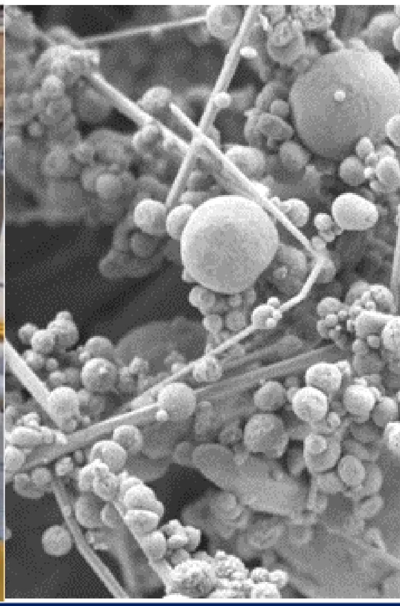
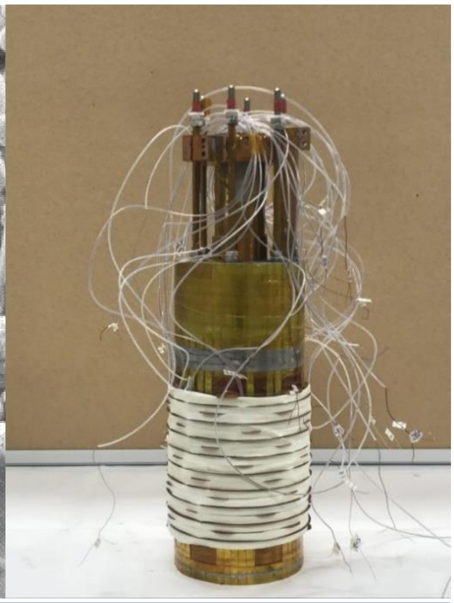
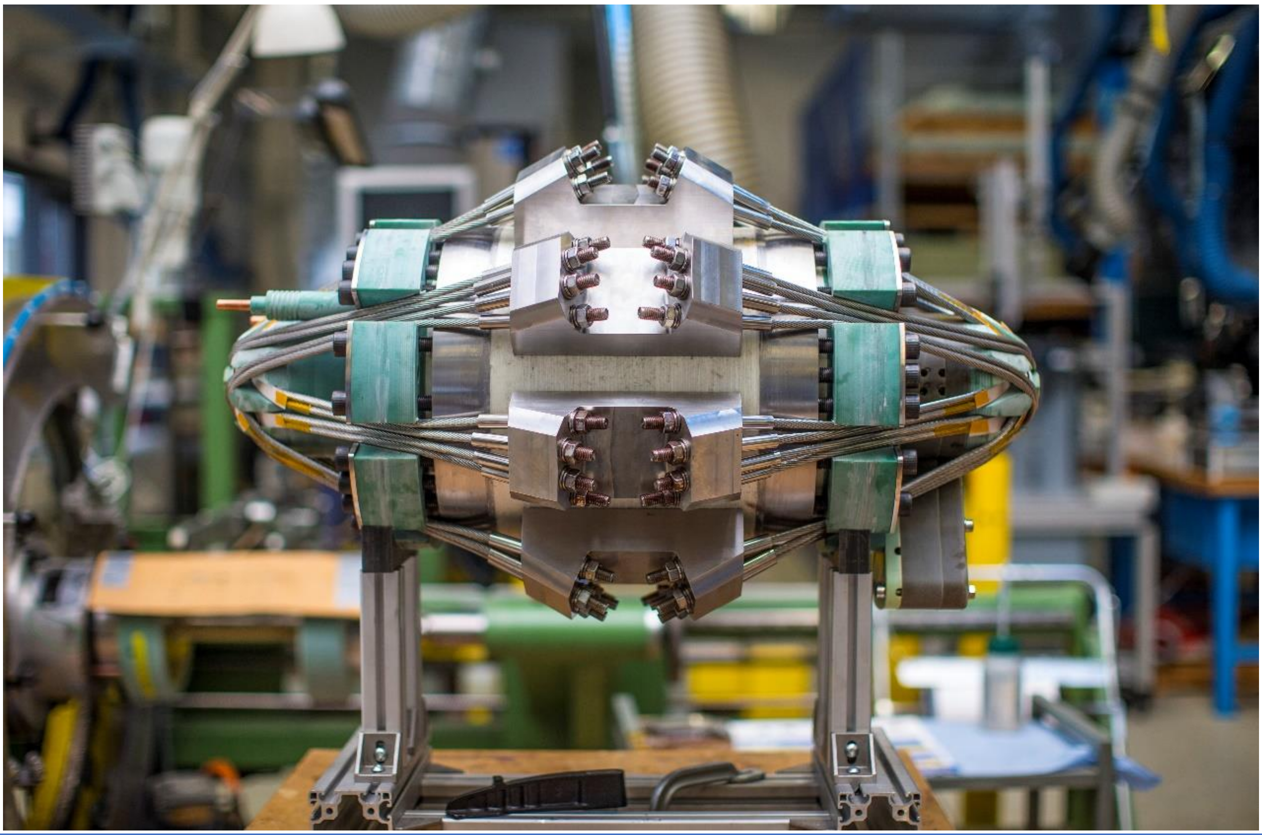
European Magnetic Field Laboratory





EMFL INDUSTRIAL SKILL MAP



Dr Aimée Savourey

EUROPEAN MAGNETIC FIELD LABORATORY | 2022

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 871106

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THE HIGH FIELD FACILITIES IN EUROPE

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INTRODUCTION

The European Magnetic Field Laboratory (EMFL) was founded in 2015 and provides **the highest possible fields** (both continuous and pulsed) for its researchers.

The EMFL is dedicated to unite, coordinate and reinforce the three existing European high magnetic field laboratories – the Dresden High Magnetic Field Laboratory (HLD, Germany), the Laboratoires National des Champs Magnétiques Intenses (LNCMI) in Grenoble and Toulouse (France), and the High Magnetic Field Laboratory in Nijmegen (HFML, The Netherlands) – within a single body as a world-leading infrastructure.

This document aims to highlight the skills, expertise and know-how of all EMFL facilities. It has been created to be a useful tool for all potential industrial partners to facilitate the interaction and communication between them and EMFL researchers and engineers.

This skill map covers all available competences of EMFL and is organized in a special way in order to give an easy access to a large industrial community. The document is divided into four parts: Industrial Applications, Scientific Fields, Experiments and Available Equipment. The two first domains provide a short overview of all research and engineering fields in four EMFL facilities. The available information in these domains will be particularly useful for the "non-magnetic" industrial community - the industries who do not deal with the magnetic field phenomena. Two other domains "Experiments" and "Available Equipment" will be an essential support for the industrial partners that are currently working and familiar with magnetic fields. Here they will find the detailed description of all realized experiments in EMFL and all specific technical equipment available in all EMFL facilities.

Once our industrial partners identify the needed expertise browsing this skill map, they will have a possibility to ask for further information. Detailed contact information is provided on each page.

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HOW TO ACCESS INFORMATION

BROWSE BY INDUSTRIAL APPLICATIONS

Here the EMFL skills are gathered by the actual or possible industrial applications such as energy, sensors, healthcare, metrology, etc.

Classification by industrial application

BROWSE BY SCIENTIFIC FIELDS

Each research axe or team of EMFL is ranged here by the scientific field or scientific domain, such as magnetism, optics, quantum electronics, etc.

Classification by scientific field

BROWSE BY EXPERIMENTS

All realised experiments in EMFL are resumed here such as NMR, different spectroscopies, different magnetometries, etc.

Classification by experiments

BROWSE BY AVAILABLE EQUIPMENT

Here all available equipement are described and will be useful for detailed technical discussions

Classification by equipment

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BROWSE BY INDUSTRIAL APPLICATIONS

The following table will help the readers to choose the Industrial domains which are closed to their activity and business. All EMFL laboratories provided their team overviews and classified them in corresponding industrial domains. You can just click on a highlighted cross-section in this table and you will be automatically redirected to the corresponding detailed team description with further contact information.

EMFL TEAMS / *INDUSTRIAL*	OPTICS/ELECTRONICS	MATERIALS/CHEMISTRY	HEALTH CARE/ PHARMACEUTICS	MEASUREMENTS/SENSORS	PROCESS	ENERGY/TRANSPORT	METROLOGY
HFML NIJMEGEN							
QUANTUM MATERIALS (GROUP SEMICONDUCTOR & NANOSTRUCTURES)		7		7		7	
MAGNETO-OPTICAL SPECTROSCOPY ON (NANO)MATERIALS	9	9				9	
MAGNETIC MANIPULATION OF MOLECULAR MATERIALS		11	11		11		
UNCONVENTIONAL SUPERCONDUCTIVITY AND QUANTUM CRITICALITY		13		13		13	
LOW DIMENSIONAL ELECTRON SYSTEMS (GROUP SEMICONDUCTOR & NANOSTRUCTURES)		15		15		15	15
LNCMI GRENOBLE							
HIGH FIELD RESISTIVE MAGNETS		19			19	19	
INSTRUMENTATION AND CRYOGENICS		20	20	20			20
NUCLEAR MAGNETIC RESONANCE (NMR)	22	22		22			22
SEMICONDUCTOR AND NANOPHYSICS	24	24		24			
HIGH TEMPERATURE SUPERCONDUCTOR (HTS) DEVELOPMENT		26		26	26	26	
43T+ HYBRID MAGNET	28	28	28	28	28	28	28
HLD DRESDEN							
THERMOMETRY AND SENSING		33		33		33	

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EMFL TEAMS	*INDUSTRIAL*	OPTICS/ELECTRONICS	MATERIALS/CHEMISTRY	HEALTH CARE/ PHARMACEUTICS	MEASUREMENTS/SENSORS	PROCESS	ENERGY/TRANSPORT	METROLOGY
PULSED-POWER SUPPLIES						35	35	
MAGNET FABRICATION						36	36	
ADVANCED CHARACTERIZATION		37	37		37			37
LNCMI TOULOUSE								
FUNDAMENTAL INTERACTION TESTS IN MAGNETO-OPTICS		41						
HIGH TEMPERATURE SUPERCONDUCTORS			43					
HIGH STRENGTH CONDUCTORS			45			45	45	
PULSED MAGNETS AND GENERATORS						47	47	
CRYOGENICS				49		49		
OPTICAL INSTRUMENTATION		51			51			
RF INSTRUMENTATION					52			
MEGA-GAUSS MAGNETIC FIELD GENERATION		54	54				54	54
QUANTUM ELECTRONICS		55						
HIGH RESOLUTION OPTICAL SPECTROSCOPY FOR ACURATE B-FIELD MEASUREMENT		56						56
NANO-OBJECTS AND SEMI-CONDUCTING NANOSTRUCTURES		57						
QUANTUM CONDUCTORS AND MAGNETS					59			
MAGNETO-CHIRAL ANISOTROPY		61	61					

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BROWSE BY SCIENTIFIC FIELD

This table will provide you easy navigation inside the scientific competences of EMFL teams. You need just to choose the Scientific Field and then click on the highlighted cross-section of the corresponding EMFL team. On the dedicated page you will find detailed information with a further contact information.

EMFL TEAMS / SCIENTIFIC FIELDS	OPTICS/MAGNETO-OPTICS	SOLID STATE PHYSICS	QUANTUM ELECTRONICS	MAGNETISM/ELECTRICITY	NANOSCIENCE	CRYOGENICS	ATOMIC PHYSICS	SEMICONDUCTORS	CHEMISTRY/MATERIAL SCIENCE	CONDENSED MATTER PHYSICS
HFML NIJMEGEN										
QUANTUM MATERIALS (GROUP SEMICONDUCTOR & NANOSTRUCTURES)		7		7				7	7	7
MAGNETO-OPTICAL SPECTROSCOPY ON (NANO)MATERIALS	9	9			9			9	9	9
MAGNETIC MANIPULATION OF MOLECULAR MATERIALS	11				11				11	11
UNCONVENTIONAL SUPERCONDUCTIVITY AND QUANTUM CRITICALITY		13		13					13	13
LOW DIMENSIONAL ELECTRON SYSTEMS (GROUP SEMICONDUCTOR & NANOSTRUCTURES)		15	15	15	15			15	15	15
LNCMI GRENOBLE										
HIGH FIELD RESISTIVE MAGNETS				19			19		19	
INSTRUMENTATION AND CRYOGENICS	20			20		20				
NUCLEAR MAGNETIC RESONANCE (NMR)		22						22	22	22
SEMICONDUCTOR AND NANOPHYSICS	24	24			24			24		
HIGH TEMPERATURE SUPERCONDUCTOR (HTS) DEVELOPMENT		26		26		26			26	26
43T+ HYBRIDE MAGNET			28	28	28	28		28		
HLD DRESDEN										
THERMOMETRY AND SENSING				33		33			33	
PULSED-POWER SUPPLIES		35		35	35	35		35	35	35
MAGNET FABRICATION		36		36		36			36	36

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EMFL TEAMS / ***SCIENTIFIC FIELDS***	OPTICS/MAGNETO-OPTICS	SOLID STATE PHYSICS	QUANTUM ELECTRONICS	MAGNETISM/ELECTRICITY	NANOSCIENCE	CRYOGENICS	ATOMIC PHYSICS	SEMICONDUCTORS	CHEMISTRY/MATERIAL SCIENCE	CONDENSED MATTER PHYSICS
ADVANCED CHARACTERIZATION		37		37		37		37		37
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HIGH STRENGTH CONDUCTORS				45	45				45	45
PULSED MAGNETS AND GENERATORS				47						
CRYOGENICS						49				
OPTICAL INSTRUMENTATION	51									
RF INSTRUMENTATION			52						52	52
MEGA-GAUSS MAGNETIC FIELD GENERATION	54	54		54					54	54
QUANTUM ELECTRONICS			55					55		
HIGH RESOLUTION OPTICAL SPECTROSCOPY FOR ACURATE B-FIELD MEASUREMENT	56			56			56			
NANO-OBJECTS AND SEMI-CONDUCTING NANOSTRUCTURES		57	57		57			57		
QUANTUM CONDUCTORS AND MAGNETS		59	59							
MAGNETO-CHIRAL ANISOTROPY										61

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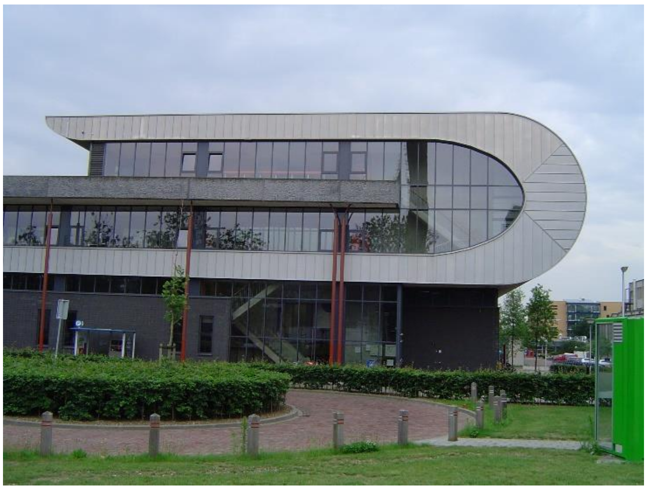
HIGH FIELD MAGNET LABORATORY

HFML-FELIX



Contact

HFML - FELIX

Toernooiveld 7

6525 ED NIJMEGEN

The Netherlands

HFML-FELIX@ru.nl

+31 (0)24 3652525

https://www.ru.nl/hfml/

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QUANTUM MATERIALS

(GROUP SEMICONDUCTOR & NANOSTRUCTURES)

➢ **TEAM INTEREST:** Fundamental investigation of quantum matter under extreme conditions

➢ BRIEF DESCRIPTION

The core of the group's research program is based on studying the electronic, structural and thermodynamic properties of emergent materials including topological semi-metals, correlated electron systems and novel semiconductors from bulk materials to thin films. Characterizing and tuning the properties of novel states of matter is essential for their fundamental understanding and a crucial step towards the design and manufacturing of novel functional devices. Along these lines, we work on the development of instrumentation that we also make available for external users.

• TEAM ASSETS

Low noise measurements in extreme conditions:

- electrical and thermal transport,
- torque magnetometry,
- thermal expansion and magnetostriction,
- electrical transport under uniaxial strain,
- thermal expansion and magnetostriction under uniaxial strain

➢ SCIENTIFIC FIELDS

- Fundamental solid states physics
- Topological matter (topological insulators and semimetals)
- Correlated electron systems (Magnetism and superconductivity)
- Correlated topological matter
- (Novel) semiconductors
- Material characterization

➢ KEY WORDS

- Magnetic fields
- Topological matter
- Correlated systems
- Transport measurements
- Dilatometry
- Uniaxial strain

➢ COLLABORATIONS

- Open to on demand R&D studies
- Princeton University (US)
- Aarhus University
- University of Bristol (UK)
- Kuechler Innovative measurement Technology
- Razorbill Instruments

➢ CONTACT

Dr. Steffen WIEDMANN
steffen.wiedmann@ru.nl
+31 24 3653370
HFML-FELIX Nijmegen

HFML-NIJMEGEN

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QUANTUM MATERIALS

(GROUP SEMICONDUCTOR & NANOSTRUCTURES)

SPECIFIC EQUIPMENT

- Phase sensitive (lock-in) amplifier
- Capacitive dilatometer (32 and 50 mm bore)
- CS100 uniaxial strain cell
- He4, He3, dilution fridge cryostat (base temperature down to 50 mK)
- static magnets (magnetic fields up to 38 T)

MATERIALS

(from bulk to thin films - 2D)

- Nodal line semimetals (ZrSiS, ...)
- Topological matter (WTe_2, ...)
- Rare earth-tritellruides
- Layered superconductors ($NbSe_2$, ...)

PUBLICATIONS AND ADDITIONAL INFORMATION

- J. F. Linnartz *et al.*, *PRR* **4,** L012005 (2022).
- C.S.A. Müller *et al.*, *PRR* **2,** 023217 (2020).
- M. Keshavarz *et al., Advanced Materials* **31** (2019), 1900521.
- L. Rossi *et al.*, *PRL* ***123,*** 027205 (2019).
- M. R. van Delft *et al.*, *PRL* **121**, 256602 (2018).
- S. Pezzini *et al.*, *Nature Physics* **14**, 178-183 (2018).
- R. Küchler *et al.*, Review of Scientific Instruments **88**, 083903 (2017).

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European Magnetic Field Laboratory

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MAGNETO-OPTICAL SPECTROSCOPY ON (NANO)MATERIALS

➢ **TEAM INTEREST:** Investigation of (nano)materials in high magnetic fields

➢ BRIEF DESCRIPTION

Measuring the optical response of semiconductor nanostructures, molecular materials and magnetic materials in high magnetic fields uncovers their optical, electronic and magnetic properties. Optical techniques are combined with high magnetic fields and low temperatures. Using free beam optics allows for full polarization control in the experiments, down to a time-resolution of 100 femtoseconds and a spatial resolution better than 1 micron.

• TEAM ASSETS

Optical experiments in high magnetic fields (< 38 T) and low temperatures (> 0.35 K)

- (micro-) Photoluminescence, incl. lifetime expts
- Raman spectroscopy
- Reflection spectroscopy
- Linear birefringence & dichroism
- Magneto-Optical Kerr Effect (MOKE)
- Femtosecond pump-probe experiments

➢ SCIENTIFIC FIELDS

- Physics of semiconductor nanostructures, molecular materials and magnetic materials.
- Electric, Optical and Magnetic properties
- Materials characterization
- Photovoltaics

➢ KEY WORDS

- Magnetic fields
- Optical Spectroscopy
- Semiconductor
- Nanostructures
- Molecular materials

➢ COLLABORATIONS

- Many universities and research institutes around the world
- Open to on demand R&D studies

➢ CONTACT

Prof. Dr. Peter CHRISTIANEN
peter.christianen@ru.nl
+31 24 365 22 45
HFML- FELIX

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MAGNETO-OPTICAL SPECTROSCOPY ON (NANO)MATERIALS

SPECIFIC EQUIPMENT

- Several light & laser sources, c.w. and pulsed
- Wide range of optical spectrometers
- Wide range of detectors and CCD cameras
- He4 and He3 cryostats
- Free beam and fiber optics
- 50 mm and 32 mm bore magnets (< 38 T)

MATERIALS

- 2D Semiconductors (Transition metal dichalcogenides)
- II-VI & perovskite semiconductor colloidal nanocrystals
- III-V & II-VI semiconductor nanostructures
- Organic semiconductors & Perovskites
- Magnetic materials (Ferro-, Ferri- & Antiferromagnets)

PUBLICATIONS AND ADDITIONAL INFORMATION

- Raman (sample: $PbMnBO_4$), Phys. Rev. Res. 4, 013004 (2022)
- Photoluminescence (sample: InP nanowires), ACS Nano 14, 11613 (2020)
- Photoluminescence (sample: TIPS tetracene), PNAS 115,5077 (2018)
- Femtosecond pump-probe spectroscopy (sample: GdFeCo), Phys. Rev. Lett. 118, 117203 (2017)
- Microphotoluminescence (sample: $WSe_2/MoSe_2$ heterostructure), Nature Comm. 8,1551 (2017)
- Fluorescence Line narrowing (Sample: colloidal nanocrystals), ACS Nano 8,5921–5931 (2014)
- Photoluminescence lifetimes (Sample: CdSe/CdS Colloidal Nanoplatelets), Nano Lett. 18,373–380 (2018)

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EMFL European Magnetic Field Laboratory

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MAGNETIC MANIPULATION OF MOLECULAR MATERIALS

➢ **TEAM INTEREST**: Investigation of magnetic manipulation of "non-magnetic" matter

➢ BRIEF DESCRIPTION

Molecular materials are seemingly nonmagnetic due to the absence of unpaired electrons. Strong fields however induces a weak magnetic moment in these materials, which can be used for manipulation, such as magnetic alignment, structural transformations and magnetic levitation to simulate weightlessness.

