NÉEL institut

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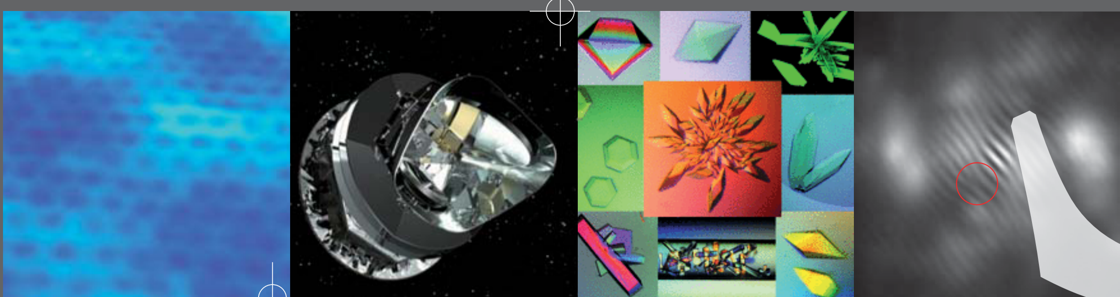
highlights 3



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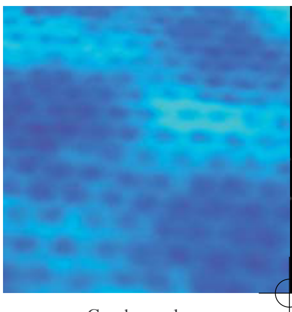
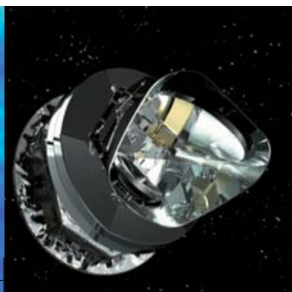
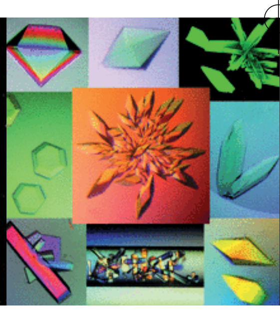
highlights 3



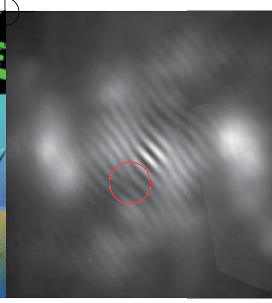
Graphene plane



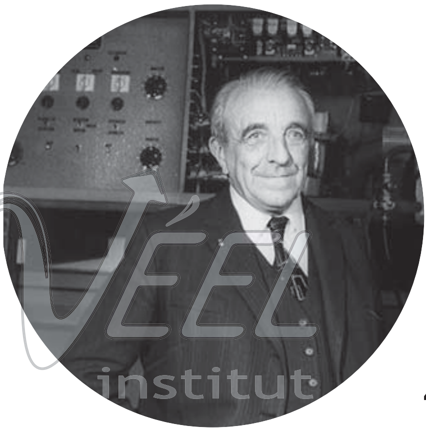
Planck telescope



Protein crystals



Polariton vortex



2010 will mark the **40th anniversary** of the **Nobel Prize** of **Louis Néel**

"I had a predecessor in the 13th Century, Pierre de Maricourt, who wrote the first serious treatise on magnets in 1269. In science, our precursors are often much further back in time than we think."

Louis Néel, Stockholm, 1970

"The first scientist who tried to explain magnetism was **Ampere** …
In 1907, **Pierre Weiss** …,
in 1911 **Niels Bohr** …
in 1928 **Heisenberg** …
[made significant contributions].
Néel in 1932
added [a new type of magnetism]
anti-ferromagnetism ...
[and later] in 1948
ferrimagnetism."

Torsten Gustafsson, Nobel Lectures 1970 introducing Louis Néel at Stockholm

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Editorial

The Néel Institute is now in its third year: it was created on 1st January 2007, when four laboratories established for forty years on the CNRS campus in Grenoble were refounded and joined by four other distinguished Grenoble teams in response to this intitiative.

These few words remind us that our Institute's wide range of expertise and its present, striking success have very deep roots. These roots were put down by individuals, first and not least Louis Néel, and also by talented groups of people working in synergy. We can never emphasize too much the importance of human resources in the achievements of fundamental research. Increasing group consciousness of the benefits of pooled expertise is crucial and a task for everyone. The organizational structure acts mainly as a catalyst, fostering increased effectiveness: the Laboratory is the crucible of synergies where we create the constructive interactions that can serve us so well at all levels- local, national and international.

