to beyond 95 T
> LNCMI - Toulouse - France: Pulsed magnetic fields of long duration, to over 90 T and on the microsecond scale to beyond 180 T

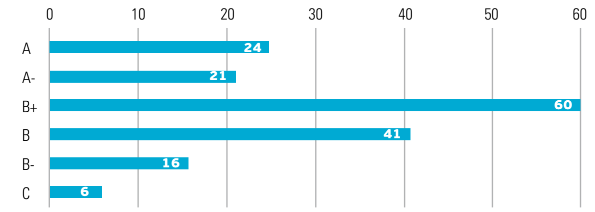
operate a joint transnational access program, which gives full access to their installations and all associated scientific infrastructure to qualified external users, together with the necessary support from their scientific and technical staff.

For this 16th call, 168 applications from 26 different countries were received which have been evaluated by the Selection Committee until December 15th, 2016. The Selection Committee consists of 18 specialists covering the five scientific topics

> Magnetism (66 applications),
> Metals and Superconductors (48 applications),
> Semiconductors (42 applications),
> Soft Matter and Magnetoscience (10 applications),
> Applied Superconductivity (2 applications).

Besides of ranking the proposals the Committee decides on the number of accepted magnet hours or number of pulses.

NEXT CALL :
Launch: April 15, 2017
Deadline: May 15, 2017

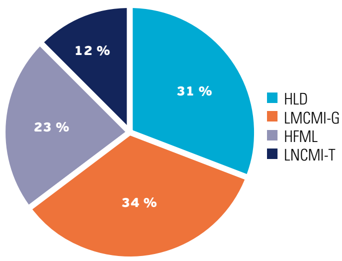


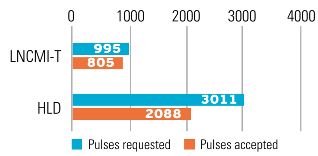
Evaluation of applications

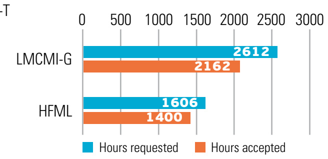
Projects are classified in three classes:
A (excellent proposal to be carried out),
B (should be performed but each facility has some freedom considering other constraints),
C (poor proposal or one that does not need any of the four unique high magnetic field laboratories).

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

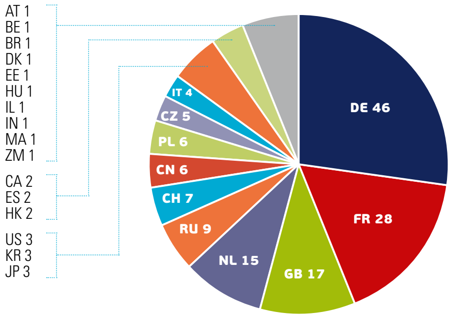
Distribution by facilities
Number of applications







Distribution by countries
Number of applicants



HFML'S UNDERGROUND COOLING WATER TANK "BAPTIZED"

Martin van Breukelen, HFML Nijmegen

On Tuesday November 8, 2016, the HFML celebrated the milestone of reaching the deepest point of the construction of a new underground cooling water tank. HFML director Nigel Hussey "baptized" the tank by symbolically pouring in the first bucket of water, with representatives of the Radboud University and the contractor parties REEF infra, Croonwolterendros and Building Technology.

The HFML is in the process of expanding its cooling capacity by the construction of an underground cooling water tank of 2500 m^3. Excavation work started in early September, and recently the deepest point of the construction was reached. In the meantime, the concrete on the structure floor has been poured, providing a solid foundation. The cooling water tank will be operational in February 2017, allowing the HFML to make efficient use of the extra cooling capacity.

Nigel Hussey: "The HFML offers its high magnetic fields to external users from all over the world, but to produce longer magnet times, expanding the cooling capacity was necessary. This will enable users to stay at maximum fields for up to four hours, significantly increasing the range of experiments that could be carried out at HFML. Moreover, we can now cool our magnets more efficiently by pre-cooling the water in the cooling tank during cold nights." But before that can happen, the tank needs to be filled first. "The first bucket of water is already in. The next 299.999 buckets needed to fill the tank will be in the hands of designated professionals."