➢ TEAM ASSETS

Room temperature optical experiments

- Optical microscopy in Faraday and Voight configurations down to 1 μm
  - Polarized microscopy
  - Fluorescence microscopy
  - Dark-field imaging
  - Schlieren and schadowgraphy
- Confocal microscopy (under development)
  - Fluorescence autocorrelation
  - Fluorescence lifetime imaging
- Polarized UV/VIS spectroscopy
- Linear birefringence and dichroism
- Circular dichroism and birefringence

➢ SCIENTIFIC FIELDS

- Supramolecular chemistry
- Molecular materials
- Magnetic manipulation
- Soft condensed matter

➢ KEY WORDS

- Magnetic fields
- Molecular matter
- Optics
- Magnetic levitation
- Magnetic alignment
- Magnetic manipulation

➢ COLLABORATIONS

- Systems chemistry, IMM, Radboud University
- Institute for Technology-Inspired Regenerative Medicine,
- Maastricht University
- Laboratory for Biotechnological Research '3D Bioprinting Solutions', Moscow, Russia.

➢ CONTACT

Dr Hans Engelkamp

h.engelkamp@ru.nl

+31 24 3653367

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MAGNETIC MANIPULATION OF MOLECULAR MATERIALS

MATERIALS

- Block copolymers
- Polymersomes
- Liquid crystals
- Molecular crystals

SPECIFIC EQUIPMENT

- Several light sources
- Sensitive optical detectors and cameras
- Autocorrelators
- Photo-elastic modulators
- Lock-in amplifiers

PUBLICATIONS AND ADDITIONAL INFORMATION

- van Silfhout *et al.* J Phys Chem Lett 11, 5908-5912, 1804 (2020).
- Parfenov, V. A. *et al*. Biofabrication 12, 045022 (2020).
- Rikken, R. S. M. *et al.* Nat. Commun. 7, 12606 (2016).
- Potticary, J. *et al.* Nat. Commun. 7, 11555 (2016).
- Micali, N. *et al.* Nat. Chem. 4, 201-207 (2012).

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UNCONVENTIONAL SUPERCONDUCTIVITY AND QUANTUM CRITICALITY

➢ **TEAM INTEREST:** Link between criticality, superconductivity and strange metallicity

➢ BRIEF DESCRIPTION

Unconventional superconductors order (often magnetically) *before* superconductivity sets in. Suppressing this order to zero Kelvin, electrons begin to fluctuate quantum mechanically between the ordered and disordered phases. Just above this so-called *quantum critical point*, the resistivity acts in a highly anomalous way. Moreover, these critical fluctuations may also induce or promote pairing. Hence, studying the transport and thermodynamic properties of this 'strange' metal might help to identify the interaction that causes the superconductivity.

➢ KEY WORDS

- Magnetic fields
- Exotic superconductivity
- Quantum criticality
- Transport and thermodynamic properties

➢ TEAM ASSETS

Low noise measurements in extreme conditions:

- electrical and thermal transport,
- magnetization,
- ac susceptibility
- thermo-electricity
- torque magnetometry
- specific heat
- high pressures
- ultrafast current pulses

➢ COLLABORATIONS

- University of Bristol (UK)
- University of Oxford (UK)
- Berkeley (USA)
- LNCMI-G (France)
- Kyoto (Japan)

➢ SCIENTIFIC FIELDS

- Fundamental solid state physics
- Magnetism and superconductivity
- Materials characterization

➢ CONTACT

Prof. Nigel HUSSEY
nigel.hussey@ru.nl
Dr. Alix MCCOLLAM
alix.mccollam@ru.nl
HFML-FELIX, Nijmegen

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UNCONVENTIONAL SUPERCONDUCTIVITY AND QUANTUM CRITICALITY

SPECIFIC EQUIPMENT

- He-4, He-3, dilution fridge cryostat (base temperature down to 50 mK)
- High-resolution ac susceptibility
- Quantitative magnetization measurements
- Piezo-cantilevers and torque magnetometers
- Phase sensitive lock-in detection techniques
- Oscilloscope (1GHz,12bits)
- Relaxation calorimetry
- Piston and diamond anvil pressure cells

MATERIALS

- High-T_c cuprates (crystals and thin films)
- Skutterudites
- $CeCoIn_5$ and derivatives
- $Li_{0.9}Mo_6O_{17}$
- $FeSe_{1-x}S_x$
- URhGe and derivatives
- Organic conductors
- Multiferroics
- Infinite-layered nickelates
- Oxide heterostructures
- Others

RECENT PUBLICATIONS

- S. Pezzini *et al.*, *Nature Physics* **14**, 178 (2018)
- D. Maryenko *et al.*, *Nature Comm.* **9**, 4356 (2018)
- A. I. Coldea *et al.*, *npj Quant. Mat.* **4**, 2 (2019)
- S. Licciardello *et al.*, *Nature* **567,** 213 (2019)
- S. Kasahara *et al.*, *PRL* **124**, 107001 (2020)
- S. Mishra *et al.*, *PRL* **126**, 016403 (2021)
- C. Putzke *et al.*, *Nature Physics* **17**, 826 (2021)
- J. Ayres *et al.*, *Nature* **595,** 661 (2021)

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https://www.ru.nl/hfml-felix/about-hfml-felix/staff/staff/mccollam/

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LOW DIMENSIONAL ELECTRON SYSTEMS

(GROUP SEMICONDUCTOR & NANOSTRUCTURES)

- **TEAM INTEREST:** Fundamental understanding of semiconducting, superconducting and magnetic materials using high magnetic fields and low temperatures.

BRIEF DESCRIPTION

The group carries out a versatile research programme addressing the electronic properties of low-dimensional materials such as semiconductor heterostructures (II-V based and complex oxides), 2D materials (graphene and TMDC) and (magnetic) nanostructures. We develop and apply a variety of techniques such as magneto transport, magnetometry and infrared spectroscopy to uncover new fundamental properties of emerging systems in view of fundamental physics and possible application perspectives.

KEY WORDS

- High magnetic fields
- Low temperatures
- Semiconductors
- Magnetic materials
- Magneto-transport
- Magnetization
- Thermodynamic properties
- THz spectroscopy

TEAM ASSETS

- Magneto-transport in tilted magnetic fields and in a wide temperature range (50 mK – 400 K).
- Time resolved resistivity measurements
- Far infrared transmission and resistively detected resonances in semiconducting and magnetic nanostructures
- Magnetometry in high magnetic fields (VSM, torque)
- Thermopower and thermal conductivity

COLLABORATIONS

<u>Industrial</u>

- Leiden cryogenics (NL)
- Paragraf (UK)
- NOVIOTECH (NL)

<u>Scientific (selection)</u>

- RWTH Aachen
- University of Groningen
- ETH Zürich
- Basque Center on Materials
- Maglab Los Alamos
- PTOLEMY collaboration

SCIENTIFIC FIELDS

- Condensed matter science
- Semiconductors
- Superconductivity
- Magnetism
- Low-dimensional electron systems
- 2D materials
- Magnetic materials

CONTACT

Prof. Dr. Uli ZEITLER
uli.zeiter@ru.nl
+31 24 3653061
HFML-FELIX Nijmegen

https://www.ru.nl/hfml-felix/about-hfml-felix/staff/staff/zeitler/

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LOW DIMENSIONAL ELECTRON SYSTEMS

(GROUP SEMICONDUCTOR & NANOSTRUCTURES)

SPECIFIC EQUIPMENT

- $^4He/^3He$ dilution refrigerator (0.05 … 4 K)
- ^3He system (0.3 ... 30 K)
- Variable temperature inserts (1.5 … 400 K)
- DC resistive magnets up to 38 T
- VSM & torque magnetometers
- Free electron lasers (FIR)

MATERIALS

- Convectional and unconventional 3D semiconductors
- Heterostructures: III-V and oxides
- 2D materials
- Magnetic materials, molecular magnets
- Superconductors

PUBLICATIONS AND ADDITIONAL INFORMATION

- Zijin Lei *et al.*, Phys. Rev. Research **4,** 013039 (2022)
- L.C.J M. Peters *et al.*, Phys. Rev. Research **3,** L042042 (2021)
- Km Rubi *et al.*, Phys. Rev. Research **3,** 033234 (2021)
- M. Schmitz *et al.,* 2D Materials **7**, 041007 (2020)
- S. Pezzini *et al.*, Phys. Rev. B **99**, 045440 (2019)
- D. Maryenko *et al.*, Nat. Commun. **8**, 4358 (2018)
- Jianming Lu *et al.*, PNAS **115** (2018)
- T. Khouri *et al.*, Phys. Rev. Lett. **117**, 256601 (2016).

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LABORATOIRE NATIONAL DES CHAMPS MAGNETIQUES INTENSES - GRENOBLE

LNCMI-GRENOBLE

LNCMI

Contact

25, avenue des Martyrs
BP 166
38042 Grenoble Cedex 9
direction@lncmi.cnrs.fr
04.76.88.10.48

http://lncmi.cnrs.fr/

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HIGH FIELD RESISTIVE MAGNETS

- **TEAM INTEREST:** Design and fabrication of continuous high field magnets and energetic systems

BRIEF DESCRIPTION

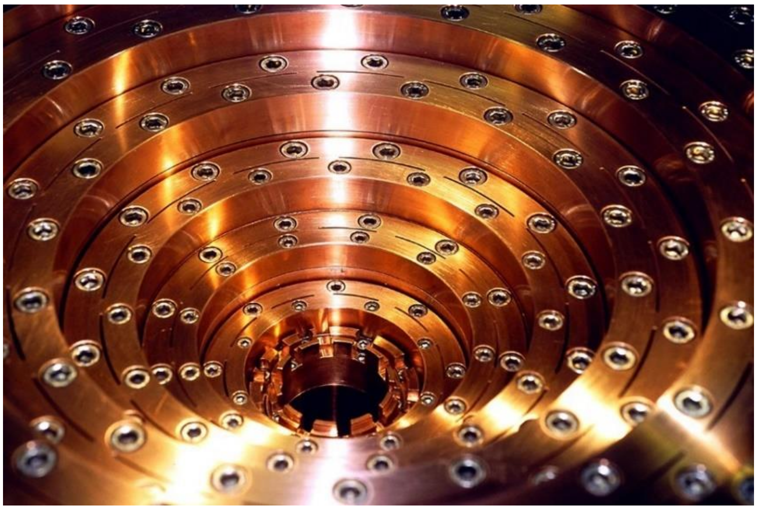
We develop copper alloy-based magnets for high magnetic fields or high magnetic field gradients. These developments include thermal, mechanical and electromagnetic studies and magnet fabrication. Our expertise extends to material choice and magnet fabrication.

TEAM ASSETS

- In-house magnets productions for high continuous magnetic fields (today up to 37 T)
- Design and fabrication for specific needs (*X-Ray*, Neutrons, Ion Source, levitation)
- Optimization of energetic systems (high heat fluxes, heat recovery)
- Copper alloy development for specific use

SPECIFIC EQUIPMENT

- 24 MW power supply (30 MW in 2023)
- Hydraulic system for 30 MW cooling
- 7 high field magnets for experimentations
- Design office & workshop for coil conception and production



KEY WORDS

- Continuous magnets
- Energetic system

COLLABORATIONS

- Energy Pool
- ICB-Univ. Tech. Belfort -Montbeliard
- High Engineering school on Water Energy & Environment (ENSE3-Univ. Grenoble Alpes)

PUBLICATIONS

- Energy- and exergy-based optimal designs of a low-temperature industrial waste heat recovery system in district heating
Energy Conversion and Management Volume 211, 1 May 2020, 112753
https://doi.org/10.1016/j.enconman.2020.112753

- Cold Spray Manufacturing for Structural Materials for High Field Magnet Production
Materials Science Forum Online: 2018-12-26, ISSN: 1662-9752, Vol. 941, pp 1540-1545
https://doi.org/10.4028/www.scientific.net/MSF.941.1540

CONTACT

Dr. François Debray
francois.debray@lncmi.cnrs.fr
LNCMI-GRENOBLE

LNCMI-GRENOBLE

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INSTRUMENTATION AND CRYOGENICS

➢ **TEAM INTEREST**: Experimental devices and techniques in high continuous magnetic fields

➢ BRIEF DESCRIPTION

The LNCMI instrumentation team supports and conducts developments of scientific instrumentation, experimental techniques and cryogenic devices compliant with the particular constraints of a high magnetic field environment.

➢ TEAM ASSETS

- Access to low temperatures (20 mK).
- Metrology service for thermometers in high magnetic field (36 T, 1.2 K).
- Metrology service for precise magnetic field characterisation: absolute field values, spatial field mapping, temporal field characterisation by Hall, Pick-up and Nuclear Magnetic Resonance.
- Design and development of experimental setups for measurements in high magnetic field and/or low temperatures.
- Software development (data recording and analysis) and simulation of material's properties in magnetic field.
- Magneto-mechanical device characterisation in high magnetic fields, strong magnetic field gradients and stray fields.

➢ SCIENTIFIC FIELDS

- Cryogenics, Mechanics, Mechatronics
- Metrology, Magnetometry
- Optics

➢ MATERIALS

- Non-magnetic metals (stainless steel, titanium).
- High performance composite compounds (e.g. Torlon).
- Low temperature bonding compounds and techniques.
- µm to mm sized sensors and electrical wires.

➢ KEY WORDS

- Low temperatures
- Temperature and magnetic field metrology
- Design of instruments
- Data recording and analysis

➢ COLLABORATIONS

- LNCMI and EMFL research and engineering teams.
- External scientific users.
- External industrial users.
- Cryogenic, vacuum, instrument and material suppliers.

• PUBLICATIONS AND ADDITIONAL INFORMATION

Examples for recent developments and industrial collaborations available upon request.

➢ CONTACT

Dr. Steffen Krämer
steffen.kramer@lncmi.cnrs.fr
+ 33 (0)4 76 88 74 44
LNCMI Grenoble

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INSTRUMENTATION AND CRYOGENICS

➢ **SPECIFIC EQUIPMENT**

- Low temperature environment (He4, He3 and dilution refrigerator, 20 mK – 300 K).
- Instruments and sensors for temperature recording and control (20 mK -300 K).
- Instruments and sensors for field recording: NMR, Hall and Pick-up devices.
- Goniometers and piezo-driven devices for rotation and positioning.
- General purpose instruments and software for data recording: High precision current and voltage sources and recording devices, Lock-In amplifiers, oscilloscopes, dynamic signal analyser, filters.
- 3D printing (polymere-based)

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NUCLEAR MAGNETIC RESONANCE (NMR)

➢ **TEAM INTEREST**: Ultra-high-field NMR investigations

➢ BRIEF DESCRIPTION

Nuclear magnetic resonance (NMR), well known for its application in medical imaging (MRI) and widely used for determining molecular structures in chemistry and biology, is also an extraordinarily powerful microscopic probe of the electronic properties. At LNCMI, NMR is performed in particularly intense magnetic fields, used to induce and study new quantum phases of matter and to control the transitions between them. These field-induced phenomena occur in strongly correlated electron systems, which are the principal subject of fundamental research in Solid State Physics.

➢ TEAM ASSETS

Broad-band NMR measurements in extreme conditions of ultra-high magnetic field, very low temperature and high pressure.

➢ SCIENTIFIC FIELDS

Fundamental solid states physics:

- Quantum magnetism
- High temperature superconductors
- Exotic, field-induced superconducting states
- Heavy Fermions

Chemistry :

- Paramagnetic Relaxation Enhancement for MRI contrast agents
- Ultra-high field NMR

➢ KEY WORDS

- Magnetic fields
- NMR
- Quantum Magnetism
- High temperature superconductivity
- Strongly correlated systems

➢ COLLABORATIONS

- Open to on demand R&D studies
- ETH Zürich
- MPI Stuttgart
- UBC Vancouver
- Inst. Néel, Grenoble
- JAEA, Japan
- Karlsruhe Institute of Technology

➢ CONTACT

Dr. Mladen HORVATIC
mladen.horvatic@lncmi.cnrs.fr
+33 (0)4 76 88 74 43
LNCMI GRENOBLE

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NUCLEAR MAGNETIC RESONANCE (NMR)

MATERIALS

- Quantum antiferromagnets: insulating compounds described as quasi-one-dimensional and quasi-two-dimensional spin systems
- High-Tc superconductors: Cu-oxide and Fe-based materials
- Heavy Fermions: UCoGe, URhGe, $Ce_3Pd_{20}Si_6$
- Topological materials, "Quantum Well" heterostructures, single-molecule magnets
- Paramagnetic relaxation enhancement (PRE): large-size paramagnetic molecules in aqueous solution, *e.g.* paramagnetic polyoxometalates.

SPECIFIC EQUIPMENT

- Broad-band NMR spectrometers
- RF electronics
- Cryogenic NMR probes
- Sample rotators, pressure cells
- He^4, He^3 and dilution-refrigerator cryostats (from room temperature down to 50 mK)
- Variable-field magnets (superconducting, resistive and hybrid magnets) employed for high-field NMR

PUBLICATIONS AND ADDITIONAL INFORMATION

- Overview: C. R. Physique **18**, 331 (2017)
- Quantum magnets: Phys. Rev. Lett. **121**, 177202 (2018); Phys. Rev. B **101**, 220406(R) (2020); Phys. Rev. Research **3**, 023177 (2021)
- High-Tc superconductors: PNAS 114, 13148 (2017); Nature Phys. **16**, 1064 (2020); Nature Commun. **12**, 3274 (2021)
- Organic conductors: Nature Phys. **10**, 928 (2014)
- Heavy Fermions: Phys. Rev. Lett. **114**, 216401 (2015)
- Paramagnetic relaxation enhancement (PRE): Molecules **2021**, 26, 7481.

http://srv-web.lncmi.cnrs.fr/la-recherche/magnetism/rmn/

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SEMICONDUCTOR AND NANOPHYSICS

- **TEAM INTEREST**: We are interested low energy excitations and in effects of interactions in low dimensional condensed matter systems (semiconductor nanostructures, two dimensional materials, topological semimetals) that we investigate using optical spectroscopy methods combined with high magnetic fields.

BRIEF DESCRIPTION

Magneto-optical spectroscopy with micrometer spatial resolution in extreme environments of low temperature, high magnetic fields and high pressure. We are interested in the effects of interactions (electron-electron, electron-phonon, magnon-phonon)

KEY WORDS

- High magnetic fields
- Low-dimensional systems
- Magneto-optics
- Low temperature

TEAM ASSETS

- Bulk layered materials (semiconductors, semimetals, magnetic)
- Two dimensional materials and their heterostructures (encapsulated in hBN, hetero-multilayers)
- Semiconductor nanostructures (quantum wells and quantum dots)
- Spatially resolved optical spectroscopy in extreme environments

COLLABORATIONS

- Tech. Uni. Munich
- Uni. of Strasbourg
- Uni. of Fribourg
- Uni. of Warsaw
- Uni. of Pragues
- Uni. of Manchester
- C2N-CNRS

CONTACT

Dr Faugeras Clément
clement.faugeras@lncmi.cnrs.fr
Dr Orlita Milan
milan.orlita@lncmi.cnrs.fr
LNCMI-GRENOBLE

SCIENTIFIC FIELDS

- Semiconductor physics
- Two dimensional materials
- Dirac and Weil semimetals
- Magnetic systems

MATERIALS

- Semiconductor nanostructures
- Two dimensional materials (semimetals, semiconductors, magnetic materials, charge density waves/periodic lattice distortion)
- Topological matter
- Molecular solids

European Magnetic Field Laboratory

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SEMICONDUCTOR AND NANOPHYSICS

SPECIFIC EQUIPMENT

- 16T and 14T superconducting magnets
- Micro-optical set-ups for low temperature – high magnetic fields visible/NIR spectroscopy (Photoluminescence, Reflectance, PLE, Raman scattering)
- Triple grating spectrometer for Raman scattering
- Time resolved photoluminescence (TRPL) with a femtosecond laser (515 nm)
- Supercontinuum laser
- Diamond Anvil Cells for high pressures (up to 10 GPa)
- Transmission and Reflectivity FTIR set-up

PUBLICATIONS AND ADDITIONAL INFORMATION

http://srv-web.lncmi.cnrs.fr/la-recherche/semiconducteur-nanophysics/la-recherche-2/publications/

LNCMI-GRENOBLE

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European Magnetic Field Laboratory

HIGH TEMPERATURE SUPERCONDUCTOR (HTS) DEVELOPMENT

LNCMI-GRENOBLE

TEAM INTEREST

- Characterization and use of high temperature superconductors (HTS) (wires, tapes or coils) in high magnetic field
- Design and fabrication of HTS insert for very high field magnets (>30 T)

BRIEF DESCRIPTION

The implementation of several test benches through collaborations and visitor support while using the unique field configurations available at LNCMI for the functional characterizations of HTS wires, tapes and coils or sub-elements have paved the way for further development of the HTS technology. We are now engaged in the race towards very high field all-superconducting user magnets.

KEY WORDS

- HTS conductor
- High magnetic field
- HTS insert
- Quench protection

TEAM ASSETS

- Functional characterisations of HTS wires, tapes and coils under high magnetic field and low temperature.
- Pancake winding technology and associated instrumentation.
- Design and fabrication of HTS inserts.
- Metal-as-insulation technique implementation.
- A record for the operation of HTS insert with a 38 mm useful diameter, operating in a central magnetic field of 32.5 T, T of which 14.5 T are derived from the superconducting magnet only.