Grenoble's Science Peninsula

The increasing visibility of the Néel Institute's accomplishments can be measured by our publications in high impact journals, by a broadened range of conference invitations, by the successful outcome of applications to funding agencies.

Three exceptional events have marked the last six months:

1. "*An exceptional harvest of Scientific Prizes 2007-2008*"
On 6 November 2008, the Institute held a special event to celebrate the nine scientific prizes and distinctions awarded to seven of our researchers during the Institute's first two years. Details of the prizes are given in pages 5-6 of this issue. Pride in these awards can be shared by the whole Institute.

Exhibition poster

2. "*Crystals and the science of crystallography- an exhibition*".
We all know the importance of disseminating the culture of science to young students and the general public, of showing them that science is both important and exciting. This is the purpose of the exhibition "Voyage dans le Cristal" (pages 11-12). The exhibition, installed within the splendid renaissance walls of the former Palace of the Dauphiné Parliament, was inaugurated by the Mayor of Grenoble on 25th April. Essential contributions were made by many people at Néel Institute, especially Jean-Louis Hodeau as the project's leader. I thank Armand Fayard, the Chief Curator of the Museum of Natural History of Grenoble, for his warm words (page 11) celebrating this initiative.

Parliament Palace, Grenoble

3. "*Launch of the Planck telescope: A European space instrument will measure the Cosmic Background Radiation*"
On 14th May 2009, an Ariane 5 rocket launched two scientific spacecraft of the European Space Agency: the Herschel Space Telescope and the Planck Scientific Observatory (page 3). The Planck Observatory will measure with unprecedented precision the anisotropy of the 2.7 K cosmic background radiation emitted only 300 000 years after the Big Bang. This will provide vital information concerning the creation and the structure of the Universe. At the heart of the Planck telescope is the High Frequency Instrument (HFI), a set of microwave detectors cooled to near absolute zero to minimise their thermal noise. Interviewed recently by the newspaper "Liberation", Jean-Loup Puget, astrophysicist and leader of the international consortium that built the HFI, pointed out that if Europe has now taken the lead in this kind of science it is largely due to the talent of Alain Benoît's team in Grenoble. Fifteen years of efforts by Benoît and colleagues at the former CRTBT (Centre for Research on Very Low Temperatures), now part of the Néel Institute, enabled construction of an innovative dilution refrigerator adapted to operation in space. Far above our heads, the refrigerator will maintain the Planck instrument's detectors at 0.1K, through the two year life of the Planck mission.

Herschel/Planck liftoff

Photo Arianespace

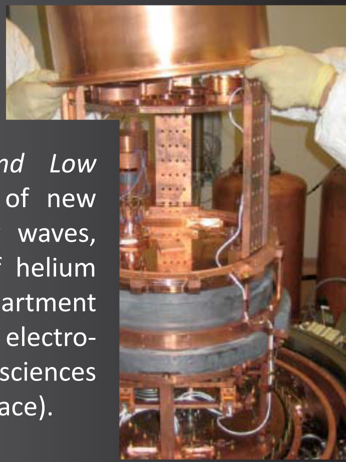
June 2009
Alain Fontaine
Director of the Néel Institute, CNRS-UJF

DÉPARTEMENT

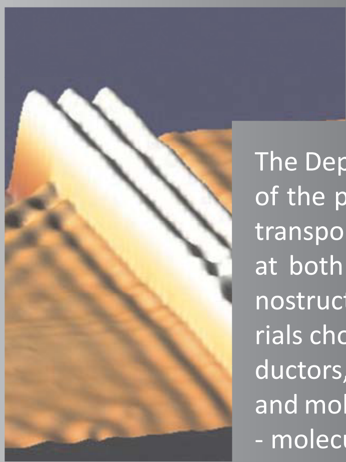
MCBT

MATIÈRE CONDENSÉE ET BASSES TEMPÉRATURES

The Department of *Condensed Matter and Low Temperatures* conducts fundamental studies of new states of matter (magnetism, charge density waves, superconductivity, etc.) and of the physics of helium between 100 μK and room temperature. The department develops transverse activities in cryogenic electro-technology, fluid mechanics, astronomy, the life sciences and associated applications (cryogenics, aero-space).