The cooling tank will be filled beginning of February, after a commissioning and testing period it will become available for external users.

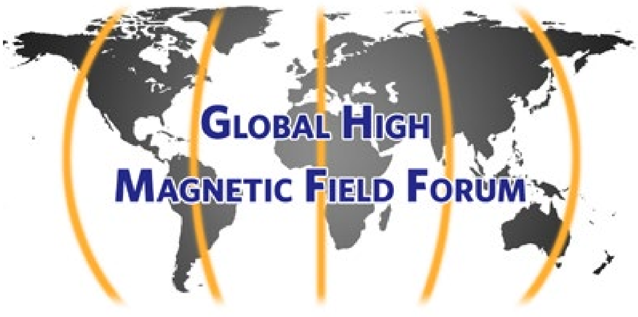
Tank specifications:

Diameter = 21.3 meters
Depth = 7.35 meters
Volume = 2,500 m^3
Location = underground near HFML

Underground cooling water tank "baptized"

Nigel Hussey is baptizing the new cooling tank

GLOBAL HIGH FIELD FORUM: WEBSITE LAUNCHED



High magnetic field research is inherently multidisciplinary and spans physics, materials science, engineering, chemistry, biochemistry, and biomedicine. The historic and still dominant application of high magnetic field research is in condensed-matter physics, in which pioneering discoveries, including Nobel Prize winning discoveries, have resulted due to the unique interaction of magnetic fields on the electronic and magnetic states of all forms of matter.

The Global High Field Forum (HiFF), with EMFL being the European partner, was launched in November 2014 to unite the world's high magnetic field laboratories to work together to:

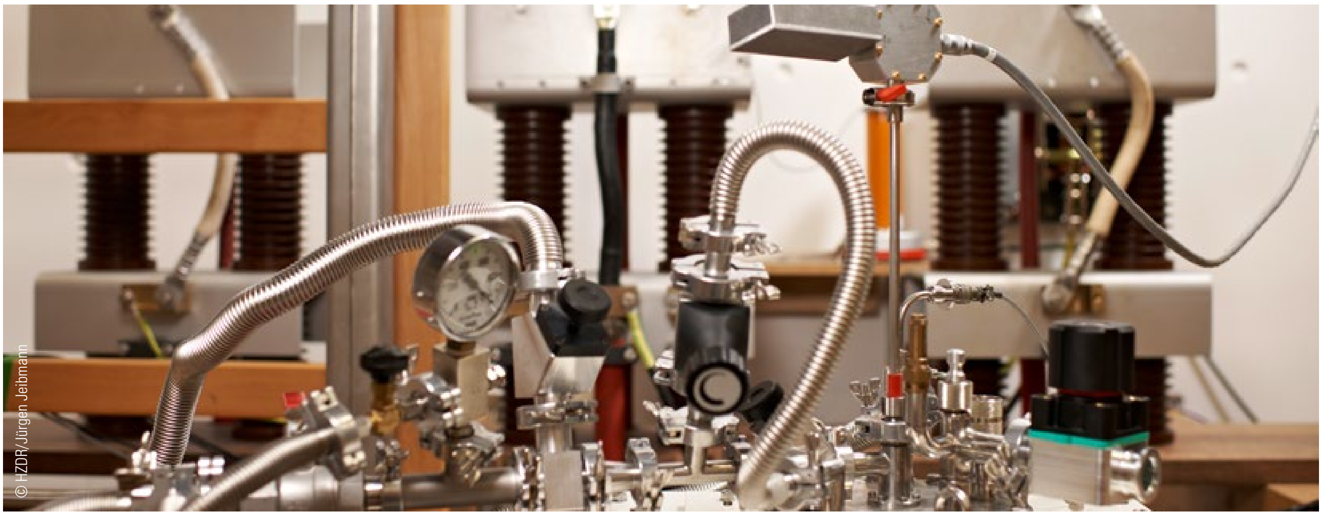
> Promote top-level science through the use of high magnetic fields
> Facilitate access of external users to the facilities best suited to advance their science
> Improve efficient operations of high magnetic field installations
> Stimulate the development and dissemination of new experimental techniques utilizing high magnetic fields
> Cooperate to advance magnet technologies, including the development of new materials specially designed for constructing improved high-field magnets
> Promote the development of new high-field magnets and laboratories
> Serve as a global representative of the high-magnetic-field research community and the laboratories that support their research.