COLLABORATIONS

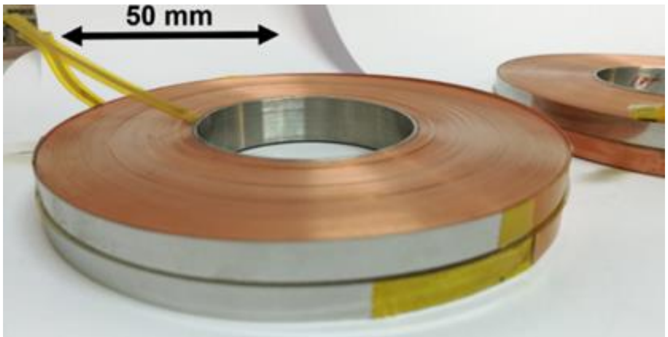
- CEA DACM Saclay
- CNRS Institut Néel/G2Elab Grenoble
- U. of Twente, the Netherlands
- U. of Geneva, Switzerland
- IEE,SAS, Slovakia
- HZDR, Germany
- Radboud University, the Netherlands
- Theva, Germany
- Bilfinger Noell, Germany
- Oxford Instruments

SCIENTIFIC FIELDS

- Applied superconductivity

CONTACT

Dr. Xavier Chaud
xavier.chaud@lncmi.cnrs.fr
04 76 88 74 87
LNCMI Grenoble



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HIGH TEMPERATURE SUPERCONDUCTOR (HTS) DEVELOPMENT

➢ MATERIALS

- REBaCuO superconductors

➢ SPECIFIC EQUIPMENT

- Several test benchs (sample holder, power supply, acquisition for critical current Jc measurement or coil testing – field, stability, quench) for several field configurations:
  - 30 T ∅50 mm RTB, ∅38 mm CB for sample holder (wire, tape or VAMAS coil);
  - 20 T ∅170 mm RTB, ∅128 mm CB for sample holder (wire, tape, coil or coil sub-element);
  - 10 T ∅376 mm RTB, ∅298 mm CB for sample holder (e.g. race track coil).

  RT for room temperature bore (available space inside the magnet) and CB for cold bore (available space in the cryostat).
- Home-made winding machine for REBCO pancakes made out of tapes with 3 independent spools
- DC power supplies (10V 1200 to 5 V 3000 A).
- NI data acquisitions cards and modules.

➢ PUBLICATIONS AND ADDITIONAL INFORMATION

Metal-as-insulation variant of no-insulation HTS winding technique: pancake tests under high background magnetic field and high current at 4.2 K, Supercond. Sci. Technol. **31** (2018) 055008. DOI:10.1088/1361-6668/aab4ec

38 mm diameter cold bore metal-as-insulation HTS insert reached 32.5 T in a background magnetic field generated by resistive magnet, Cryogenics **106** (2020) 103053**.** Cryogenics BEST PAPER AWARD 2020. DOI:10.1016/j.cryogenics.2020.103053

LNCMI-GRENOBLE

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43T+ HYBRIDE MAGNET

➢ **TEAM INTEREST**: High Magnetic Field Science & Technology (hybrid & DC magnets)

➢ BRIEF DESCRIPTION

Based on resistive and superconducting technologies, a modular user platform is being built with the objective to deliver to the scientific community various continuous high magnetic field and flux configurations. They range from 43 T in 34 mm diameter using 24 MW of electrical power down to 9 T in 800 mm diameter when the large bore superconducting outset magnet is used alone.

➢ TEAM ASSETS

- Conception studies of large scale superconducting magnets
- Hybrid magnet technologies
- Low temperature superconducting cable & conductors
- Large scale Cryogenics (construction and process)
- Large scale mechanical assembly & handling
- Call for tenders and follow-up of large industrial contracts (up to 2-3 MEUR, Total budget 15 MEUR)
- Expertise delivered for Large scale superconducting magnet projects (MADMAX, PBC Working Group@CERN, AMS-02 installed on ISS)

➢ SCIENTIFIC FIELDS

- Superconductivity
- Cryogenics & vacuum technologies
- Electricity & Magnetism
- Experimental physics

➢ KEY WORDS

- DC High Magnetic Fields
- Hybrid Magnets
- Superconducting magnet technologies
- Applied Superconductivity
- Cryogenics with N2, He, including superfluid He
- Vacuum technologies
- R&D

➢ COLLABORATIONS & CONTRACTS

- Air Liquide (38)
- A.t.c.i Sarl (38)
- Aurubis (Olen)
- AW Pont-roulant
- Bruker (Germany)
- Bilfinger NOELL GmbH
- CEA-Saclay
- CERN
- Cryo Diffusion (38)
- Danfysik
- Ets PETERS (59)
- Forissier SAS (Tresses métalliques)
- GRUTER & MARCHAND
- OERLIKON LEYBOLD
- Pfeiffer Vacuum
- Ravni Technologies
- SDMS (38)
- Sofranel
- University Grenoble Alpes

➢ CONTACT

Dr. Pierre PUGNAT
pierre.pugnat@lncmi.cnrs.fr
LNCMI-Grenoble

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43T+ HYBRIDE MAGNET

SPECIFIC EQUIPMENTS

- The superconducting conductor assembly line

A dedicated in-house production line for the soft-soldering assembly of the superconducting conductor via induction heating was developed and installed. A total of 44 unit lengths of 265 m long conductor were successfully produced and wound in a single pancake coil prior to the delivery to the coil manufacturer (Bilfinger NOELL GmbH).

Conductor cross-section= 18x13 mm^2

- Part of the cryogenic utilities (High pressure gaseous He tanks @ 200 bars

- Part of the cryogenic satellite producing the superfluid He (current leads and lambda plate)

PUBLICATIONS & ADDITIONAL INFORMATION

- IEEE Transactions on Applied Superconductivity (Volume: 32, Issue: 6, Feb. 2022), DOI: 10.1109/TASC.2022.3151838
- IEEE Transactions on Applied Superconductivity (Volume: 30, Issue: 4, June 2020), DOI: 10.1109/TASC.2020.2972509
- IEEE Transactions on Applied Superconductivity (Volume: 28, Issue: 4, June 2018), DOI: 10.1109/TASC.2018.2797548
- Poster@ https://indico.cern.ch/event/659554/contributions/2714073/
- IEEE Transactions on Applied Superconductivity (Volume: 28, Issue: 3, April 2018), DOI: 10.1109/TASC.2017.2780820
- Presentation & video @ https://indico.cern.ch/event/445667/contributions/2562521/
- IEEE Transactions on Applied Superconductivity (Volume: 28, Issue: 3, April 2018), DOI: 10.1109/TASC.2017.2783345
- https://iopscience.iop.org/article/10.1088/1757-899X/171/1/012107
- Physics Procedia, Volume 67, 2015, Pages 692-697; DOI: 10.1016/j.phpro.2015.06.117
- IEEE Transactions on Applied Superconductivity (Volume: 24, Issue: 3, June 2014), DOI: 10.1109/TASC.2013.2286351
- IEEE Transactions on Applied Superconductivity (Volume: 22, Issue: 3, June 2012), DOI: 10.1109/TASC.2011.2180882
- IEEE Transactions on Applied Superconductivity (Volume: 22, Issue: 3, June 2012), DOI: 10.1109/TASC.2011.2178581

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DRESDEN HIGH MAGNETIC FIELD LABORATORY

Helmholtz-Zentrum Dresden-Rossendorf

HLD-HZDR

Contact

Bautzner Landstraße 400,

01328 Dresden - Germany

kontakt@hzdr.de

+49 351 260 – 0

https://www.hzdr.de/db/Cms?pOid=10379&pNid=580

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European Magnetic Field Laboratory

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THERMOMETRY AND SENSING

➢ **TEAM INTEREST:** Studying magnetic materials for the potential use in cooling applications

➢ BRIEF DESCRIPTION

Our team is specialized in the characterization of magnetocaloric materials in static and pulsed magnetic fields. We develop measurement probes that allow the direct determination of temperature changes simultaneously with their magnetization and strain. We are focussed on materials for room-temperature applications, but also for the liquefaction of gases at cryogenic temperatures.

➢ TEAM ASSETS

- Simultaneous measurements of adiabatic temperature changes, magnetization and strain of magnetocaloric materials in pulsed fields
- Characterization of multicaloric materials under uniaxial load and magnetic fields
- Specific-heat measurements in static fields
- Synthesis of magnetocaloric materials
- Thermodynamic and magnetic simulations
- Calibration of temperature sensors


Foto: HZDR/Rainer Weisflog

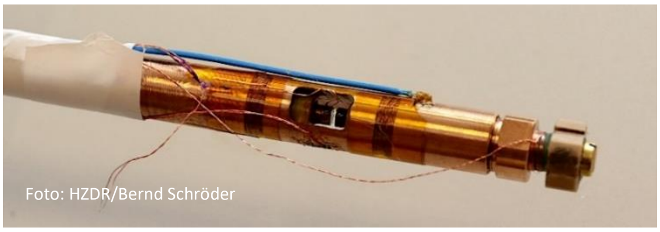
Foto: HZDR/Bernd Schröder

➢ KEY WORDS

- Magnetocaloric materials
- Multicaloric effects
- Specific heat
- Simultaneous measurements of various physical properties
- Magnetic cooling
- Magnetic shape memory

➢ COLLABORATIONS

- MagnoTherm Solutions

➢ PUBLICATIONS AND ADDITIONAL INFORMATION

https://www.hzdr.de/db/!PublJournalsFWH?pNid=636

- **Patents**

Elektronische Baugruppe, Kühlvorrichtung, Kühlvorrichtungsanordnung, Kühlelementanordnung, sowie Verfahren davon
J. Hornung, T. Gottschall,
DE 10 2018 118 813.7 (21.11.2019)

Kühlvorrichtung und ein Verfahren zum Kühlen
T. Gottschall, K.P. Skokov, and O. Gutfleisch
DE 10 2016 110 385.3 (06.06.2016)

➢ CONTACT

industry-hld@hzdr.de

Helmholtz-Zentrum Dresden-Rossendorf

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THERMOMETRY AND SENSING

SCIENTIFIC FIELDS

- Magnetic and multicaloric refrigeration
- Magnetic liquefaction of hydrogen
- Characterization of magnetic materials

MATERIALS

- Metal alloys
- Composites

SPECIFIC EQUIPMENT

- Pulsed fields up to 70 T from 1 K to 400 K
- Static fields up to 20 T
- ^{3}He system from 0.36 K up to 320 K
- Dilution refrigerator down to 20 mK
- Uniaxial-load cell up to 250 MPa in pulsed fields up to 50 T
- Thermometry with ultra-thin thermocouples
- Dilatometry using strain gauges
- Magnetization measurements under adiabatic conditions
- Sputtering of thermocouples and resistive thermometers

European Magnetic Field Laboratory

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PULSED-POWER SUPPLIES

➢ **TEAM INTEREST:** Development, design and construction of pulsed-power equipment

➢ BRIEF DESCRIPTION

The HLD develops pulsed-power supplies up to gigawatt strength, pulsed magnets up to the 100 T feasibility limit, experimental measurement equipment as well as the cryotechnical sample environment. The HLD is engaged in realizing unprecedented high-field setups for advanced experiments at other large-scale facilities, in particular at advanced radiation sources.

➢ TEAM ASSETS

- Development, design, fabrication, and testing of modular capacitive pulsed-power supplies for fundamental research and industrial applications
- Finite-element simulation of pulsed-power circuits
- Fabrication of pulsed-power components
- Software engineering of pulsed-power supplies

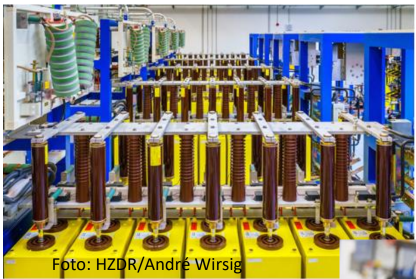

Foto: HZDR/André Wirsig

Foto: HZDR/Jürgen Jeibmann

➢ SCIENTIFIC TECHNICAL FIELDS

- Magnetic and multicaloric refrigeration
- Magnetic liquefaction of hydrogen
- Characterization of magnetic materials
- Pulse-field joining, forming, and welding
- Medical technology applications for tumor therapy and the treatment of neurodegenerative diseases

➢ KEY WORDS

- Pulsed-power supply
- Gigawatt power
- Capacitor bank

➢ COLLABORATIONS

- European XFEL
- LULI @ Saclay
- BESSY @ HZB

➢ PUBLICATIONS AND ADDITIONAL INFORMATION

https://www.hzdr.de/db/!PublJournalsFWH?pNid=636

- PATENTS

Anordnung zur Erzeugung hochenergetischer Protonenstrahlen und deren Verwendung
T.E. Cowan, R. Sauerbrey, T. Herrmannsdörfer
DE 10 2011 052 269 (22.03.2012)

Vorrichtung zur Stromverstärkung für die elektromagnetische Pulsumformung und Verwendung
T. Herrmannsdörfer, S.Dittrich
EP 111545455 (15.02.2011)

➢ CONTACT

industry-hld@hzdr.de

Helmholtz-Zentrum Dresden-Rossendorf

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MAGNET FABRICATION

➢ **TEAM INTEREST:** Design and fabrication of magnets

➢ BRIEF DESCRIPTION

The Dresden High Magnetic Field Laboratory (HLD) at the Helmholtz-Zentrum Dresden-Rossendorf is available to external scientists as a user facility. It enables experiments in the highest pulsed magnetic fields up to the 100 tesla range. In the HLD workshop, resilient pulsed magnetic-field coils are designed and manufactured to meet the highest demands. We offer this cutting-edge technology for generating high pulsed magnetic fields as individual one-off productions for industrial applications.

➢ TEAM ASSETS

In the workshop of the Dresden High Field Magnetic Laboratory (HLD), we develop and manufacture special magnetic-field coils individually. After assessing the technical feasibility and estimating the development and manufacturing effort, we will be happy to make you an offer.

➢ KEY WORDS

- Magnet fabrication
- Simulation of magnetic fields

➢ COLLABORATIONS

- European XFEL

➢ PUBLICATIONS AND ADDITIONAL INFORMATION

https://www.hzdr.de/db/!PublJournalsFWH?pNid=636

➢ CONTACT

industry-hld@hzdr.de

Helmholtz-Zentrum Dresden-Rossendorf

HLD-DRESDEN

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ADVANCED CHARACTERIZATION

➢ **TEAM INTEREST:** Invention of advanced measurement techniques for the characterization of materials under extreme conditions

➢ BRIEF DESCRIPTION

The Dresden High Magnetic Field Laboratory focuses on modern materials research in high magnetic fields. High-magnetic-field experiments are the ideal way to gain insights into the matter that surrounds us. Magnetic fields allow for the systematic manipulation and control of material properties – which is why these kinds of experiments are conducted on new materials so that their fundamental properties can be explored and so that they can be optimized for future application.

➢ TEAM ASSETS

Our team conducts experiments under extreme conditions. For this purpose, we develop most of our experimental equipment ourselves. One example is ROTAX:

With the two-axis rotator, we can control two rotation axes independently and simultaneously. This precise alignment is available

- in small space sample rods,
- in strong electromagnetic fields,
- at very low temperatures.

The relevant components from ROTAX are made from the plastic polyether ether ketone, which hardly wears out and withstands the lowest temperatures without damage. The material is also non-magnetic.

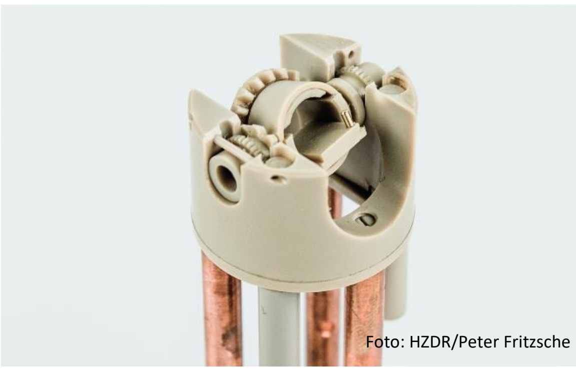
Foto: HZDR/Peter Fritzsche

➢ KEY WORDS

- High-magnetic-field experiments
- mK temperatures
- Hydrostatic pressure
- Uniaxial load

➢ COLLABORATIONS

- Universities, Max Planck Institutes and others

➢ PUBLICATIONS AND ADDITIONAL INFORMATION

https://www.hzdr.de/db/!PublJournalsFWH?pNid=636

- **Patents**

Justiereinrichtung
U. Bartheld
DE 10 2017 123 920.0
(13.10.2017)

➢ CONTACT

industry-hld@hzdr.de

Helmholtz-Zentrum Dresden-Rossendorf

HLD-DRESDEN

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ADVANCED CHARACTERIZATION

SCIENTIFIC FIELDS

- Electrical transport
- Magnetization
- Ultrasound
- Electron Spin Resonance
- Magnetostriction
- Nuclear Magnetic Resonance
- Magnetic torque
- Magnetocaloric effect
- Electrical polarization
- Magneto-optical transmission

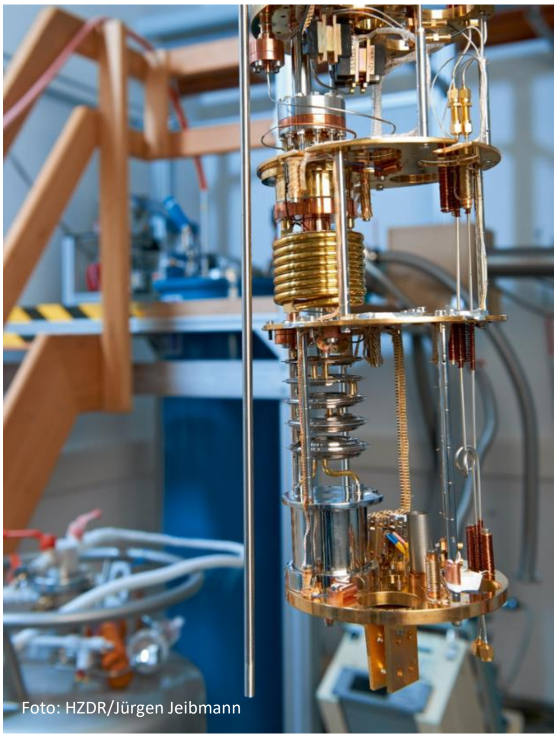

Foto: HZDR/Jürgen Jeibmann

MATERIALS

- Metals
- Semiconductors
- Superconductors
- Low-dimensional materials
- Magnetic materials
- Nanostructured materials

SPECIFIC EQUIPMENT

- Pulsed fields up to 70 T
- Static fields up to 22 T
- ^{3}He system from 0.36 K up to 320 K
- Dilution refrigerator down to 20 mK

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LABORATOIRE NATIONAL DES CHAMPS MAGNETIQUES INTENSES - TOULOUSE

LNCMI-TOULOUSE

Contact

143, avenue de Rangueil
31400 Toulouse
FRANCE
direction@lncmi.cnrs.fr
05.62.17.28.60

http://lncmi.cnrs.fr/

European Magnetic Field Laboratory

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FUNDAMENTAL INTERACTION TESTS IN MAGNETO-OPTICS

- TEAM INTEREST: Ultimate measurements for fundamental interaction tests

BRIEF DESCRIPTION

Our principal goal is the experimental demonstration of fundamental results of the quantum electrodynamic theory. This encompasses ultimate measurement of the effect of magnetic field on light polarization and magnetic effects on the atomic response.

TEAM ASSETS

- Precise optical polarization measurement
- Realization of optical cavities of very high finesse
- Laser frequency locking to cavities
- Magneto-optics
- Interferential mirrors and birefringent materials

SPECIFIC EQUIPMENT

- Ultra-sharp optical cavities(finesse > 500000)
- Very low losses interferential mirrors (losses ~ 10^{-6})
- Opto-electronic instrumentation for laser locking
- Clean room facilities
- Ultra-High vacuum technics
- Guided and Free space Optics
- Very precise polarimetry

SCIENTIFIC FIELDS

- Magneto-optics
- Fundamental Interaction

MATERIALS

- Vacuum
- Gases: N_2, Ar, Ne, He, etc.

KEY WORDS

- Magnetic field
- Fundamental interaction
- Optics
- Polarimetry
- Quantum Electrodynamics
- Metrology
- Interferential Mirrors
- Cotton-Mouton effect

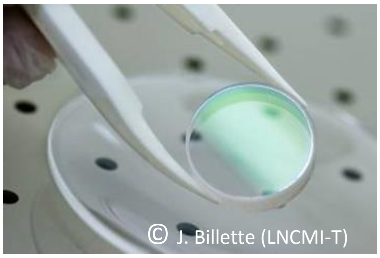
COLLABORATIONS

Open to on demand R&D studies

Laboratoire des Matériaux Avancés, Lyon

CONTACT

Dr. Carlo Rizzo
carlo.rizzo@lncmi.cnrs.fr
05 62 17 29 81
LNCMI-Toulouse



This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 871106

FUNDAMENTAL INTERACTION TESTS IN MAGNETO-OPTICS

➢ **PUBLICATIONS AND ADDITIONAL INFORMATION**

- Rep. Prog. Phys. **76** 016401 (2013)
- Phys. Rev. D 95, 099902 (2017)
- Phys. Rep. 765-766, 1-39 (2018)
- Review of Scientific Instruments **92**, 104710 (2021); https://doi.org/10.1063/5.0064111

LNCMI-TOULOUSE

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 871106

HIGH TEMPERATURE SUPERCONDUCTORS

- **TEAM INTEREST:** Fundamental investigation of superconductors

BRIEF DESCRIPTION

Super-conductive materials allow for transport of electricity without any loss (zero resistance) and for stable levitation. But these striking phenomena are only observable at low temperatures. Developing room temperature superconductors necessitates deep understanding of the underlying physical properties. Our team is involved in the study of electronic and thermic properties of such materials, in extreme conditions of temperature, magnetic fields and pressure.