Edelweiss Cryostat



Surface electronic waves

DÉPARTEMENT

NANO

NANOSCIENCES

The Department of *Nanosciences* is engaged in the study of the physical properties of nanostructures : electronic transport, magnetism, nanomechanics, spectroscopy... at both experimental and theoretical levels. These nanostructures are prepared from various types of materials chosen for their specific properties - novel semiconductors, superconductors, metals, magnetic materials and molecules... Their fabrication at the nanometre scale - molecular films, nanowires, nanotubes, quantum wells and dots - leads to novel functions resulting from the most fundamental aspects of quantum physics.

DÉPARTEMENT

MCMF

MATIÈRE CONDENSÉE MATÉRIAUX & FONCTIONS

The Department of *Condensed Matter, Materials & Functions* fosters fundamental research of materials and their applications. It has wide range experimental and theoretical expertises in material preparation, crystallography, electronic structure, magnetism, lasers, non-linear optics, catalysis and energy. The Department is distinguished by a strong interplay between physics and chemistry. It manages national projects at the ESRF and ILL and coordinates two thematic networks of the CNRS.

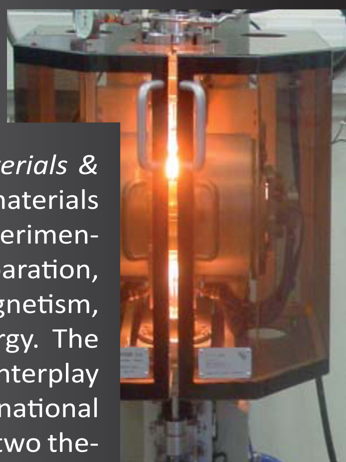


Image furnace for crystal growth

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Grenoble cryogenics honoured : Ariane 5 launches Herschel & Planck spacecraft

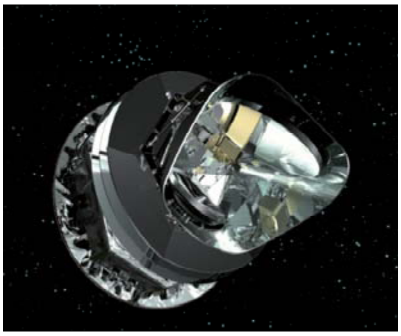
Ariane 5 launcher

On 14th May 2009 an Ariane 5 rocket launched the European Space Agency's Planck and Herschel scientific spacecraft into orbit. Cryogenic components and systems developed by Grenoble region research and technology teams are essential elements in these two missions. The two spacecraft are now moving independently to their final orbits at the Second Lagrange Point (L2). Situated 1.5 million km from the Earth in the direction away from the Sun, the L2 Point is an ideal position for observations of the Universe.

The two-year Planck mission will measure and map the Cosmic Background Radiation with unprecedented sensitivity and angular resolution. The Planck instrument is equipped with a 1.5 m mirror and arrays of microwave detectors for a wide range of mm and sub-mm wavelengths. Filling all space and with a spectrum equivalent to a black body at temperature 2.7 K, the Cosmic Background is the remnant of the radiation that filled the Universe immediately after the Big Bang. The goal of the Planck mission is to reconstruct the evolution of the universe since the origin. It will seek answers to fundamental questions of observational cosmology: What triggered the Big Bang? Exactly when did the Big Bang occur ? How will the expanding Universe evolve in the future ?

Herschel telescope

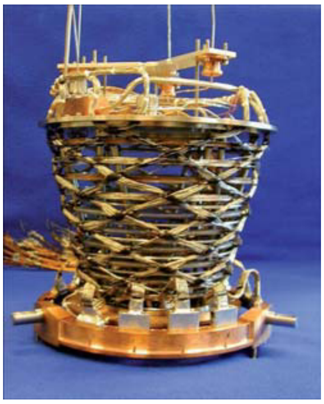
The Herschel Space Observatory's main mission will be to study the formation and evolution of galaxies and stars and of the interstellar medium and its dusts, from the earliest times. This instrument mounts the largest telescope ever launched into space, with a 3.5 metre mirror. It will be equipped for making infrared observations capable of piercing through dust clouds.



Planck telescope

The unique expertise in cryogenics technology concentrated in the Grenoble region has made a very large contribution to the realization of these two space instruments. To eliminate thermal noise, their microwave and infrared detectors must be cooled to very low temperatures. The CNES (French Space Agency) assigned the CNRS to develop the principal instrument of the Planck spacecraft, dedicated to measurements of the 2.7 K Cosmic Background. The instrument exploits a unique refrigeration technique for cooling its microwave detectors to a temperature of 0.1 K under conditions of zero-gravity, a technique that was invented at the Néel Institute. Following construction of a demonstration device at the Néel Institute, the technique was industrialized by Air Liquide Advanced Technologies at Sassenage near Grenoble. The Air Liquide teams met major technological challenges to develop a dilution-refrigerator with unprecedented performance for embarkment on the Planck mission.