This new collaboration seeks to:

> Bring together world expertise on the operation of facilities dedicated to the generation of the highest magnetic fields for scientific research
> Expand the knowledge base for technologies needed to generate such magnetic fields
> Stimulate worldwide activities promoting scientific research and technology development using the highest magnetic fields.

The next generation of high-field magnets, already called for by the international research community and reports from prestigious research panels, will require substantial advances in our present state-of- the-art; advances best achieved by a global commitment to communication, coordination, and collaboration among the leaders of the world's high-magnetic-field facilities.

You may find more and regularly updated information on the recently launched HiFF website: **http://globalhiff.org**



USER MEETING 2017 IN NOTTINGHAM

The yearly user meeting of the European high field magnet facilities for

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

will be hosted by Prof. Amalia Patanè (The University of Nottingham, UK) and will take place in the School of Physics and Astronomy of the University of Nottingham **on Friday, June 23, 2017**.

The aim of the meeting is to update our users on recent developments in the EMFL facilities, exchange ideas and experiences, present scientific results, and discuss possibilities for joint research programs and improving the facilities attractiveness.

During the meeting several talks will be given by the users and the directors of the EMFL to inform the user community about recent scientific and technical developments in high magnetic fields. Users are also invited to present their scientific work on posters.
Details of the program will soon be announced on the EMFL website: **www.emfl.eu**

Registration is free of charge.

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 could 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: **www.emfl.eu/user/user-committee.html**

Also, users can contact the User Committee directly via e-mail: **UserCommittee@gmail.com**

The User Committee will meet with the users during the day. Chair of the User Committee is Prof. Raivo Stern (National Institute of Chemical Physics & Biophysics, Tallinn, Estonia).

EPSRC
Engineering and Physical Sciences Research Council

Contact: info@emfl.eu

25TH INTERNATIONAL CONFERENCE ON MAGNET TECHNOLOGY

The 25th International Conference on Magnet Technology will take place in 2017 from August 27 to September 1 in Amsterdam, the Netherlands. The conference organization is a joint effort of the Applied Superconductivity and Cryogenics Laboratory at the University of Twente and the High Field Magnet Laboratory at the Radboud University Nijmegen.

Scope of the Conference

The International Conference on Magnet Technology is the most important international forum addressing all aspects of magnet research, development, construction, testing, and operation.

The subject of the 2017 conference MT25 is the technology associated with the construction of coils and magnets. Coils can be part of devices for power, energy, transport, and other applications. Magnets for generating magnetic field can either be of electromagnetic nature comprising turns of a current carrying conductor or be of a permanent magnetic material.

The scope includes structural and insulating materials, superconducting materials, normal conducting materials, cooling technology including cryogenics, power technology, design and analysis, instrumentation and measurement techniques, testing and operational experience.

The objective of the conference is to provide a forum for the exchange of coil and magnet-related technology as well as design and analysis techniques, to diffuse in the scientific community new applications for coils and magnets, to provide an exchange between research activities and industrial applications, and to encourage professional scientists and engineers to follow careers in magnet technology and its applications.

Venue: RAI Congress Center, Amsterdam, The Netherlands
Period: August 27 – September 1, 2017
Abstract submission deadline: March 3, 2017

More information can be found at **www.MT-25.org**

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