TEAM ASSETS

Low noise measurements in extreme conditions:

- Electrical and thermal transport
- Ultrasound measurement
- Magnetization
- Sound velocity
- Thermo-electricity
- Torque magnetometry
- Contactless transport measurement based on Tunneling Diode Oscillator

SCIENTIFIC FIELDS

- Fundamental solid states physics
- Magnetism and superconductivity
- Electronic properties of high Tc superconductors

KEY WORDS

- Magnetic fields
- High temperature superconductivity
- Strongly correlated systems

COLLABORATIONS

- Open to on demand R&D studies
- Université de Sherbrooke (Canada)
- Université de Bristol (UK)

CONTACT

Dr. Cyril PROUST
cyril.proust@lncmi.cnrs.fr
05 62 17 28 61
LNCMI Toulouse

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 871106

HIGH TEMPERATURE SUPERCONDUCTORS

SPECIFIC EQUIPMENT

- Phase sensitive (lock-in) amplifier
- Ultra-sound spectrometer
- Oscilloscope (1 GHz,12 bits)
- Fast acquisition systems (up to 1 MHz@24 bits resolution)
- He_4, He_3, dilution fridge cryostat (base temperature down to 50 mK)
- Pulse magnets (magnetic fields up to 90 T)

MATERIALS

- High temperature superconductors ($YBa_2Cu_3O_y$, $HgBa_2CuO_{4+\delta}$, $Tl_2Ba_2CuO_{6+\delta}$, etc.)

PUBLICATIONS AND ADDITIONAL INFORMATION

- N. Doiron-Leyraud *et al.*, *Nature* **447,** 565 (2007)
- S. Badoux *et al.*, *Nature* **531,** 210 (2016)
- Annual Review of Condensed Matter Physics 10, 409 (2019))
- Legros *et al.*, *Nature Physics* **15,** 142 (2019)
- S. Benhabib et al., Nature Physics 17, 194 (2021)
- M. Lizaire, et al., Physical Review B 104, 014515 (2021)

http://lncmi.cnrs.fr/la-recherche/metals-supra/

European Magnetic Field Laboratory

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 871106

HIGH STRENGTH CONDUCTORS

➢ TEAM INTEREST: Research and development of high strength conductors for pulsed magnets and other industrial applications

➢ BRIEF DESCRIPTION

Production of high magnetic fields requires the use of specific coils where cables are submitted to very harsh environment. Conductors need to be carefully designed in order to resist to mechanical deformations due to heating and electrodynamic forces and at the same time maintaining a good level of conductivity. Our team is specialized in whole process of wire design and fabrication, starting from material sintering and ending with wire drawing and macroscopic characterization.

➢ KEY WORDS

- High strength conductors
- Nanostructured materials
- Copper
- Wire-drawing
- Severe plastic deformation
- Mechanical strength
- Electrical conductivity

➢ TEAM ASSETS

- Design of high strength conductors
- Material and process choices
- Elaboration by drawing or accumulative drawing and bundling processes
- Mechanical and electrical characterization at -196 °C and +20 °C

➢ COLLABORATIONS

- Open to on demand R&D studies
- Past and ongoing collaboration:

B-MAX/I-Cube Research
TORNS SOFILEC
IRT-Safran
ALSTOM MSA (FR)

➢ SCIENTIFIC FIELDS

- Electricity and Magnetism
- Material characterization
- Nanomaterials
- Conductive Materials

➢ CONTACT

Dr. Florence Lecouturier-Dupouy
florence.lecouturier@lncmi.cnrs.fr

Dr. Simon Tardieu
simon.tardieu@lncmi.cnrs.fr

Phone: 05 62 17 28 61
LNCMI-Toulouse

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 871106

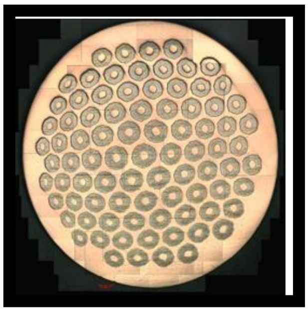
HIGH STRENGTH CONDUCTORS

➤ SPECIFIC EQUIPMENT

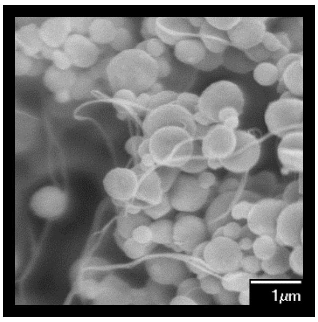
- 2 draw-benches (300 KN, L=6m;100 KN, L=16,5 m)
- Drawing bull-block (40 KN, d=600 mm),
- Wire-drawing machine (10 KN, d=300 mm)
- Cylindrical drawing dies (from 40 mm to 0.2 mm)Turk-head
- shaping die
- Dynamic (varying speed, L=3 m) or static furnaces (L=1 m) under neutral atmosphere (Tmax=1150 °C)
- Tensile test machine (100 KN, T=+20 °C and -196 °C)

➤ MATERIALS

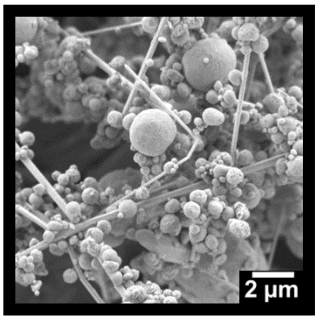
- Cu/SS



- Cu/Nb Nanostructures



- CNT/Cu Nanostructures



- Ag/Cu Nanostructures

➤ PUBLICATIONS AND ADDITIONAL INFORMATION

Patents :

- FR3084376(B1), 2021
- FR2968823(B1), 2015

Groupe web-page :

http://lncmi.cnrs.fr/la-recherche/magnet-materials-technology/high-strength-conductors/

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 871106

PULSED MAGNETS AND GENERATORS

- **TEAM INTEREST:** Design and fabrication of pulsed magnets and their associated generators for fundamental research and industrial applications

BRIEF DESCRIPTION

With a strong interdisciplinary background, at the frontier between research and engineering, we develop pulsed magnets and generators for high magnetic field generation. These developments encompass thermal, mechanical and electro-magnetic studies before magnet fabrication. Our expertise also extends to material choice for critical applications.

KEY WORDS

- Pulsed magnet
- Thermal, mechanical and electromagnetic simulation
- High power and high energy
- High strength material

TEAM ASSETS

- Non-destructive pulsed magnet production (up to 100 T)
- Specific design and fabrication for large scale research facility integration (RX, neutrons, High power lasers)
- Design of transportable pulsed energy supply units for on-site use (from 10 kJ to 6 MJ)

COLLABORATIONS

- Open to on demand R&D studies
- Past and ongoing collaboration
  - BMax/I-Cube Research (FR)

SCIENTIFIC FIELDS

- Electricity and Magnetism
- Physical modelling

CONTACT

Jérôme Béard

jerome.beard@lncmi.cnrs.fr

05 62 17 29 75

LNCMI Toulouse

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 871106

PULSED MAGNETS AND GENERATORS

SPECIFIC EQUIPMENT

- Capacitor banks (up to 21 MJ)
- Coil winding tools (up to 1m diameter and 2 m long coils)– possibility to add high strength polymer fibers for reinforcement and/or cooling channels
- Reinforced concrete cells for tests with risk of explosion
- Magnet monitoring, destructive event prevention
- Transportable pulsed energy supply units for on-site use (from10 kJ to 6 MJ)

PUBLICATIONS AND ADDITIONAL INFORMATION

http://lncmi.cnrs.fr/la-recherche/magnet-materials-technology/non-destructive-pulsed-magnetic-fields/

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 871106

CRYOGENICS

- **TEAM INTEREST**: Design and fabrication of cryostats and cryogenic infrastructure for scientific research

BRIEF DESCRIPTION

Development of ultralow-temperature cryostats for measurements in both high pulsed and steady magnetic fields.

Development and operation of a vacuum facility.

KEY WORDS

- Very low temperature
- ^{3}He, ^{4}He
- Cryostats
- Dilution fridges
- Metal-plastic cryostats
- Magnetic fields

TEAM ASSETS

- In-house development, manufacturing and test of cryogenic systems meeting scientific needs and adapted to experimental environment
- In-house Helium liquefaction

COLLABORATIONS

Open to on demand R&D studies

CONTACT

Marc Nardone
marc.nardone@lncmi.cnrs.fr
05 62 17 29 76
LNCMI Toulouse

3He - 4He dilution refrigerator
50mK in pulsed magnet 60T

3He cryostat 0,5K in pulsed magnets 90 - 100 T

LNCMI-TOULOUSE

CRYOGENICS

MATERIALS

- ^3He, ^4He, LN_2, Ar, H_2
- Stainless steel, Brass, copper, Cu-Ni alloys, Cu-Be Alloys
- Glass fiber epoxy composite G11 FR4
- Technical polymers

SPECIFIC EQUIPMENT

- Conception/Design: Inventor, Autocad
- Machining: Numeric and conventional mills and lathes
- Sheet metal work machinery
- TIG welding stations, silver brazing station, bonding
- Sintering: Controlled atmosphere furnace
- Tests: leak detector, RGA, Lakeshore temperature controllers, LabVIEW, ORIGIN…
- Vacuum production: Fixes and mobiles vacuum stations equipped with scroll, vane, turbo-molecular and diffusion pumps.
- Helium liquefier: Pulse tube cryo-generators, Helium compressors, gas bag + high pressure cylinders recovery

PUBLICATIONS AND ADDITIONAL INFORMATION

- Communications Physics, volume 4, Article number: 40 (2021)
- JOURNAL OF THE PHYSICAL SOCIETY OF JAPAN Volume: 88 Issue: 6 (2019)
- Review of Scientific Instruments, Volume 85, Issue 5 (2014)
- Physical review letters 110 (26), 266601 (2013)
- Review of scientific instrument, volume 77,063903 (2006)
- Cryogenics Volume 41, Issue 3, Pages 175-178 (2001)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 871106

OPTICAL INSTRUMENTATION

- **TEAM INTEREST**: Instrumentation for the experiments under high pulsed magnetic field and extremely low temperatures

BRIEF DESCRIPTION

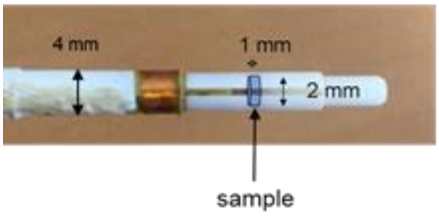
Development of probes of different sizes and geometries for the measurements inside the bore of pulsed field magnets. The probes are suitable for magnetic, optical and electrical measurements in high magnetic field and low temperatures.

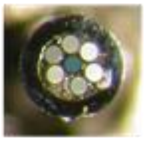
KEY WORDS

- Probes
- Magnetic fields
- Low temperature
- Optical fibre

TEAM ASSETS

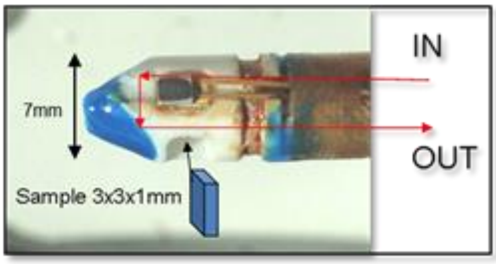
- Probes for photoluminescence and reflectivity spectroscopy based on fiber bundle's up to 90 T, 1.2 °K





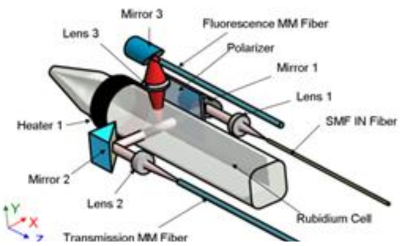
Fiber Bundle's

- Probes for transmission spectroscopy up to 80 T, 1,2 °K



- Probes for Magnetic Field Metrology based on the fluorescence spectroscopy of Rubidium vapor. Up to 58 T.

- Data acquisition systems for pulsed fields measurement: light sources, spectrometers, temperature controllers, timing systems



COLLABORATIONS

Open to on demand R&D studies

SCIENTIFIC FIELDS

- Optics
- Magneto-optics

MATERIALS

- Probes are made of ceramic materials:
- Alumina and zircon
- Macor
- Plastic materials:
- PEEK
- Torlon

CONTACT

Dr. Nicolas Bruyant
nicolas.bruyant@lncmi.cnrs.fr
05 62 17 29 72
LNCMI Toulouse

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 871106

RF INSTRUMENTATION

- **TEAM INTEREST**: Instrumentation for the experiments under high pulsed magnetic field and extremely low temperatures

BRIEF DESCRIPTION

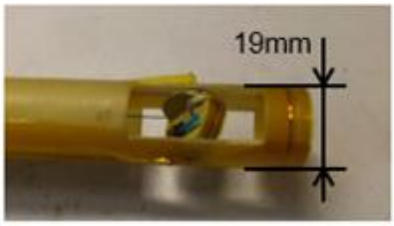
Development of probes of different sizes and geometries for the measurements inside the bore of pulsed field magnets. The probes are suitable for nuclear magnetic resonance and contactless resistivity measurements in high magnetic field and low temperatures.

KEY WORDS

- Probes
- Magnetic fields
- Low temperature
- Radio frequency
- NMR
- Resistivity

TEAM ASSETS

- Probes anglular dependance up to 60 T, 1.5 °K



Rotating sample holder : 0 to 90°.
Up to 60T – 1.5 K

- Probes for two samples, 90 T, 0.5 °K

Sample holder. Up to 90T – 1.5 K

COLLABORATIONS

Open to on demand R&D studies

CONTACT

Dr. Nicolas Bruyant
nicolas.bruyant@lncmi.cnrs.fr
05 62 17 29 72
LNCMI Toulouse

SCIENTIFIC FIELDS

- Electronics
- Material Science

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 871106

RF INSTRUMENTATION

MATERIALS

- Probes are made of ceramic materials:
- Alumina and zircon
- Macor
- Plastic materials:
- PEEK
- Torlon

SPECIFIC EQUIPMENT

Data acquisition systems for pulsed fields measurement:

- RF sources, Vector network analyser & spectrum analyser up to 3 GHz
- Power amplifiers in 0.1 – 1 Ghz range and up to 500 W

PUBLICATIONS AND ADDITIONAL INFORMATION

- L. Drigo et al.: Tunnel diode oscillator-based measurement of quantum oscillations amplitude in pulsed high magnetic fields: a quantitative field-dependent study, The European Physical Journal - Applied Physics 52, 10401 (2010)
- Field-induced magnetic transitions in $Ca_{10}(Pt_3As_8)$*$((Fe_{1-x}Pt_x)2As_2)_5$ compounds, PHYSICAL REVIEW B 89, 205136 (2014)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 871106

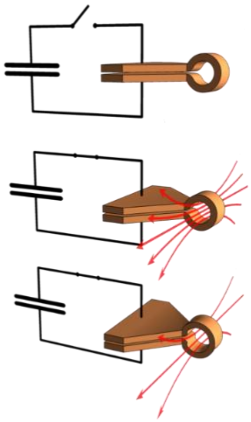
MEGA-GAUSS MAGNETIC FIELD GENERATION

➢ TEAM INTEREST: Generation of high magnetic fields (beyond 100 T)

➢ BRIEF DESCRIPTION

Our Mega-gauss generator is one out of three platforms worldwide that makes use of capacitor-driven single-turn coils (STC) to produce fields in the **150 to 250 T range** for scientific applications. Although still higher fields can be obtained with flux compression techniques, STCs have the advantage that the coil destruction does not affect the experimentally useful volume: samples, cryostats and other equipment generally survive and experiments can therefore be performed reproducibly.

➢ TEAM ASSETS



- Magnetic field generation up to 200 T
- Different measurements in high pulsed magnetic field (200 T, 6 µs):
  - VIS-NIR fibre-based spectroscopy
  - MIR free-beam spectroscopy
  - Studies of magnetization and electrical transport properties

➢ SCIENTIFIC FIELDS

- Magnetism
- Magnetic field metrology
- Magneto-spectroscopy from visible towards near-infrared
- Magneto-transport

➢ SPECIFIC EQUIPMENT

- Capacitor driven generator up to 60 kV and 2 MA.
- Cryogenic environment down to 1.8 K
- Ultrafast 10 GHz acquisition
- Enhanced EMI protection

➢ KEY WORDS

- Mega-gauss
- Semi-destructive magnets
- Magnetization
- Magneto-spectroscopy in NIR-VIS
- Magneto-transport

➢ COLLABORATIONS

Open to on demand R&D studies

➢ PUBLICATIONS AND ADDITIONAL INFORMATION

- Miyata et al., Phys. Rev. B 96, 121111 (2017)
- L. Opherden et al., Physical Review B 99, 085132 (2019)
- A Miyata et al., Nature Physics 11, 582 (2015)

➢ CONTACT

Dr. Oleksiy Drachenko
oleksiy.drachenko@lncmi.cnrs.fr
Dr. Oliver Portugall
oliver.portugall@lncmi.cnrs.fr
Phone : 05 62 17 29 87
LNCMI-Toulouse

European Magnetic Field Laboratory

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 871106

QUANTUM ELECTRONICS

- **TEAM INTEREST**: fundamental physics of low dimensional systems including individual nano-objects at low temperature and in high magnetic field

BRIEF DESCRIPTION

Our team specializes in high magnetic field magneto-optics and magneto-transport measurements. We investigate the electronic properties of quantum wires, monolayer transition metal dichalcogenides, monolayer black phosphorus and perovskites with a further device application.

TEAM ASSETS

- Semi-conductor physics and low dimensional materials (GaAs/AlGaAs core-shell and core-multi-shell nanowires)
- Exfoliated monolayer transition metal dichalcogenides (WS2 and WSe2)
- Fundamental electronic properties of Perovskites for efficient solar cells

SCIENTIFIC FIELDS

- Semiconductors
- Low dimensional systems
- Electronic properties, excitons, phonons

MATERIALS

- GaAs/AlGaAs core-shell and core-multi-shell nanowires
- Transition metal dichalcogenides (WS2 and WSe2)
- Perovskites

SPECIFIC EQUIPMENT

- He^3/He^4 Dilution refrigerator (T=10 mK) with a 16 T superconducting magnet
- Micro-photo luminescence (MPL) and Micro-Raman for individual nano-objects investigation
- Time resolved photoluminescence (TRPL) and transmission (pump probe) with a femtosecond Ti-sapphire laser, OPO and streak camera

KEY WORDS

- High magnetic fields
- Low-dimensional systems
- Magneto-optics and magneto-transport
- Low temperature

COLLABORATIONS

- Ecole Polytech. Fed. de Lausanne
- Weizmann Inst. Of Sc.
- U Leipzig
- U of Cambridge
- U Paris-Saclay
- MIT/ChemE
- TUM
- U of Groningen
- U of Tokyo
- Inst. Des Sc. Chim. De Rennes

PUBLICATIONS AND ADDITIONAL INFORMATION

https://scholar.google.fr/citations?user=4ono85UAAAAJ&hl=en

CONTACT

Dr. Duncan Maude
duncan.maude@lncmi.cnrs.fr
Dr. Paulina Plochocka-Maude
paulina.plochocka@lncmi.cnrs.fr
05 62 17 28 68
LNCMI Toulouse

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European Magnetic Field Laboratory

HIGH RESOLUTION OPTICAL SPECTROSCOPY FOR ACURATE B-FIELD MEASUREMENT

- **TEAM INTEREST:** atomic physics in high B-fields

BRIEF DESCRIPTION

Development of a combined RMN and optical frequency metrology approach for better physical constants determination and accurate measurement of B-fields.

TEAM ASSETS

- Accurate determination of the magnitude of a 60 T pulsed magnetic field.

SCIENTIFIC FIELDS

- Atomic physics
- Optical metrology
- B-field metrology

MATERIALS

- Cesium and Rubidium vapour cells

SPECIFIC EQUIPMENT

- Stabilized lasers on Rubidium D1 and D2 lines
- Stabilized lasers on Cesium D2 line
- Optical HR Fizeau lambdameter
- Laser beat note equipment

KEY WORDS

- B-field metrology
- HR laser spectroscopy
- Zeeman effect
- Rubidium vapour

COLLABORATIONS

Open to on demand R&D studies

PUBLICATIONS AND ADDITIONAL INFORMATION

- https://doi.org/10.1063/1.4993760
- https://doi.org/10.1103/PhysRevA.92.063810

CONTACT

Dr. Renaud Mathevet
renaud.mathevet@lncmi.cnrs.fr
05 62 17 28 68
LNCMI-Toulouse

LNCMI-TOULOUSE

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 871106

NANO-OBJECTS AND SEMI-CONDUCTING NANOSTRUCTURES

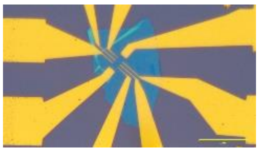
➢ **TEAM INTEREST**: Electronic properties of nano-objects in extreme conditions of low temperature and high magnetic field

➢ BRIEF DESCRIPTION

Our team is specialized in electrical conductivity measurements under high magnetic field of nano-devices and semiconducting nano-structures in order to discover their electronic properties. We aim at understanding of fundamental quantum characteristics of low-dimensional conductors in order to pave the way for next-generation electronic devices.

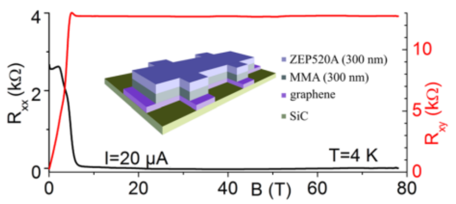
➢ TEAM ASSETS

- **Nanofabrication (sub-micrometer scale)**



Realization of contacts to nano-objects for electrical measurements.