Dilution refrigerator



As concerns the Herschel mission, the Low Temperature Service of the Institute of Nanophysics and Cryogenics (INAC) at the CEA's Grenoble site developed and constructed the two 0.3 K coolers. Air Liquide designed and constructed a leak-tight 2400 litre capacity reservoir to stock the superfluid helium that cools the Herschel telescope, as well as the associated thermal shields and other cryogenics equipment on the spacecraft.

Further reading

- Air Liquide - DTA, 2 rue de Clémencière - BP15 - 38360 Sassenage - http://www.dta.airliquide.com
- INAC - CEA, 17 rue des Martyrs - 38054 Grenoble Cedex 9 - France - http://inac.cea.fr
- Institut Néel - CNRS, 25 rue des Martyrs - 38042 Grenoble Cedex 9 - France - http://neel.cnrs.fr

Towards a new generation of high T_C superconductor wires

Ideal electrical materials, superconductors offer considerable possibilities for energy applications. The high critical temperature superconductors, requiring only liquid nitrogen cooling, are being studied worldwide in view of such applications. The main effort at present is on epitaxially deposited YBaCuO materials. Our consortium, involving the NEXANS Company, a world leader in electrical cables, is very well placed in this highly competitive field. Following up on our previous work on 2nd generation flat tape conductors, we have invented a new concept of a round superconductor wire (patent applications in 2008). The round geometry answers real wishes of the designers of superconducting systems ("a YBCO round wire technology would be the Holy Grail", J. Schwartz of the National High Field Magnet Laboratory, plenary address at MT20, Philadelphia, September 2008).

The last eight years have seen the emergence of two successive generations of strong and flexible High Temperature Superconductor (HTS) wires for electrical current transport. The first generation, BiSrCaCuO produced by the "Powder In Tube" (PIT) technology, is now being used in large scale demonstration projects: our consortium partner NEXANS has installed a 600 m long, 138 kV, 3-phase cable in a suburban New York network feeding 300 000 homes (Fig.1).

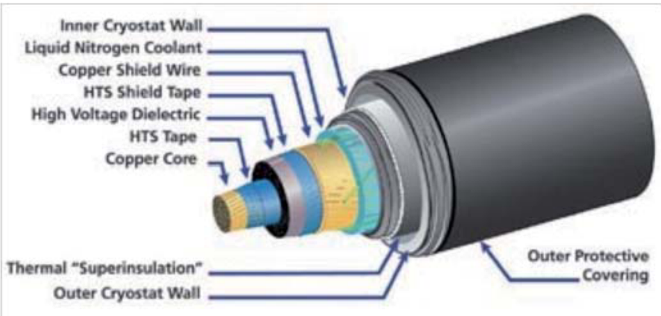


Fig.1 Liquid nitrogen cooled, 1st Generation, High Temperature Superconductor power cable made by Nexans.

The second generation of HTS cables uses the "Coated Conductors" technology, in which the superconductor is a bi-axially textured YBCO. The conductor is made up of a succession of bi-axially textured oxide buffer layers on a polycrystalline, textured metal frame (Fig. 2). These layers are then covered by the YBaCuO superconductor layer, which is covered by a silver layer, and finally a copper layer that facilitates assembly and improves thermal transfer. The term "texture" designates a non-random, preferential orientation of the grains of the polycrystalline material.

There are two main possible architectures for obtaining a "bi-axial texture" of the crystal grain alignments in the superconducting ceramic layer, necessary for passing a high current from grain to grain. One approach uses a physical method: Pulsed Laser Deposition. The other approach involves metallurgical preparation of the substrate and chemical deposition of the buffers and YBCO films. In the latter method, one starts with a textured metallic substrate (the "Rolling Assisted Biaxially Textured Substrates" or RABiTS architecture) and one deposits oxides on this substrate by various chemical methods. Grown epitaxially with good lattice parameter matching to the metal, these oxides transfer the metal's initial texture. The actual superconducting layer is deposited by chemical methods (Metal-Organic Deposition MOD or Metal-Organic Chemical Vapour Deposition MOCVD) on the last oxide layer. Finally, the upper layers (Ag, Cu) are deposited by MOCVD, by evaporation, or electrochemically.