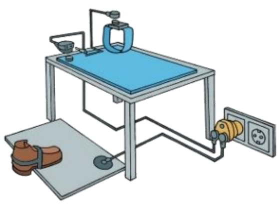
- **Electronic properties of nano-devices**



Study of electron transport in nano-devices in extreme conditions.

- **Low-noise electrical measurements**

- Electro-Static Discharge (ESD) sensitive devices



Electrical measurements of ESD sensitive devices.

➢ KEY WORDS

- High magnetic fields
- Low-dimensional systems
- Electronic transport
- properties
- Low temperature

➢ COLLABORATIONS

- Open to on demand R&D studies

Past and on-going collaborations:

- Intel (IR)
- Charles Coulomb Lab (Montpellier)
- Univ. Nottingham (U.K.)
- Radbout Univ. Nijmegen (The Netherlands)
- LPCNO (Toulouse)
- AIME (Toulouse)

➢ CONTACT

Dr. Walter ESCOFFIER
walter.escoffier@lncmi.cnrs.fr
05 62 17 29 70
LNCMI-Toulouse

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 871106

European Magnetic Field Laboratory

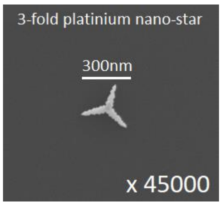
NANO-OBJECTS AND SEMI-CONDUCTING NANOSTRUCTURES

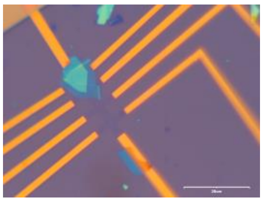
➢ SCIENTIFIC FIELDS

- Solid State Physics
- Nanoscience
- Semiconductors
- Quantum electronics

➢ MATERIALS

Quantum nano-systems:





- 2D materials (graphene, TMDCs, topological insulators)
- 2D electron gas at the interface of complex oxides ($LiAlO_3/SrTiO_3$, perovskites)
- Nano-objects from soft chemistry: (Gold nano-wires, platinum nano-stars)

➢ SPECIFIC EQUIPMENT

- Pulsed magnetic field in 3He cryostat (360 mK, 60 T)
- Electrostatic discharge control environment
- Fast electronic acquisition systems (up to 4 MHz@16 bits resolution)

PUBLICATIONS AND ADDITIONAL INFORMATION

http://lncmi.cnrs.fr/la-recherche/semiconducteur-nanophysics/home/

LNCMI-TOULOUSE

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 871106

QUANTUM CONDUCTORS AND MAGNETS

- **TEAM INTEREST**: Investigation of quantum conductors and magnets under intense magnetic field

BRIEF DESCRIPTION

Quantum conductors and magnets offer the possibility to investigate a large range of new quantum phenomena. Amongst them, quantum phase transitions delimiting different magnetic phases, unconventional superconductivity, valence transitions and crossovers. The team works on the experimental investigation of these quantum materials under intense magnetic field, with the aim to discover new quantum phases and elucidate their microscopic nature.

TEAM ASSETS

In recent years, the team has developed a unique panel of microscopic and macroscopic probes to study the electronic properties of correlated electron systems under extreme conditions of intense magnetic field, which can be combined with low temperature and high pressure.

- At the ESRF synchrotron facility, X-ray (absorption and magnetic circular dichroism) spectroscopy in pulsed field allows accessing the valence and element-selective magnetization of materials under magnetic fields up to 30 T.
- At the ILL neutron source, neutron diffraction permits determining the magnetic structure of magnets in magnetic fields up to 40 T.
- At the LNCMI-T site, a various set of extreme conditions can be combined for electrical resistivity and magnetization measurements: magnetic fields up to 90 T (and >100 T soon), high pressures up to 4 GPa or temperatures down to 100 mK combined with magnetic fields up to 60 T.

SCIENTIFIC FIELDS

- Correlated-electrons physics
- Quantum magnetism
- Unconventional superconductivity

KEY WORDS

- Quantum phase transitions
- Quantum magnetism
- Heavy-fermion systems
- Low-dimensional magnetism
- Frustrated magnetism
- Superconductivity

COLLABORATIONS

- ESRF-Grenoble
- ILL-Grenoble
- CEA-Grenoble
- University of Tohoku

CONTACT

Dr. Fabienne Duc
fabienne.duc@lncmi.cnrs.fr
Dr. William Knafo
william.knafo@lncmi.cnrs.fr
LNCMI-TOULOUSE

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QUANTUM CONDUCTORS AND MAGNETS

MATERIALS

- Correlated electron systems, including heavy-fermion materials, iron-based superconductors and their magnetic parents
- Low-dimensional and frustrated magnets

SPECIFIC EQUIPMENT

- At the ESRF, cryomagnet for XAS and XMCD in transmission mode in high pulsed magnetic fields up to 30 T.
- At the ILL, cryomagnet for neutron diffraction in magnetic fields up to 40 T.
- At the LNCMI-T, multiple probes and their electric apparatus for electrical resistivity and magnetization experiments under pulsed fields up to 90 T.

PUBLICATIONS AND ADDITIONAL INFORMATION

- Nat. Commun. **7**, 13075 (2016)
- J. Phys. Soc. Jpn. **88**, 063705 (2019)
- Nature Phys. **16**, 942 (2020)
- Phys. Rev. 102, 094408 (2020)

Miniaturized probe for electrical-resistivity measurements up to 90 T

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 871106

MAGNETO-CHIRAL ANISOTROPY

- **TEAM INTEREST**: chiral systems in a magnetic field

BRIEF DESCRIPTION

Optical and electrical measurements to observe magneto-chiral anisotropy in condensed matter systems

KEY WORDS

- Chirality
- Polarization optics
- Magneto-transports

TEAM ASSETS

- Highly sensitive measurements of optical and electrical non-reciprocities
- UV-VIS-NIR spectroscopy

COLLABORATIONS

Open to R&D requests

SCIENTIFIC FIELDS

Electrical and optical properties of condensed matter

MATERIALS

Chiral molecules, semi-conductors and metals

SPECIFIC EQUIPMENT

- Alternating polarity electromagnet
- Magneto-chiral dichroism UV-VIS-NIR spectrometer
- Electrical non-reciprocity measurement setup

PUBLICATIONS AND ADDITIONAL INFORMATION

- M. Atzori et al, Validation of Microscopic Magneto-Chiral Dichroism Theory, Science Advances 2021, 7: eabg2859, DOI: 10.1126/sciadv.abg2859
- Matteo Atzori et al. Magneto-Chiral Anisotropy: from fundamentals to perspectives, Chirality 2021, http://doi.org/10.1002/chir.23361

CONTACT

Dr. Geert RIKKEN
geert.rikken@lncmi.cnrs.fr
LNCMI-TOULOUSE

European Magnetic Field Laboratory

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 871106

BROWSE BY EXPERIMENTS

EXPERIMENTAL TECHNIQUES	HFML NIJMEGEN	LNCMI GRENOBLE	HLD DRESDEN	LNCMI TOULOUSE
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EXPERIMENTAL TECHNIQUES	HFML NIJMEGEN	LNCMI GRENOBLE	HLD DRESDEN	LNCMI TOULOUSE
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OPTICAL IMAGING

FEATURES	HFML NIJMEGEN
LOCAL CONTACT	**Dr. Hans ENGELKAMP** hans.engelkamp@ru.nl
FIELD RANGE	Up to 33 T
SPECTRAL RANGE	**Illumination**: Lamps: Halogen, Xenon, Deuterium Different types of lasers: HeNe: 632.8 nm, 543.5 nm Ti:Sapphire: 700 – 1070 nm Solid State: 375 nm, 405 nm, 485 nm, 488 nm, 515 nm, 532 nm, 640 nm, 685 nm, 730 nm. Dye laser: 540-655 nm **Detection:** Sony dxc-990p CCD camera with YH18x6.7 KRS SX7 lens
TEMPERATURE RANGE	278-363 K Stabilized to 0.1 K
SAMPLE SIZE	Optical cuvettes with thickness 0.01-0.5 cm (Voight configuration) Microscopy cover slip up to 12.5 cm (Faraday configuration)
SENSITIVITY	Depends on magnification and light source Resolution down to 1 µm
TYPICAL EXPERIMENT	Transmission microscopy Scattering microscopy Imaging of levitation experiments
SAMPLE HOLDER	Modular design
SAMPLE ENVIRONMENT	Solutions or dispersions
PUBLICATIONS	R. Hemmersbach, A. Simon, K. Wasser, J. Hauslage, P.C.M. Christianen, P.W. Albers, M. Lebert, P. Richter, W. Alt and R. Anken, "Impact of a High Magnetic Field on the Orientation of Gravitactic Unicellular Organisms-a Critical Consideration About the Application of Magnetic Fields to Mimic Functional Weightlessness", Astrobiology 2014, 14, 205.

BIREFRINGENCE, DICHROISM AND FARADAY ROTATION

FEATURES	HFML NIJMEGEN	LNCMI-TOULOUSE
LOCAL CONTACT	**Dr. Hans ENGELKAMP** hans.engelkamp@ru.nl	**Dr. Remy Battesti** remy.battesti@lncmi.cnrs.fr
FIELD RANGE	Up to 38 T	Up to 15 T
SPECTRAL RANGE	**Excitation Different types of lamps**: Halogen, Xenon, Deuterium Different types of lasers (wavelength in nm): HeNe: 632.8, 543.5 Ti:Sapphire: 700 – 1070 Solid State: 375, 405, 485, 488, 515, 532, 640, 685, 730. Dye laser: 540-655 **Detection Ocean Optics Spetrometer**: 350nm – 1000 nm Si photodiode : 375 – 1000 nm	Laser Nd:YAG 1064 nm
TEMPERATURE RANGE	278 -363 K Stabilized to 0.1 K	300 K
SAMPLE SIZE	Optical cuvettes with thickness 0.01-1 cm	Gas in 1 m tube
SENSITIVITY	Polarized UV/VIS spectroscopy Absorbance (A) 0.01-2.0 Linear birefringence $\Delta n=10^{-8}$; Linear dichroism: ΔA=0.001	Ellipticity: 10^{-8} Linear birefringence $\Delta n=10^{-19}$
TYPICAL EXPERIMENT	Polarized UV/VIS spectroscopy; Linear birefringence; Linear dichroism Circular dichroism and birefringence on request	Linear birefringence; Circular birefringence on request
SAMPLE HOLDER	Optical cuvettes with thickness 0.01 – 1 cm	2 m Tube
SAMPLE ENVIRONMENT	Solutions	Gas
PUBLICATIONS	Linear birefringence &dichroism (sample: gold nanorods), PRL *111*, 127202 (2013) Polarized UV/VIS (sample: cyanine dyes), J. Phys. Chem. B *108*, 16386-16391 (2004)	J. Chem. Phys. 142, 124313 (2015); https://doi.org/10.1063/1.4916049

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 871106

MICRO - PHOTOLUMINESCENCE SPECTROSCOPY AND MICRO-RAMAN SCATTERING IN CONTINUOS FIELD

FEATURES	HFML NIJMEGEN	LNCMI-GRENOBLE
LOCAL CONTACT	**Prof. Dr. Peter CHRISTIANEN** peter.christianen@ru.nl	**Dr. Clément FAUGERAS** clement.faugeras@lncmi.cnrs.fr
FIELD RANGE	Up to 38 T	Up to 31 T
SPECTRAL RANGE	Excitation: Lamps: Halogen, Xenon, Deuterium Lasers (wavelength in nm): HeNe: 632.8, 543.5 Ti:Sapphire: 700 – 1070 Solid State: 375, 405, 485, 488, 515, 532, 640, 685, 730. Dye laser: 540-655 Pulsed Solid State lasers: 405, 485, 640, 730 Detection: Si CCD: 350nm – 1000 nm InGaAs array: 950 - 1700 nm Si APDs: 375 – 1000 nm	Different laser excitation sources (laser diodes from 390nm to 785 nm, Dye laser, Ti:Sapph laser, supercontinuum laser with monochromator from 400 nm to 800 nm, white light sources). Circular and linear polarization resolved.
TEMPERATURE RANGE	Temperature range depends on sample holder, optics used and cryostat In general: 0.35 ... 290 K	1.2 K – 300 K
SAMPLE SIZE	< 5 mm lateral size, ~ 1 mm or less height	Substrate up to 12x12 mm, thickness below 5 mm, sample minimal size of from 2-3 µm
SENSITIVITY	Spectral resolution depends on spectrometer: 0.3 m focal length single grating: 150, 300, 600, 1200 grooves/mm. 1.0 m focal length single grating: 1200, 1800 grooves/mm 0.5 m focal length triple grating: 1800 grooves/mm. Temporal resolution: 100 ps with pulsed laser and APD Stray light reduction (Raman): down to 7 wavenumbers	Different spectrometers available for high spectral resolution, high throughput, spectral range from 400 nm to 1600 nm (Si and InGaAs camera), photon correlation experiments (APD) and time resolution (~500 ps).
TYPICAL EXPERIMENT	Polarized (Micro)Photoluminescence (excitation) Polarized (Micro)Raman spectroscopy Fluorescence Line Narrowing (FLN) Polarized Photoluminescence lifetime measurements Polarized Reflectivity spectroscopy	Micrometer spatial resolution for magneto-photoluminescence, magneto-Raman scattering (E > 1-2 meV), magneto-PLE, magneto-reflectivity, magneto-absorption, possibility to electrically contact the sample (gate, etc ...). Spatial mapping of optical response, evolution with magnetic field, with temperature.

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FEATURES	HFML NIJMEGEN	LNCMI-GRENOBLE
SAMPLE HOLDER	Sample mounted on xyz-Attocube positioner with feedback (50 mm bore 30 T magnet) or without feedback (32 mm bore 38 T magnet) Faraday and Voigt configuration	Metallic, non-magnetic. Sample attached with regular glue or silver epoxy. Mounted on X-Y-Z piezo positioners.
SAMPLE ENVIRONMENT	Helium exchange gas	Helium exchange gas
PUBLICATIONS	Raman (sample: PbMnBO4), Phys. Rev. Res. 4, 013004 (2022) Polarized photoluminescence (sample: InP nanowires), ACS Nano 14, 11613 (2020) Photoluminescence (sample: TIPS tetracene), PNAS 115,5077 (2018) Microphotoluminescence (sample: WSe2/MoSe2 heterostructure), Nature Comm. 8,1551 (2017) Fluorescence Line narrowing (Sample: colloidal nanocrystals), ACS Nano 8,5921–5931 (2014) Photoluminescence lifetimes (Sample: CdSe/CdS Colloidal Nanoplatelets), Nano Lett. 18,373−380 (2018)	Magneto -PL: 2D Materials, Volume 7, Number 4, 2020 Magneto-Raman: Nano Lett. 2014, 14, 8, 4548–4553. Time resolved magneto-PL: Nat Commun 12, 3489 (2021).

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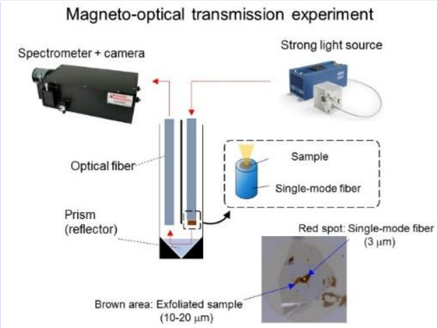
MICRO - PHOTOLUMINESCENCE SPECTROSCOPY AND MICRO-RAMAN SCATTERING IN PULSED FIELD

FEATURES	LNCMI-TOULOUSE	HLD-DRESDEN
LOCAL CONTACT	**Dr. Paulina PLOCHOCKA** paulina.plochocka@lncmi.cnrs.fr	**Dr. Atsuhiko MIYATA** a.miyata@hzdr.de
FIELD RANGE	Up to 90 T	Up to 70 T
SPECTRAL RANGE	Si CCD, ~350 nm - 950 nm InGaAs array detectors: 950 - 1700 nm or 1000 - 2200 nm.	Si CCD, ~350 nm - 950 nm
TEMPERATURE RANGE	1.2 ... 290 K	Standard temperature range is 1.5 – 300 K
SAMPLE SIZE	< 2 mm lateral size,~ 1 mm or less height (other arbitrarily shaped samples can also be accommodated)	< 2 mm lateral size
SENSITIVITY	Usually limited by spectral resolution of the spectrometer, most commonly used 0.3 m focal length with 150, 300 or 600 grooves/mm. Resolution ~0.8-0.2 nm. Longer spectrometer can be also made available.	
TYPICAL EXPERIMENT	Photoluminescence and reflectivity spectroscopy	
SAMPLE HOLDER	Reflectivity sample holder with typical sample inside Samples are mounted and fixed by mechanical clamping on a cylindrical zircone holder	Gaseous helium from 300K down to 4K, liquid helium below
SAMPLE ENVIRONMENT	Gaseous helium from 300 K down to 4 K, liquid helium below in sample holder	
PUBLICATIONS	Reflectivity (sample: single crystal perovskites) J.Phys.Chem.Lett. 8, 1851 (2017) Photoluminescence (sample: TIPS tetracene): PNAS 115,5077 (2018)	

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(FAR-) INFRARED SPECTROSCOPY IN CONTINUOS FIELD

FEATURES	HFML NIJMEGEN	LNCMI-GRENOBLE
LOCAL CONTACT	**Dr. Hans ENGELKAMP** hans.engelkamp@ru.nl	**Dr. Milan Orlita** milan.orlita@lncmi.cnrs.fr
FIELD RANGE	Up to 33 T	Up to 36 T
SPECTRAL RANGE	5-10000 cm^{-1} (Bruker Vertex 80v)	Identical to FIR, MIR and NIR ranges of the Bruker Vertex 80v spectrometer (5-10 000 cm^{-1})
TEMPERATURE RANGE	1.3 - 50 K	1.5 – 4.2 K (reflectivity also at 77 K and RT)
SAMPLE SIZE	88x3 mm^3 or smaller	Disc-shaped, maximal dimensions Ø5 mm and height 5 mm, samples with other (but smaller than disc indicated) shapes can also be accommodated
SENSITIVITY	<1%	Down to 0.1 % of the relative change with the magnetic field
TYPICAL EXPERIMENT	Magneto-transmission in Faraday or Voight configuration	Magneto-transmission (absolute, relative) Magneto-reflectivity (relative)
SAMPLE HOLDER		Drawing of the sample holder for absolute magneto-transmission experiments (for sample up to Ø5 mm)
SAMPLE ENVIRONMENT	Helium exchange gas	Sample in the helium exchange gas
PUBLICATIONS	"Experimental Observation of Bethe Strings", Nature 2018, 554, 219. "One-Way Transparency of Four-Coloured Spin-Wave Excitations in Multiferroic Materials", **Nat. Commun. 2014, 5, 3203.** "Terahertz Spectroscopy of Spin Waves in Multiferroic Bifeo3 in High Magnetic Fields", **Phys. Rev. Lett. 2013, 110, 257201.** "Si:P as a Laboratory Analogue for Hydrogen on High Magnetic Field White Dwarf Stars", **Nat. Commun. 2013, 4, 1469.**	Graphene-based materials - Comptes Rendus Physique 14, 78 (2013) Semimetals, Dirac matter - Nature Phys. 10, 233 (2014) Semiconductors - Phys. Rev. B 80, 073303 (2009) Molecular magnets - Nature Comm. 7, 10467 (2016) Multiferroics - Phys. Rev. B 85, 134445 (2012) Superconductors - Phys. Rev. B 94, 180503 (2016)

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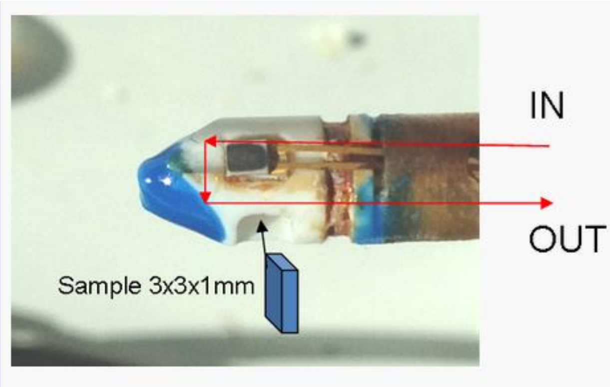
(FAR-) INFRARED SPECTROSCOPY IN PULSED FIELD

FEATURES	LNCMI-TOULOUSE
LOCAL CONTACT	Dr. Paulina PLOCHOCKA paulina.plochocka@lncmi.cnrs.fr
FIELD RANGE	Up to 80 T
SPECTRAL RANGE	Si CCD, ~350nm - 950nm InGaAs array detectors: 950 - 1700 nm or 1000 - 2200nm.
TEMPERATURE RANGE	1.2 - 290 K
SAMPLE SIZE	< 3 mm lateral size,~ 1 mm or less height (other arbitrarily shaped samples can also be accommodated) minimum sample sized limited by beam size (1mm) Space for circular polarization optics is available
SENSITIVITY	Usually limited by spectral resolution of the spectrometer, most commonly used 0.3 m focal length with 150, 300 or 600 grooves/mm. Resolution ~0.8-0.2 nm. Longer spectrometer can be also made available.
TYPICAL EXPERIMENT	Transmission spectroscopy
SAMPLE HOLDER	
SAMPLE ENVIRONMENT	Gaseous helium from 300 K down to 4 K, liquid helium below
PUBLICATIONS	PhysRevB 93, 165412 (2016) Nature Physics 11, 582 (2015) Energy and Environmental Science 9,962 (2016) Energy and Environmental Science 10, 1358 (2017) ACS Energy Letters 2, 1621 (2017)

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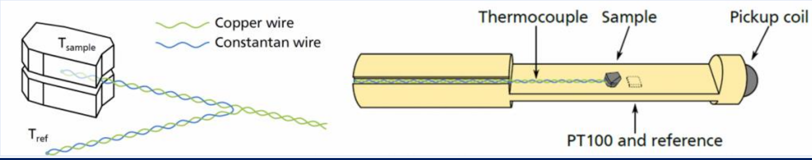
ULTRAFAST DYNAMICS

FEATURES	HFML NIJMEGEN
LOCAL CONTACT	Prof. Dr. Peter CHRISTIANEN peter.christianen@ru.nl
FIELD RANGE	UP to 37.5 T
SPECTRAL RANGE	Excitation: Different types of pulsed lasers (wavelength in nm): Ti:Sapphire oscillator: 100 fs @ 80 MHz: 690 – 1040 OPA: 100 fs @ 1 kHz: 290- 1160 Balanced photo-detector: Si diode: 375 – 1000 nm
TEMPERATURE RANGE	Temperature range depends on sample holder and cryostat In general: 1.5 ... 290 K
SAMPLE SIZE	< 5 mm lateral size, ~ 1 mm or less height
RESOLUTION	Temporal resolution: 100 fs MOKE: 2 mdeg
LIMITATIONS	
TYPICAL EXPERIMENT	Femtosecond pump-probe experiment: magneto-optical Kerr effect (MOKE) or reflectivity
SAMPLE HOLDER	Sample mounted on xyz-Attocube positioner with feedback (50 mm bore 30 T magnet) or without feedback (32 mm bore 38 T magnet) Faraday and Voigt configuration
SAMPLE ENVIRONMENT	Helium exchange gas
PUBLICATIONS	Femtosecond MOKE (sample: iron garnet), Appl. Phys. Lett. 120, 012401 (2022) Femtosecond MOKE (sample: GdFeCo), Phys. Rev. B. 100, 174427 (2019), Phys. Rev. Lett. 118,117203 (2017)

European Magnetic Field Laboratory

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 871106

MAGNETOCALORIC EFFECT

FEATURES	HDL-DRESDEN
LOCAL CONTACT	**Dr. Yurii Skourski** i.scurschii@hzdr.de **Dr. Tino Gottschall** t.gottschall@hzdr.de
DESCRIPTION	The magnetocaloric effect is measured directly by a differential copper – constantan thermocouple, having one junction "sandwiched" within the sample, and another one fixed nearby, and exposed to the same conditions as the sample. 
FIELD RANGE	**Up to 60 T**
TEMPERATURE RANGE	80-360 K
SAMPLE SIZE	Typically, two plates with < 4x4 mm², 2 mm height (other arbitrarily shaped samples can also be accommodated, but two flat surfaces are essential for mounting the thermocouple) Minimum sample size 1x1x1 mm³ The samples can be mounted with a defined orientation
SENSITIVITY	0.01 K absolute
TYPICAL EXPERIMENT	Direct adiabatic temperature change ΔTad (H) ΔTad as a function of the initial temperature Field sweep rates can be varied between 200 … 8000 T/s for time-dependent studies of the magnetocaloric effect. Rate: < 3 K/min (controlled, typical)
SAMPLE HOLDER	The sample is fixed by using GE varnish. The holder is surrounded by a heater.
SAMPLE ENVIRONMENT	Vacuum from 375 K down to 80 K
PUBLICATIONS	[1] M. Ghorbani et al., Appl. Phys. Lett. 106, 071904 (2015) [2] F. Scheibel et al., J. Appl. Phys. 117, 233902 (2015) [3] T. Gottschall et al., Phys. Rev. Applied 5, 024013 (2016)

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SPECIFIC HEAT MEASUREMENT

FEATURES	HFML NIJMEGEN	LNCMI-GRENOBLE
LOCAL CONTACT	**Dr. Nigel HUSSEY** nigel.hussey@ru.nl	**Dr. Albin DE MUER** albin.demuer@lncmi.cnrs.fr
FIELD RANGE	Up to 37 T (from 2023)	Up to 36 T
TEMPERATURE RANGE	500 mK – 40 K	500 mK – 40 K
SAMPLE SIZE	500x500x100 μm^3 (ideal)	500x500x100 μm^3 (ideal)
SENSITIVITY	10^{-3} (accuracy 10^{-2})	10^{-3} (accuracy 10^{-2})
TYPICAL EXPERIMENT	Available to users from 2023	
SAMPLE HOLDER	BareChip cernox	BareChip cernox
SAMPLE ENVIRONMENT	Vacuum	Vacuum

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THERMOPOWER AND NERNST-ETTINGHAUSEN MEASUREMENT

FEATURES	HFML NIJMEGEN		LNCMI-GRENOBLE
LOCAL CONTACT	**Dr. U. Zeitler, Dr. S. Wiedmann** steffen.wiedmann@ru.nl		**Dr. G. Seyfarth, Dr. D. LeBoeuf** gabriel.seyfarth@lncmi.cnrs.fr
FIELD RANGE	**Up to 38 T**		**Up to 35 T**
TEMPERATURE RANGE	50 K -> 0.4 K		10K -> 400mK or dilution
SAMPLE SIZE	5 mm x 2 mm	min. 0.5 mm, max. 2.0 mm	Several mm
SENSITIVITY	Voltage noise level: < 50 nV with digital nanovoltmeter (Keithley 2182A), 5 nV with analogue nanovoltmeter (N11a from EM Electronics) Thermometers & heater: RuO chip resistor with approx. 3.3 kOhm resistance at room temperature		Voltage noise level: few nV at low T and low B, about 10 nV at highest field
TYPICAL EXPERIMENT	Seebeck + Nernst effect		Seebeck + Nernst coefficients
SAMPLE HOLDER	Ag	Ag	Ag
SAMPLE ENVIRONMENT	Vacuum		Vacuum
PUBLICATIONS	A. Jost et al., Proceedings of the National Academy of Sciences (USA), 114 (13) 3381-3386 (2017).		

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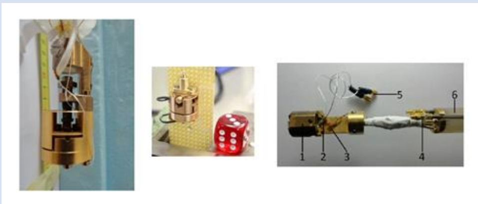
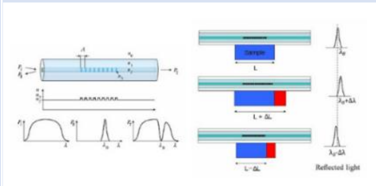
MAGNETOSTRICTION AND THERMAL EXPANSION (UNDER UNIAXIAL STRAIN)

FEATURES	HFLM-NIJMEGEN	HLD-DRESDEN
LOCAL CONTACT	Dr. Steffen WIEDMANN steffen.wiedmann@ru.nl	Dr. Yurii Skourski i.scurschii@hzdr.de
DESCRIPTION	***Capacitive dilatometry* is the standard method for measuring thermal expansion and magnetostriction in DC magnetic fields. At HFML, we have** - a standard dilatometer (50 mm bore) - a uniaxial strain dilatometer (50 mm bore) - a mini-dilatometer (32 mm bore) with in situ rotation (50 mm bore)  (left) Dilatometer for 50 mm bore, (middle) dilatometer for 32 mm bore, (right) dilatometer for 32 mm bore on stick.	An optical fiber Bragg grating (FBG) method is used to measure magnetostriction in pulsed and continuous magnetic fields. The relative length change ΔL/L can be obtained from the shift of the wavelength of the reflected light. 
FIELD RANGE	Up to 30 T in 50 mm bore Up to 38 T in 32 mm bore	Up to 85 T
TEMPERATURE RANGE	0.3 ... 4.2 K (^{3}He system) in 50 mm bore 1.2 K ... 300 K (^{4}He system) in 50 mm bore 1.2 K ... 30 K (^{4}He system) in 32 mm bore	Standard temperature range is 1.4 – 300 K. Measurements down to ~0.6 K with a 3He system are also possible.
SAMPLE SIZE	In 50 mm bore < 3x3 mm2, thickness L < 2 mm In 32 mm bore < 2x2 mm2, thickness L < 1.5 mm	The sample size should be > 1 mm. The samples can be mounted with a defined orientation
SENSITIVITY	$\Delta L/L < 10^{-7}$	Resolutions of about $\Delta L/L \sim 10^{-7}$ are achievable.
TYPICAL EXPERIMENT	ΔL/L(B) - magnetostriction at constant T: Field sweep rates (typical) <0.5 ... 1 T/min; ΔL/L(T) - thermal expansion at constant B: T sweep rates (typical) <0.5 ... 1 K/min;	
SAMPLE ENVIRONMENT	^{3}He or ^{4}He contact gas	Gaseous helium from 270 K down to 4 K, liquid helium below

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FEATURES	HFLM-NIJMEGEN	HLD-DRESDEN
PUBLICATIONS	The world's smallest capacitive dilatometer: Review of Scientific Instruments 88 (2017), 083903; Field-induced states of graphite: Nature Communications 8 (2017), 1337; Lead halide perovskites: Advanced Materials 31 (2019), 1900521; Negative Thermal Expansion in frustrated spinel: Physical Review Letters 123 (2019), 027205;	R. Daou et al., Rev.Sci Instum. 81, 033909 (2010)

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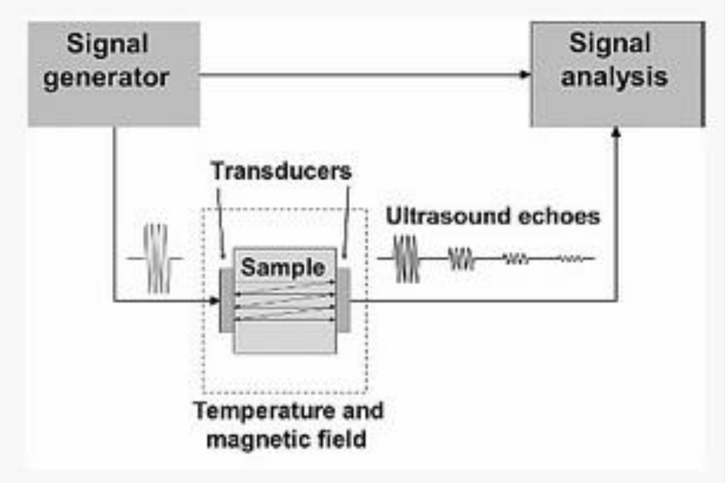
ULTRASONIC MEASUREMENTS (SOUND VELOCITY AND ATTENUATION)

FEATURES	LNCMI-TOULOUSE	HLD-DRESDEN	LNCMI-GRENOBLE
LOCAL CONTACT	Dr. Cyril Proust cyril.proust@lncmi.cnrs.fr	Dr. Sergei Zherlitsyn Dr. Denis Gorbunov Dr. Toshihiro Nomura s.zherlitsyn@hzdr.de	Dr. David Le Boeuf david.leboeuf@lncmi.cnrs.fr
DESCRIPTION	The ultrasound technique is highly sensitive to phase transitions in high magnetic field. The sound velocity and attenuation are measured using a pulse-echo method with a phase-sensitive detection technique which is available both in DC and pulsed field. 		
ULTRASOUND FREQUENCY		5 - 900 MHz	
FIELD RANGE	Up to 90 T	Up to 90 T	Up to 36 T
TEMPERATURE RANGE	0.5 – 300 K	0.02 – 300 K	0.05-325 K
SAMPLE SIZE	Typically, 1 mm length, in the direction of sound propagation	Typically sizes 0.6 - 5 mm The samples can be mounted with a defined orientation	Typically, 1mm length, in the direction of ultrasound propagation
SENSITIVITY	~10^{-5} for the relative change of sound velocity in pulsed field	The resolution for the relative sound-velocity change is 10^{-6} and 10^{-3} for the sound attenuation	Depends a lot on the echo pattern: 1 ppm in sound velocity change in the best conditions.
TYPICAL EXPERIMENT	Field sweeps at fixed temperature		Both, temperature sweeps and field sweeps are possible. The technique is available both in DC and pulsed field.
SAMPLE HOLDER	Please, contact the local contacts.		The sample holder is a simple plate with thermometer connected to it. The probe is equipped with two low attenuation coax

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FEATURES	LNCMI-TOULOUSE	HLD-DRESDEN	LNCMI-GRENOBLE
			cables, allowing to perform reflection or transmission experiments. Specific sample mounting can be achieved if required.
SAMPLE ENVIRONMENT	Gaseous helium from 300 K down to 4 K, liquid helium down to 1.4 K (0.5 K for 3He)	Gaseous helium from 300 K down to 4 K, liquid helium down to 1.3 K	VTI environment between 325 and 1.2 K. For lower temperatures,3He and dilution refrigerator can be used.
PUBLICATIONS	In pulsed fields : D. LeBoeuf et al., Nature Physics 9, 79 (2013). F. Laliberté et al., npj Quantum Materials 3, 11 (2018). In zero field : S. Benhabib, Nature Physics 17, 194 (2021).	S. Zherlitsyn et al., Low Temp. Phys. 40, 123 (2014) Z. Wang et al., Phys. Rev. Let. 120, 207205 (2018) V. Tsurkan et al., Science Advances 3, e1601982 (2017) S. Zherlitsyn et al., Phys. Rev. B 91, 060406(R) (2015)	Superconductors: npj Quantum Materials 3, 11 (2018) Semi-metals: Nat. Comm. 8 1337 (2017)

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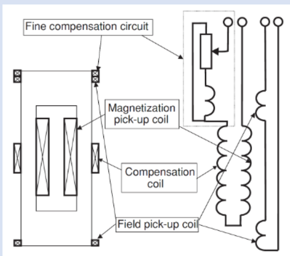
COMPENSATED COIL MAGNETOMETERY

FEATURES	LNCMI TOULOUSE MEGAGAUSS	LNCMI TOULOUSE	HLD DRESDEN
LOCAL CONTACT	**Dr. Oleksiy Drachenko** oleksiy.drachenko@lncmi.cnrs.fr	**Dr. William KNAFO** william.knafo@lncmi.cnrs.fr	**Dr. Yurii SKOURSKI** skourski@hzdr.de
FIELD RANGE	Up to 150 T	Up to 70 T	Up to 85 T
TEMPERATURE RANGE	4 ... 300 K	1.5 K ... 300 K	1.4 – 300 K ^{3}He option with a base temperature of ~0.5 K is available on request
SAMPLE SIZE	Typically, needle-shaped single crystal sample with < 1 mm diameter, 2 mm length (Powder sample is also fine) (Metallic sample gets a strong effect of eddy currents)	Sample should fit in a 1.4 mm tube, typical sample height = 4 mm, typical mass = 20-40 mg	> Sample should fit in a 1.8 mm tube, typical sample height is 4 mm; sample holders are provided in order to mount samples in a defined orientation
SENSITIVITY		Sensitivity is ok for fields below 40 T, but poor for higher fields, new prototypes are under development	Down to 10-6 J/T (10^{-3} emu) net magnetic moment. The sensitivity depends on the shape of the magnetization curve.
TYPICAL EXPERIMENT	Sweep rates (typical) 300 T/µsec Adiabatic magnetisation		Magnetisation M (B) Raise time 7- 40 ms. 
SAMPLE HOLDER	Sample holder with typical sample inside. Sample is mounted into a kapton tube.		
SAMPLE ENVIRONMENT	Gaseous helium from 300 K down to 4 K		Gaseous helium from 270 K down to 4 K or liquid helium below

FEATURES	LNCMI TOULOUSE MEGAGAUSS	LNCMI TOULOUSE	HLD DRESDEN
PUBLICATIONS	Frustrated magnets A. Miyata et al., Phys. Rev. B, 87 214424 (2013) S. Takeyama et al., J. Phys. Soc. Jpn., 81 014702 (2012)	Heavy Fermions W. Knafo et al., Nature Comm., 7, 13075 (2016) K. Kuwahara et al., Phys. Rev. Lett. 110, 216406 (2013)	Y. Skourski et al., Physical Review B 83 214420 (2011) Tsurkan et al., Sci. Adv. 3, e1601982 (2017)

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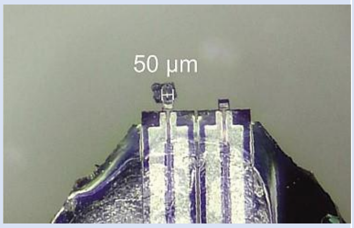
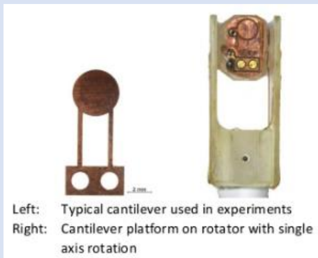
TORQUE MAGNETOMETRY

FEATURES	LNCMI TOULOUSE	HLD DRESDEN	HFML NIJMEGEN
LOCAL CONTACT	**Dr. David VIGNOLLES** david.vignolles@lncmi.cnrs.fr	**Dr. Toni Helm** t.helm@hzdr.de	**Dr. Alix McCollam** A.McCollam@ru.nl **Dr. Steffen Wiedmann** steffen.wiedmann@ru.nl **Dr. Uli Zeitler** Uli.Zeitler@ru.nl
FIELD RANGE	Up to 90 T	Up to 90 T	Up to 38 T
TEMPERATURE RANGE	0.5 K - 300 K (maximum field 90 T) 1.4 K – 300 K (maximum field 60 T or 70 T - rotating insert	1.4 K - 300 K (max field 90 T with pulse duration of 10 ms) 0.6 K – 300 K (max field 62 T & 70 T with pulse duration of 25 ms & 150 ms)	0.3 ... 80 K (3He system) 1.4 ... 380 K (flow cryostat) 0.05 ... 4 K (dilution refrigerator, on request) (Upper temperature limit depends on signal strength)
SAMPLE SIZE	100 μm *50 μm*20 μm	The size of the cantilever is 50 μm x 120 μm, which requires samples of similar size.	< 4 mm diameter, 1 mm height (other arbitrarily shaped samples can also be accommodated). Minimum sample sized limited by sensitivity. The samples can be mounted with a defined orientation Sample weight limited by signal strength
SENSITIVITY	~10^{-13} Am²	~10^{-13} Am²	10^{-9} J/T absolute
TYPICAL EXPERIMENT	Torque measurement versus field for different temperatures or angles	Torque measurement versus field for different temperatures or angles. Various magnet designs provide different pulse durations and shapes.	Magnetisation M (B,T,ϑ) Torque (B,T,ϑ) sweep rates (typical) 0.5 … 2 T/min
SAMPLE HOLDER	Sample is fixed (vacuum grease or epoxy) at the end of the cantilever beam.	Typical sample attached to a cantilever (left) with a reference cantilever on the right. 	 The samples can be mounted with a defined orientation. Sample weight limited by signal strength.
SAMPLE ENVIRONMENT	Gaseous helium from 300 K down to 4 K, liquid helium or ³He below	Gaseous helium from 300 K down to 4 K, liquid helium or ³He below	In-situ rotation available with ϑ=±100°

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FEATURES	LNCMI TOULOUSE	HLD DRESDEN	HFML NIJMEGEN
			(ϑ=0° field perpendicular to cantilever (see i and ii))
PUBLICATIONS	PhysRevLett.100.187005Jaudet C et al., PRL 100, 187005 (2008) Klein Y et al. Phys. Rev. B 97, 075140 (2018) C. Putzke et al.,Phys. Rev. Lett. 108, 047002 (2012)	E. Ohmichi and T. Osada, Rev. Sci. Instr. 73, 3022 (2002)	Henrik Grundmann *et al.,* New Journal of Physics 18, 033001 (2016)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 871106

VIBRATING-SAMPLE MAGNETOMETER (VSM)

FEATURES	LNCMI GRENOBLE	HFML NIJMEGEN
LOCAL CONTACT	**Dr. Gabriel Seyfarth** gabriel.seyfarth@lncmi.cnrs.fr	**Dr. Uli Zeitler** Uli.Zeitler@ru.nl
FIELD RANGE	Up to 35 T	Up to 33 T
TEMPERATURE RANGE	20 K -> 1.3 K (extension planned)	1.2 ... 350 K
SAMPLE SIZE	max: 1.5 mm width and length, less for thickness to avoid inhomogeneous field within sample (500 µm), single crystals	Typically, disc shaped pallets with< 4 mm diameter, 1 mm height (other arbitrarily shaped samples can also be accommodated) minimum sample sized limited by sensitivity The samples can be mounted with a defined orientation
SENSITIVITY	$5*10^{-7}$ emu (improvements ongoing)	
TYPICAL EXPERIMENT	M(H), anomalies or quantum oscillations	Magnetic materials, hysteresis loops, phase transitions, critical currents in superconductors. Isothermal magnetisation M (B) with (typical) sweep rates 0.5 … 5 T/min field cooling M (T) - rate: > 10 K/min (uncontrolled) 0.1 … 3 K/min (controlled, typical)
SAMPLE HOLDER	CuBe sample platform, single crystals attached by apiezon grease.	 VSM sample holder with typical sample inside. Samples are mounted and fixed by mechanical clamping into a cylindrical plastic holder.
SAMPLE ENVIRONMENT	Exchange gas (He)	He flow (gas, 4.2 K ...350 K) or He liquid (1.3 … 4.2 K)
PUBLICATIONS		Magnetic nanoparticles - J. Am. Chem. Soc, 130, 5335 (2008) Exchange bias in ferrimagnets - Nat. Mater. 14, 679 (2015) Martensitic transformation kinetics - Mater. Sci. Eng. A 527, 5241(2010) & Journal of Alloys and Compounds 874, 159814 (2021). Molecular magnets - Inorg. Chem. 48, 11903 (2009) Multiferroics - Phys. Rev. B 89, 064403 (2014)

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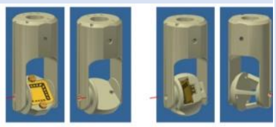
MAGNETO-TRANSPORT MEASUREMENTS WITH IN-SITU SAMPLE ROTATION

FEATURES	HFML NIJMEGEN	HLD DRESDEN	LNCMI TOULOUSE
LOCAL CONTACT	**Dr. Alix McCollam** A.McCollam@ru.nl **Dr. Steffen Wiedmann** steffen.wiedmann@ru.nl **Dr. Uli Zeitler** Uli.Zeitler@ru.nl	**Dr. Toni Helm** t.helm@hzdr.de	**Dr. Walter Escoffier** walter.escoffier@lncmi.cnrs.fr
FIELD RANGE	UP to 38 T	UP to 90 T	UP to 70 T
TEMPERATURE RANGE	0.3 ... 30 K (3He system) 1.4 … 380 K (flow cryostat) 0.05 ... 4 K (dilution refrigerator, on request)	300 K down to 1.3 K. Lower temperatures down to ~0.6 K are possible using a ^{3}He system with a 24mm bore coil (62 & 70 T)	Standard: 1.6 - 350 K On option: 350 mK - 350 K
SAMPLE SIZE	i) sample in LCC-20 chip carrier < 5x5 mm2 (inside LCC-20 dye); ii)sample directly mounted on platform < 10x10 mm^2; < 1 mm thickness (typical)sample resistance: μΩ… MΩ (AC using lock-in amplifiers) < 1 GΩ (DC, typically, using nanovoltmeters)	The maximum sample space available is 10 x 6 x 2 mm. Angular-dependent measurements and measurements in 95 T coils can be performed on two samples simultaneously, however restricting their size to 4 x 3 mm.	Typical samples: nano-devices or 2DEGs on chip Chip size: maximum 3.5 x 3.5 mm²
SENSITIVITY		Relative resolutions of 10-4 are achieved.	
TYPICAL EXPERIMENT	R(B,T,ϑ,Vg,...) sweep rates (typical) 0.5 … 5 T/min Bias current: < 1 nA …10 mA (typical,depending on sample impedance) Gate voltage: ±100 V (typical)  Rotation holders with and without LCC-20. Two-different rotation axis configurations can be chosen: out-off-plane (right) or in-plane (left).	Typical AC-excitation currents range from 1 μA to 100 mA with frequencies between 2 and 200 kHz.	Magneto-resistance and Hall effect - Current or voltage biasing - DC or AC (lock-in at 10kHz minimum frequency) measurement - Gate voltage control (top and/or back gate) - Safe handling of electrostatic-sensitive devices - Sample tilting with respect to B (perpendicular to parallel field) - UV and visible light illumination

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FEATURES	HFML NIJMEGEN	HLD DRESDEN	LNCMI TOULOUSE
SAMPLE HOLDER	a) rotate field from parallel to perpendicular orientation b) rotate field inside sample plane (azimuthal rotation) c) fixed angle (ϑ=0°), sample perpendicular to field	The standard sample holder can accommodate up to three samples when both longitudinal resistivity and Hall effect are measured.	The chip is glued on a ceramic holder which is mounted on a commercial 10 or 8-pin connector. The contact pads are connected to those on the ceramic either with wedge bonding or manually with silver-pasted gold wire.
SAMPLE ENVIRONMENT		Gaseous helium from 300K down to 4 K, liquid helium or ^{3}He below	Helium or vacuum (only for experiments up to 60 T in large-bore coils)
PUBLICATIONS	Ising superconductivity: PNAS 115, 3551 (2018);Science 350, 1353 (2015); Fractal states in graphene: PNAS 115, 5135 (2018);Quantum Oscillations in ZrSiS: Nature Physics 14 (2018), 178-183; FQHE and Wigner solid in ZnO: Nature Communications 9 (2018), 4356 ; QHE in InSe: Nat. Nanotechol. 12, 223 (2017)	[1] T. Helm et al., Physical Review B 92, 094501 (2015) [2] C. Shekhar et al., Nature Physics 11, 645–649 (2015) [3] F. Kisslinger et al., Nature Physics 11, 650–653 (2015)	Exfoliated graphene - Phys. Rev. Letters 107, 126806 (2011) SiC graphene-Phys. Rev. Letters 117, 237702 (2016) Graphene nanoribbons - Phys. Rev. Letters 107, 086601 (2011) Semiconducting nanowires - Phys. Rev. Letters 112, 076801 (2014) Topological insulators - Nano Letters 15, 7503–7507 (2015) 2DEG at complex oxide interfaces - Appl. Phys. Letters 109, 122106 (2016) Bottom-up conducting nano-objects - Nanoscale 9, 14635 (2017)

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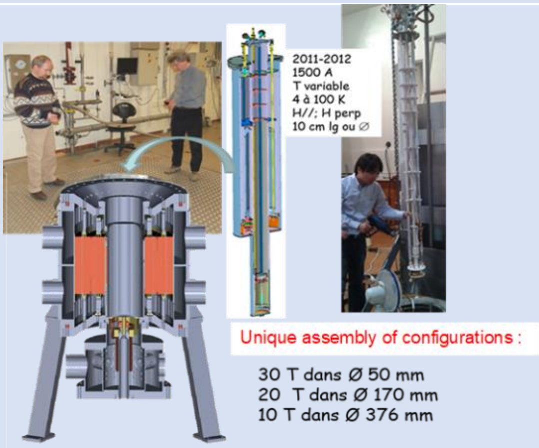
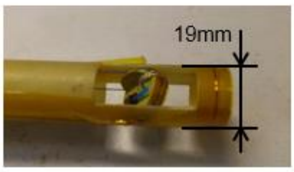
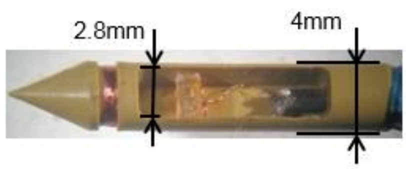
CRITICAL CURRENT OF SUPERCONDUCTORS (WIRES, TAPES AND COILS)

FEATURES	LNCMI GRENOBLE
LOCAL CONTACT	**Dr. Xavier CHAUD** xavier.chaud@lncmi.cnrs.fr
DESCRIPTION	• Wire and tape characterisation • Solenoid characterisation • Dipole characterisation
FIELD RANGE	**Up to 30 T**
TEMPERATURE RANGE	4.2 K
SAMPLE SIZE	3 cm long
SENSITIVITY	Electrical field criterion 1 µV/cm
TYPICAL EXPERIMENT	Transport measurement of Jc from 15 to 30 T at different angles on highly anisotropic REBaCuO coated conductor tapes
SAMPLE HOLDER	Ex-situ rotation
SAMPLE ENVIRONMENT	Liquid helium
PUBLICATIONS	*REBCO tape performance under high magnetic field*, Eur. Phys. J. Appl. Phys. (2017) 79: 30601 DOI: 10.1051/epjap/2017160430
ADDITIONAL INOFORMATION	

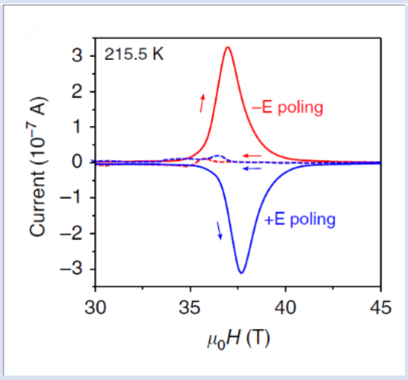
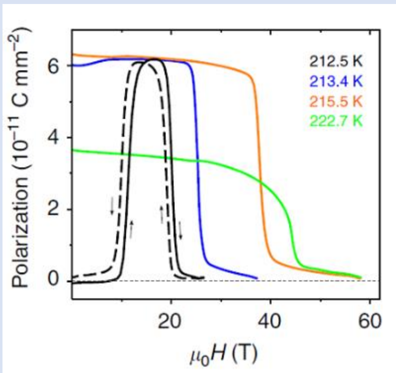
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 871106

CONTACTLESS TRANSPORT

FEATURES	LNCMI TOULOUSE
LOCAL CONTACT	**Dr. Nicolas BRUYANT** nicolas.bruyant@lncmi.cnrs.fr
FIELD RANGE	**Up to 90 T**
TEMPERATURE RANGE	0.5 ... 300 K
SAMPLES SIZES	Any type of form. Preferably circular or square. Any thickness. The size depends on the inside diameter of the cryostats depending on the desired field value. 2 Samples can be measured simultaneously. For 90 T, the sample size should not exceed 1 * 1 mm². For 70 and 80 T, the sample size can be up to 2 * 2 mm². For 60 T, the sample size can be up to 4 * 4 mm². Ability to make an angular dependency up to 60 T. Precision: 1°.
SENSITIVITY AND FREQUENCY	0.1 ppm using TDO @ 10-50 MHz 1 ppm using tramsmission technique @ 0.1-2 GHz
TYPICAL EXPERIMENT	Frequency dependence vs field Frequency dependence vs temperature (at 0 field)
SAMPLE HOLDER	Samples are glued into the Rf coil  Rotating sample holder : 0 to 90°. Up to 60T – 1.5 K  Sample holder. Up to 90T – 1.5 K
SAMPLE ENVIRONMENT	Gaseous helium from 300 K down to 0.5 K, liquid helium below
PUBLICATIONS	L. Drigo et al. : Tunnel diode oscillator-based measurement of quantum oscillations amplitude in pulsed high magnetic fields: a quantitative field-dependent study, The European Physical Journal - Applied Physics 52 , 10401 (2010) Field-induced magnetic transitions in Ca10(Pt3As8)((Fe1−xPtx)2As2)5 compounds, PHYSICAL REVIEW B 89, 205136 (2014)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 871106

ELECTRIC POLARIZATION MEASUREMENT

FEATURES	HLD DRESDEN
LOCAL CONTACT	**Dr. Sumanta Chattopadhyay** s.chattopadhyay@hzdr.de
FIELD RANGE	Up to 85 T
TEMPERATURE RANGE	1.4... 270 K
SAMPLE SIZE	The sample should be shaped as a plane-parallel plate, with a surface area of few square millimeters, and thickness 0.1 – 1 mm. The polling voltage ranges +/- 500 . Minimum sample size 1x1x1 mm³. The samples can be mounted with a defined orientation.
TYPICAL EXPERIMENT	  Magnetic-field variation of the pyro-current and the electric polarization for the two axes of the CuO single crystal. [1]
SAMPLE ENVIRONMENT	Gaseous helium from 270 K down to 4 K, liquid helium below
PUBLICATIONS	[1] Z. Wang et al., Nat. Comm. 7, 10295 (2016)

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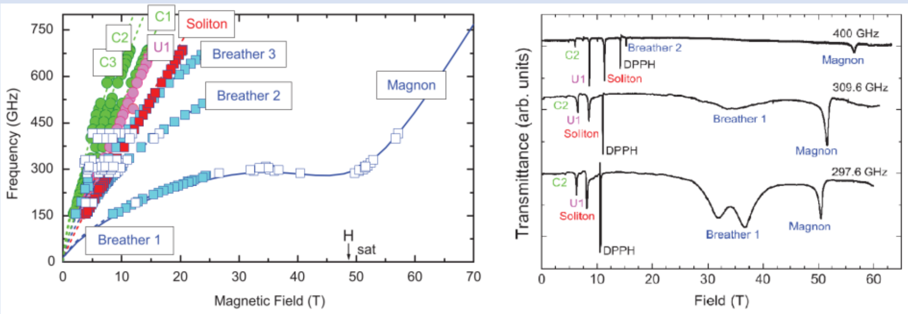
ELECTRON MAGNETIC RESONANCE

FEATURES	HLD DRESDEN
LOCAL CONTACT	**Dr. Sergei Zvyagin** s.zvyagin@hzdr.de
DESCRIPTION	Electron Magnetic Resonance (EMR) covers a variety of magnetic resonance techniques associated with the electron. The most popular of those techniques is Electron Paramagnetic/Spin Resonance (EPR/ESR). In our lab, ESR experiments can be performed in pulsed magnetic fields up to 70 T using a transmission-probe multi-frequency spectrometer operated in the 0.1 - 9 THz frequency range, covered by (i) VDI microwave chains (product of Virginia Diodes Inc.), (ii) FIRL-100 THz molecular-gas laser (product of Edinburgh Instruments Ltd), and (iii) the FELBE THz free-electron laser. The spectrometer is equipped with Ga:Ge and n-InSb bolometers. The lowest temperature available for EMR experiments is 1.5 K.
FIELD RANGE	UP to 70 T
TEMPERATURE RANGE	down to 1.5 K
AVAILABLE FREQUENCY RANGES	0.1 – 9 THz
SOURCES	VDI microwave chains (0.1 - 0.5 THz), THz molecular-gas laser (0.4-3.5 THz), THz free-electron laser (1.2 – 9 THz)
SAMPLE SIZE	Ca 4 x 4 x 1 mm
SAMPLE HOLDER	Faraday configuration
SAMPLE ENVIRONMENT	He^4 bath cryostat
TYPICAL EXPERIMENT	Examples of ESR spectra in the quasi-1D chain material Cu-PM with alternating DM interaction in pulsed magnetic fields [4]. 

FEATURES	HLD DRESDEN
	Frequency-field diagram of ESR excitations in the quasi-1D chain material Cu-PM with staggered DM interaction taken in magnetic fields up to 64 T at 1.5 K (left panel) [4]. Corresponding examples of ESR spectra (right panel).
PUBLICATIONS	• M. Ozerov et al., Electron spin resonance modes in a strong-leg ladder in the Tomonaga-Luttinger liquid phase, Phys. Rev. B **92**, 241113 (R) (2015). • 2. F. Esser et al., Direct determination of the electron effective mass of GaAsN by terahertz cyclotron resonance spectroscopy, Appl. Phys. Lett. 107, 062103 (2015). • M. Ozerov et al., Establishing the fundamental magnetic interactions in the chiral skyrmionic Mott insulator Cu2OSeO3 by terahertz electron spin resonance, Phys. Rev. Let. 113, 157205 (2014). • S.A. Zvyagin et al., Field-induced gap in a quantum spin-1/2 chain in a strong magnetic field, Phys. Rev. B 83, 060409(R) (2011). • 5. O. Drachenko et al., High-field splitting of the cyclotron resonance absorption in strained p-InGaAs/GaAs quantum wells, Phys. Rev. B 79, 073301 (2009). • 6. S.A. Zvyagin et al., Terahertz-range free-electron laser electron spin resonance spectroscopy: Techniques and applications in high magnetic fields, Rev. Sci. Instr. 80, 073102 (2009).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 871106

NUCLEAR MAGNETIC RESONANCE

FEATURES	HLD DRESDEN	LNCMI-GRENOBLE	LNCMI-TOULOUSE
LOCAL CONTACT	**Dr. Hannes Kühne** hannes.kühne@hzdr.de	**Dr. Mladen Horvatić** mladen.horvatic@lncmi.cnrs.fr **Dr. Marc-Henri Julien** marc-henri.julien@lncmi.cnrs.fr **Dr. Steffen Krämer** steffen.kramer@lncmi.cnrs.fr **Dr. Hadrien Mayaffre** hadrien.mayaffre@lncmi.cnrs.fr	**Dr. Nicolas Bruyant** nicolas.bruyant@lncmi.cnrs.fr
FIELD RANGE	**Up to 70 T**	**Up to 36 T**	**Up to 58 T**
TEMPERATURE RANGE	2.0 – 300 K	Variable temperature for solid state physics NMR: 1.3 K to 300 K with ^{4}He variable temperature insert, 350 mK to 4.2 K with ^{3}He variable temperature insert, 40 mK to 1.0 K with ^{3}He/^{4}He dilution refrigerator. Room temperature (regulated) for high resolution NMR for chemistry.	1.5 ... 300 K
SAMPLE SIZE	<10 mm^3 to avoid spectral broadening	Solid state physics NMR: < 10 mm^3, almost any sample can be accommodated. High resolution NMR for chemistry: < 1 cm^3, almost any sample can be accommodated.	Powders, liquids or single crystals < 5 mm diameter, <10 mm length minimum sample sized limited by sensitivity The samples can be mounted with a defined orientation
RESOLUTION	10^{17} ^{1}H spins	Solid state physics NMR: 50 ppm / 1 mm^3 at variable magnetic field (< 10 ppm for single-scan recordings). High resolution NMR for chemistry (ferroshim and spin-lock): 20 ppm / 1 cm^3 at fixed magnetic field (< 10 ppm for single-scan recordings)	

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FEATURES	HLD DRESDEN	LNCMI-GRENOBLE	LNCMI-TOULOUSE
LIMITATIONS			Nucleus with short T1
TYPICAL EXPERIMENT	NMR 10 – 3000 MHz with at least 200 W pulse power NMR data is recorded in the maximum regime of the field pulse during a time window of several ms, typically. Several FID or echo signals can be recorded during one field pulse.	Variable frequency NMR for any NMR active nucleus up to 1.5 GHz: Magnetic field and/or temperature dependence of NMR spectra as well as longitudinal (T_1) and transverse (T_2) NMR relaxation. High resolution NMR spectra at fixed field (ferroshim and spin-lock). CPMG multi-pulse experiments.	NMR from 200 MHz to 1200 MHz with 500 W pulse power Single scan NMR looking for phase transition in the spectrum Knight shift, chemical shift determination
SAMPLE HOLDER	The NMR coil is mounted on a platform with 10 mm diameter.	Tailored NMR coils for optimized sensitivity. Top-tuning and bottom-tuning configuration. Goniometer option. High pressure cell option (<2.4 GPa). Further details and drawings available upon request.	NMR coil is directly winded around the sample for maximum sensitivity

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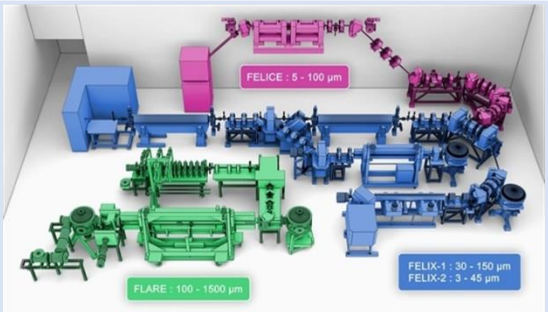
FREE ELECTRONS LASER

FEATURES	HHML NIJMEGEN
LOCAL CONTACT	Dr. Hans Engelkamp Hans.Engelkamp@ru.nl Dr. Peter Christianen peter.christianen@ru.nl
FIELD RANGE	Up to 33 T DC
SPECTRAL RANGE	Different Free Electron Lasers (www.ru.nl/felix) FELIX: 2-120 THz, FLARE: 0.25-3 THz
TEMPERATURE RANGE	Temperature range depends on sample holder and cryostat In general: 1.5 ... 290 K
SAMPLE SIZE	< 5 mm lateral size, ~ 1 mm or less height
SENSITIVITY	Spectral resolution depends on the free electron laser used.
TYPICAL EXPERIMENT	Transmission experiment (Electron spin resonance or cyclotron resonance). Electrically detected magnetic resonance Optically detected magnetic resonance
SAMPLE HOLDER	Faraday configuration
SAMPLE ENVIRONMENT	He^4 bath cryostat (cold finger of exchange gas)
PUBLICATIONS	1) M. Ozerov, B Bernáth, D. Kamenskyi, B. Redlich, A. F. G. van der Meer, P. C. M. Christianen, H. Engelkamp and J. C. Maan: A THz spectrometer combining the free electron laser FLARE with 33 T magnetic fields. Applied Physics Letters 110 (2017), 094106 2) P. Gogoi, D. Kamenskyi, D.D. Arslanov, R.T. Jongma, W.J. van der Zande, B. Redlich, A.F.G. van der Meer, H. Engelkamp, P.C.M. Christianen and J.C. Maan: Magnetoquantum Oscillations at THz Frequencies in InSb. Physical Review Letters 119 (2017), 146603
	

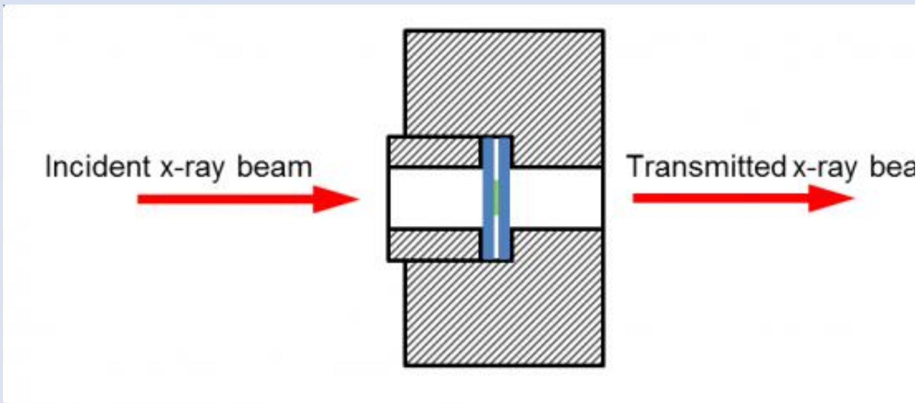
European Magnetic Field Laboratory

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 871106

X-RAY SPECTROSCOPY

FEATURES	LNCMI TOULOUSE
LOCAL CONTACT	**Dr. Fabienne DUC – LNCMI** fabienne.duc@lncmi.cnrs.fr **Dr. Olivier MATHON – ESRF** mathon@esrf.fr
PROPOSAL SUBMISSION PROCEDURE	Before writing a proposal, it is mandatory to contact well in advance both local contacts to evaluate the feasibility of the experiment. Two proposal review rounds are held each year, with deadlines for submission of applications for beam time on: 1st March (inclusive) for the scheduling period August (of the same year) to February (of the following year) 10th September (inclusive) for the scheduling period March to July (of the following year) Review Committees: The proposals submitted for 1st March and 10th September proposal rounds are reviewed during the Review Committees which are held in April and October, respectively.
FIELD RANGE	**Up to 30 T**
TEMPERATURE RANGE	**2 - 300 K**
SAMPLE SIZE	Single crystals: polished or thinned samples 100 µm < diameter < 500 µm, thickness must be homogeneous (20 µm or less) adjusted to the probed edges, surfaces without roughness are preferred. The samples are mounted with a defined orientation.
TYPICAL EXPERIMENT	XAS and XMCD in transmission mode in high pulsed magnetic fields Valence fluctuations (XAS) Element-selective magnetometry (XMCD)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 871106

<table>
<tr><th>FEATURES</th><th>LNCMI TOULOUSE</th></tr>
<tr><td>SAMPLE HOLDER</td><td>

Drawing of the sample mounting in the sample holder for XAS and XMCD in pulsed magnetic fields

Sample (drawn in green) is sandwiched between two nanopolycrystalline diamond (NPD) windows (Ø 2 mm, 100 µm thickness, drawn in blue), themselves mounted into a cylindrical plastic holder (Ø 9 mm) and maintained by a small plastic cap (Ø 2 mm).

Sample is glued with wax on one of the NPD window.</td></tr>
<tr><td>PUBLICATIONS</td><td>1. High field XMCD in multiferroic compound - Phys. Rev. B 102, 094408 (2020)
2. Description of acquisition scheme - JSR 18, 224 (2011)
3. XAS and XMCD in pulsed magnetic field on ID24 - JSR, 14, 409 (2007)</td></tr>
</table>

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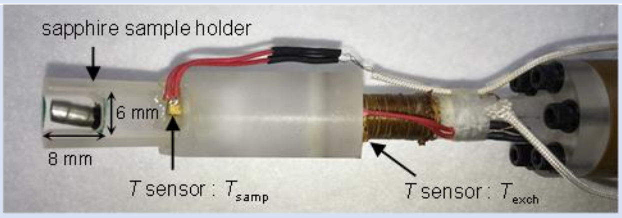
NEUTRON DIFFRACTION

FEATURES	LNCMI TOULOUSE
LOCAL CONTACT	**Dr. Fabienne DUC – LNCMI** : fabienne.duc@lncmi.cnrs.fr **Dr. Frédéric Bourdarot** - CEA and ILL: bourdarot@ill.fr **Before writing a proposal, it is mandatory to contact well in advance both local contacts to evaluate the feasibility of the experiment.**
PROPOSAL SUBMISSION PROCEDURE	**Proposal submission via ILL website:** https://www.ill.eu/fr/users-en/applying-for-beamtime/ **See:** https://www.ill.eu/fr/users-en/applying-for-beamtime/important-dates/ **for next proposal deadline and subcommittee meetings.** **Be careful: deadlines for applying for beamtime are different from EMFL deadlines and can change from one year to another.** In general, a call for proposals is launched twice a year (deadlines in February and September). Users with accepted proposal must get in touch with both local contacts as early as possible to prepare the experiment (to orientate the sample and mount it on the sample holder before the neutron beamtime).
FIELD RANGE	**Up to 40 T**
TEMPERATURE RANGE	2-300 K
SAMPLE SIZE	Single crystals Maximum available volume: 8 x 6 x 6 mm^3 The samples are mounted with a defined orientation Samples must be pre-orientated before neutron experiment
TYPICAL EXPERIMENT	Magnetic structure in high pulsed magnetic fields.
SAMPLE HOLDER	 Sapphire sample holder for neutron diffraction with typical sample inside. *Sample is glued with black stycast.*
SAMPLE ENVIRONMENT	Sample in vacuum on a sapphire sample holder. Sapphire cold finger. Cooling by conduction. Gaseous helium from 300 K down to 2 K

FEATURES	LNCMI TOULOUSE
PUBLICATIONS	• Spin-density wave in URu2Si2: - Nat. Commun. 7, 13075 (2016) • 40-T cryomagnet and device description : - Rev. Sci. Instrum. 89, 053905 (2018) • Magnetic structures in spin-1/2 dimer system: - Phys. Rev. B 104, 064430 (2021)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 871106

MEGAGAUSS FACILITY

FEATURES	LNCMI TOULOUSE
LOCAL CONTACT	**Dr. Oleksiy Drachenko** oleksiy.drachenko@lncmi.cnrs.fr **Dr. Oliver Portugall** oliver.portugall@lncmi.cnrs.fr
FIELD RANGE	**150 T, 6 µs in 10 mm** **40 T damped oscillation**
TEMPERATURE RANGE	5.0 - 300 K for optical measurement 2.0 - 300 K for magnetization
SAMPLE SIZE	1 mm (typically)
TYPICAL EXPERIMENT	Optical spectroscopy, visible to mid-infrared Faraday rotation Magnetization with inductive pickup coils
PUBLICATIONS	Field generation: https://doi.org/10.1088/0022-3727/32/18/306 Optical spectroscopy: https://doi.org/10.1038/nphys3357 https://doi.org/10.1103/physrevlett.111.096802 Magnetization: https:/doi.org/10.1103/PhysRevB.101.054432

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 871106

LEVITATION

FEATURES	LNCMI GRENOBLE
LOCAL CONTACT	**Dr. Eric Beaugnon** eric.beaugnon@lncmi.cnrs.fr
FIELD RANGE	**Up to 37 T, Grad B2 up to 4000 T/m2**
TEMPERATURE RANGE	Near room température
SAMPLE SIZE	from 0.1 mm to 1 cm
TYPICAL EXPERIMENT	Levitation of different diamagnetic materials including water, solutions, diamagnetic solids.
SAMPLE HOLDER	In situ instrumentation of oscillations/displacement of samples, far range video up to 200 and possibly 1000 images/s
SAMPLE ENVIRONMENT	Upon request
PUBLICATIONS	BEAUGNON, E., TOURNIER, R. Levitation of organic materials. *Nature* **349,** 470 (1991). https://doi.org/10.1038/349470a0

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BROWSE BY AVAILABLE EQUIPMENT

Additional information and contact: ilo-emfl@lncmi.cnrs.fr

EQUIPMENT	HFML NIJMEGEN	LNCMI GRENOBLE	HLD DRESDEN	LNCMI TOULOUSE
MAGNETS				
CONTINUOUS FIELD MAGNETS	102	102		
PULSED FIELD MAGNETS			103	103
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^{4}HE CRYOSTATS (1.5 – 300 K)	104	104	104	104
^{3}HE CRYOSTATS (DOWN TO 300 mK)	105	105	105	105
DILUTION ^{3}HE – ^{4}HE REFRIGERATOR (DOWN TO 30 – 100 mK)	106	106	106	106
POWER SUPPLY FOR PULSED MAGNETS				
CAPACITOR BANKS			107	108
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MAGNETS

CONTINUOUS MAGNETIC FIELD MAGNETS

LOCATION	MAX FIELD, T	BORE SIZE, mm	HOMOGENEITY, 1 cm DSV
LNCMI-GRENOBLE	6	284	450
LNCMI-GRENOBLE	10	376	250
LNCMI-GRENOBLE	13	130	30
LNCMI-GRENOBLE	20	170	600
LNCMI-GRENOBLE	25	50	1300
HFML-NIJMEGEN	30	50	640
LNCMI-GRENOBLE	31	50	850
HFML-NIJMEGEN	33	32	940
HFML-NIJMEGEN	33	32	1130
LNCMI-GRENOBLE	36	34	800
HFML-NIJMEGEN	37.5	32	964
HFML-NIJMEGEN	38	32	964

European Magnetic Field Laboratory
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 871106

MAGNETS

PULSED MAGNETIC FIELD MAGNETS

LOCATION	MAX FIELD, T	BORE SIZE, mm	PULSE DURATION, ms
HLD-DRESDEN	51	24	75
HLD-DRESDEN	60	40	1200
LNCMI-TOULOUSE	60	13	250
LNCMI-TOULOUSE	60	28	500
HLD-DRESDEN	65	20	25
HLD-DRESDEN	70	24	150
LNCMI-TOULOUSE	70	13	200
LNCMI-TOULOUSE	80	13	80
LNCMI-TOULOUSE	80	13	30 (Inner coil)/ 900 (outer coil)
LNCMI-TOULOUSE	90	8	30 (Inner coil)/ 900 (outer coil)
HLD-DRESDEN	85/95	16/12	10 (Inner coil)/ 120 (outer coil)
LNCMI-TOULOUSE	150 (semi-destructive monospire)*	10	0.006

* Higher fields can be generated in smaller bores

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CRYOSTATS

^{4}HE CRYOSTATS – 1.5K TO 300K. TOP LOADING

LOCATION	MAGNETS, T	Ø MAGNET BORE (mm)	Ø SAMPLE SPACE (mm)	FLANGE	DISTANCE FLANGE/FIELD CENTRE (mm)	DEPTH (mm)
LNCMI-TOULOUSE	60	28	20	KF25	820	870
	70	13	7	KF25	820	870
	80	13	7	KF25	955	1030
	90-100	8.5	4	KF25	955	1055
LNCMI-GRENOBLE	Bath cryostat (37 T)	34	24	DN 100 ISO-K		1531
	Bath cryostat (31 T)	50	38	DN 100 ISO-K		1523 and 1590
	Bath cryostat (31 T)	50	38	Tube compression fitting 39.8 mm		1653
	VTI (37 T)	34	15.8	DN 40 ISO-KF		1714
	VTI (31 T)	34	30	DN 40 ISO-KF		1495
HFML-NIJMEGEN	30	50	**	KF40	1565	*
	33	32	**	KF40	168.5	*
	38	32	**	KF40	196.5	*
HLD-DRESDEN	0.5 - 300 K Technical details upon request					

* depends on cryostat – in general some space (<10 mm) below field center
** depends on experiment: same for 33 and 38 T magnets: transport LCC 20, max. sample size 4 x 4 mm2
*** MCK model – Leiden cryogenics

CRYOSTATS

^{3}HE CRYOSTATS – DOWN TO 0.3 K. TOP LOADING

LOCATION	MAGNETS, T	BASE T ° (K)	Ø SAMPLE SPACE (mm)	FLANGE	DISTANCE FLANGE/FIELD CENTRE (mm)	DEPTH (mm)
LNCMI-TOULOUSE	60	0.3	10	KF25	1607	1629
	70	0.35	4	KF25	1063	1088
	80	0.35	4	KF25	1063	1088
	90-100	0.45	4	KF40	1245	1290

LOCATION	SAMPLE ENVIRONMENT AND MAGNETIC FIELD	Ø MAGNET BORE (mm)	Ø SAMPLE SPACE (mm)	FLANGE	DEPTH TOTAL / FLANGE - CONE (mm)
LNCMI-GRENOBLE	Sample in liquid (37 T)	34	16	DN 40 ISO-KF	1709 / 1034
	Sample in liquid (31 T)	50	30	DN 40 ISO-KF	1665 / 1018
	Sample in vacuum (37 T)	34	14		Upon request
	Sample in vacuum (31 T)	50	14		Upon request

LOCATION	MAGNETS, T	BASE T° (K)	Ø SAMPLE SPACE (mm)	FLANGE	DISTANCE FLANGE/FIELD CENTRE (mm)	DEPTH (mm)
HFML-NIJMEGEN	30	0.3	**	KF40	1565	*
	33	0.3	**	KF40	168.5	*
	38	0.3	**	KF40	196.5	*

LOCATION	
HLD-DRESDEN	0.5-300 K Technical details upon request

* depends on cryostat – in general some space (<10 mm) below field center
** depends on experiment: same for 33 and 38 T magnets: transport LCC 20, max. sample size 4 x 4 mm2
*** MCK model – Leiden cryogenics

CRYOSTATS

DILUTION ^{3}HE – ^{4}HE REFRIGERATOR

LOCATION	MAGNETS, T	BASE T° (K)	Ø SAMPLE SPACE (mm)	SAMPLE LOADING
LNCMI-TOULOUSE	60	0.07	7	bottom loading
	60	0.07	3	top loading
	16 (Superconducting)	0.008	37	top loading

LOCATION	MAGNETS, T	BASE T° (K)	Ø SAMPLE SPACE (mm)	SAMPLE LOADING
HLD-DRESDEN	60	0.05	10	bottom loading

LOCATION	MAGNETS, T	BASE T° (K)	Ø MAGNET BORE (mm)	Ø SAMPLE SPACE (mm)	SAMPLE LOADING
LCMI-GRENOBLE	37	0.02	34	16	top loading
	31	0.02	50	24	top loading

LOCATION	MAGNETS, T	BASE T° (K)	Ø SAMPLE SPACE (mm)	SAMPLE LOADING
HFML-NIJMEGEN	33	<0.05 K	**	***
	38	<0.05 K	**	***

* depends on cryostat – in general some space (<10 mm) below field center

** depends on experiment: same for 33 and 38 T magnets: transport LCC 20, max. sample size 4 x 4 mm2

*** MCK model – Leiden cryogenics

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POWER SUPPLY FOR PULSED MAGNETS

HLD – DRESDEN

CAPACITOR BANK	NUMBER OF MODULES	MOBILE
50 MJ	20	N
14 MJ	10	N
0.4 MJ	1	Y

50 MJ				
SPECIAL MODULS	NUMBER OF MODULES	CAPACITANCE [mF]	MIN. PULSE RISE TIME [mS]	MAX. CURRENT [kA]
2.88 MJ	15	10…150	7.5…8.5	350
1.44 MJ	4	5…15	2.5…3.0	100
0.9 MJ	1	3.125	0.85	100

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POWER SUPPLY FOR PULSED MAGNETS

HLD-DRESDEN

14 MJ				
SPECIAL MODULS	NUMBER OF MODULES	CAPACITANCE [mF]	MIN. PULSE RISE TIME [mS]	MAX. CURRENT [kA]
1.44 MJ	9	5…30	2.5…3.0	200
0.9 MJ	1	3.125	0.85	100
0.4 MJ				
SPECIAL MODULS	NUMBER OF MODULES	CAPACITANCE [mF]	MIN. PULSE RISE TIME [mS]	MAX. CURRENT [kA]
0.4 MJ	1	0.14	0.01	400

LNCMI-TOULOUSE

CAPACITOR BANK	NUMBER OF MODULE	CAPACITANCE /MODULES (mF)	MIN PULSE RISE TIME (mS)	MAX CURRENT (kA)	MOBILE
21 MJ	6	12.5	23	100	N
6 MJ	2	10	5	150	Y
1.6 MJ	1	5.6	4.7	40	N
1.15 MJ	2	2	4	33	Y

Pictures of one 3.5 MJ module of the 14 MJ generator

THERMOSTAT

LOCATION	MAGNETS, T	TEMPERATURE RANGE (K)	Ø MAGNET BORE (mm)
LCMI-GRENOBLE	31	300 – 1 000	50

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UNIAXIAL STRAIN

FEATURES	HFML NIJMEGEN	
LOCAL CONTACT	**Dr. Steffen WIEDMANN** steffen.wiedmann@ru.nl	
FIELD RANGE	**Up to 30 T**	
TEMPERATURE RANGE	0.3 K - 300 K (maximum field 30 T) - ^{4}He cryostat (heating element) - ^{3}He cryostat	
TYPE	**Electrical resistance under uniaxial strain (elasto-resistance)** tensile and compressive CS 100	**Thermal expansion and magnetostriction under uniaxial strain** Applied force: from 40 up to 75 N max. uniaxial stress: 3 kbar for cuboid sample of (0.5 mm)^2 cross section
SAMPLE SIZE	1600 µm * 200 µm * 50 µm	Height < 2 mm; diameter < 3 mm (L x W) = 2 mm x 2 mm (max.)
TYPICAL EXPERIMENT	Resistance for fixed strain as a function of magnetic field at different temperature Elastoresistance at constant T, B	Magnetostriction Thermal expansion
SAMPLE HOLDER	Sample is fixed epoxy, electrical contacts are attached	Sample clamped
SAMPLE ENVIRONMENT	Gaseous helium from 300 K down to 1.2 K, ^{3}He below	
DEVICE SPECIFICATIONS	Razorbill instruments : https://razorbillinstruments.com/ Kuechler innovative measuremnet technology - http://www.dilatometer.info/	
PUBLICATIONS	In preparation	

HIGH HYDROSTATIC PRESSURE

LNCMI TOULOUSE

LOCATION	GASKET	OVERALL DIMENSIONS (mm)	Ø SAMPLE SPACE (mm)	MAXIMUM PRESSURE (GPa)	TYPE OF MEASUREMENTS
LCMI-TOULOUSE	PET	Ø = 18 H = 78	Ø = 1.2 H = 0.4	1.4	Magnetotransport
	Pyrophyllite	Ø = 15 H = 45	Ø = 1 H = 0.1	4	Magnetotransport

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WORKSHOPS: CRYOGENICS

LNCMI TOULOUSE

- MACHINING: NUMERIC AND CONVENTIONAL MILLS AND LATHES
- SHEET METAL WORK MACHINERY
- TIG WELDING STATIONS, SILVER BRAZING STATION, BONDING
- SINTERING: CONTROLLED ATMOSPHERE FURNACE
- TESTS: LEAK DETECTOR, RGA, LAKESHORE TEMPERATURE CONTROLLERS, LABVIEW, ORIGIN…
- VACUUM PRODUCTION: FIXES AND MOBILES VACUUM STATIONS EQUIPPED WITH SCROLL, VANE, TURBO-MOLECULAR AND DIFFUSION PUMPS.
- HELIUM LIQUEFIER: PULSE TUBE CRYO-GENERATORS, HELIUM COMPRESSORS, GAS BAG + HIGH PRESSURE CYLINDERS RECOVERY




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WORKSHOPS: (MICRO-) MECHANICS

HFML NIJMEGEN

- 3 LATHES
- 2 MILLING MACHINES
- FLOOR STANDING PILLAR DRILL
- BRAZING

LNCMI GRENOBLE

- SCIENTIFIC INSTRUMENTATION DESIGN AND MACHINING

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WORKSHOPS: (MICRO-) MECHANICS

HLD DRESDEN

- FULLY EQUIPPED WORKSHOP

LNCMI TOULOUSE

- DIGITAL LATHES
- DRILL PRESS
- MILLING MACHINES FOR METALS AND GLASS EPOXY G10
- COLUMN DRILL
- MICROMECHANICS MACHINES

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WORKSHOPS: WIRE FABRICATION

LNCMI TOULOUSE

- 2 DRAW-BENCHES (300KN, L=6 m;100 KN, L=16,5 m)
- DRAWING BULL-BLOCK (40 KN, d=600 mm)
- WIRE-DRAWING MACHINE (10 KN, d=300 mm)
- CYLINDRICAL DRAWING DIES (from 40 mm to 0.2 mm)
- TURK-HEAD SHAPING DIE
- DYNAMIC (varying speed, L=3 m) OR STATIC FURNACES (L=1 m) UNDER NEUTRAL ATMOSPHERE (Tmax=1150 °C)
- TENSILE TEST MACHINE (100 KN, T=+20 °C and -196 °C)

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WORKSHOPS: MAGNET FABRICATION

HFML NIJMEGEN

- TENSILE TESTING MACHINE 30 kN
- HYDRAULIC ROLL FRAME PRESS 2000 kN
- HYDRAULIC PRESS 300 kN

LNCMI GRENOBLE

- HELICAL COIL CLASSICAL AND SPARK EROSION MACHINING
- EPOXY COIL IMPREGNATION

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WORKSHOPS: MAGNET FABRICATION

HLD DRESDEN

- FULLY EQUIPPED MAGNET FABRICATION WORKSHOP

LNCMI TOULOUSE

- COIL WINDING TOOLS (UP TO 1 m DIAMETER AND 2 m LONG COILS)– POSSIBILITY TO ADD HIGH STRENGTH POLYMER FIBERS FOR REINFORCEMENT AND/OR COOLING CHANNELS

CONCLUSIONS

This EMFL Industrial Skill Map was realized as part of European project ISABEL.

One of the great challenges of society *is* ***innovation through the development of new and advanced materials*****.** Such tailored materials are needed in all key-technological areas, from renewable energy concepts, through next generation data storage to biocompatible materials for medical applications and many of these future materials will be synthesized on a nano-scale. In order to reach these goals, state-of-the-art analytical tools are needed. High magnetic fields are one of the most powerful tools available to scientists for the study, modification and control of states of matter, and in order to compete on the global scale, Europe needs state-of-the-art high magnetic field facilities which provide the highest possible fields (both continuous and pulsed) for its many active and world-leading researchers.

The ISABEL project aims to strengthen the long-term sustainability of the EMFL through the realization of three objectives:

- enlargement **the EMFL structure and build a great community by improving several organisational aspects** (such as data management, outreach and access procedures).
- bridge the gap with industry **to strengthen the socio-economic impact of the EMFL.**
- strengthening of **the role of high magnetic field research in Europe.**

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 871106. Any dissemination of results reflects only the author's view and the European Commission is not responsible for any use that may be made of the information it contains.

More information about ISABEL project you can find on ISABEL website:

https://emfl.eu/isabel/h2020-project/

Our online communication channels:

www.linkedin.com/in/ilo-emfl

https://twitter.com/h2020isabel

https://emfl.eu/

2022 ISABEL EUROPEAN PROJECT

EMFL

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