In Grenoble, we are developing the metallurgical and chemical techniques, using a round, textured, metallic support of 2mm diameter, whose texture is schematized at right in Fig. 2. After depositing several layers of $La_2Zr_2O_7$, the metal tube was sufficiently well protected to receive a bi-axially textured, superconducting YBCO layer. We produced the world's first round HTS wires in September 2008.

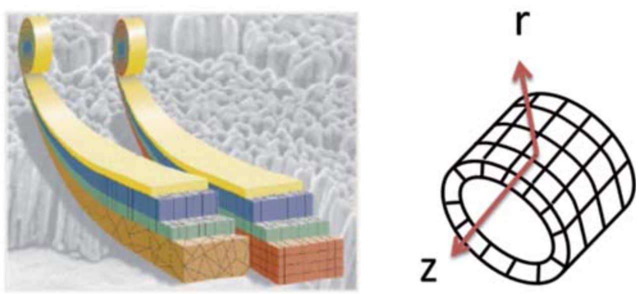


Fig.2. At left, 2nd Generation HTS tapes with a planar bi-axial texture of deposited buffer (green) and YBCO (blue) films. At right, new concept of cylindrical geometry bi-axial texture under development by Néel Institute and Nexans. Our process yields grains with near-parallel crystallographic orientations where one axis is close to direction z and a second axis close to radial direction r.

This project is supported by the New and Renewable Energies Competiveness Cluster of the Rhone-Alpes Region (TENNERDIS), by a French government "FUI" Applied Research grant, and by the European Union's "FEDER" fund.

Contacts

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• Philippe Odier, Email : philippe.odier@grenoble.cnrs.fr , Telephone : +33 476889034.

Further reading

• "$La_2Zr_2O_7$ single buffer layer for YBCO RABiTS coated conductors, T. Caroff, S. Morlens, A. Abrutis, M. Decroux, P. Chaudouët, L. Porcar, Z.Saltyte, C. Jimenez, P. Odier, F. Weiss, Supercond. Sci. Technol. 21, 075007 (2008).
• "Successful commissioning of the world's first transmission voltage superconductor cable in Long Island", Nexans company press release, Paris, June 25, 2008, see http://www.nexans.com .

Bose-Einstein Condensation of magnons in superfluid ^{3}He

When Bose-Einstein Condensation (BEC) occurs for a system of particles, all the particles condense into a unique macroscopic ground state governed by a single wave function. This phenomenon has been observed in a number of systems, including cold atomic gases, where a macroscopic number of particles are in the Bose condensate. We have succeeded in observing a Bose-Einstein condensation of quasiparticles, the nuclear-spin waves or magnons in superfluid ^{3}He. High densities of magnons are created by pulsed Nuclear Magnetic Resonance (NMR). These non-equilibrium magnons live a very long time, much longer then needed for them to be condensed into a coherent state. The condensate is possible because the number of magnons is nearly conserved, leading to very long lived magnetic collective states. Indeed, nearly twenty years ago, a BEC of magnons was observed, but not interpreted as such at the time: This was the "Homogenously Precessing Domains" (HPDs) in the B phase of superfluid ^{3}He. And, recently, the Ultra Low Temperatures group at the Néel Institute has discovered other magnon condensate phenomena: magnon "Q balls" and coherent precession of magnons in 3He-B confined in compressed aerogels.

The experimental results concerning Homogeneously Precessing Domains in bulk superfluid ^{3}He-B (Fig. 1) have now been theoretically understood as a Bose-Einstein condensation of about 99.9% of the magnons. Furthermore, because of the rich nature of the order parameter in superfluid ^{3}He, other BEC states can exist and have been observed. Among them are magnons trapped in the potential well of the orbital texture, which condense in a similar way to cold atoms in an optical trap. Since the number of magnons (similar to the total charge Q for charged systems) is nearly conserved, an inhomogenous Bose condensate can exist. In its simplest form this looks like a ball (hence the name Q-ball following S. Coleman). The observation and interpretation of such a state in ^{3}He-B presents a significant advance in our understanding of Bose-Einstein Condensation and macroscopic quantum phenomena.

Most recently, the observation of an imperfect condensation of magnons in superfluid ^{3}He confined in an aerogel matrix has been achieved. In this state, only a fraction of the magnons are in their ground state, as for the condensation of ^{4}He atoms in superfluid ^{4}He.

The Néel Institute Ultra Low Temperatures group consists at present of Yu. M. Bunkov, E. Collin and H. Godfrin. The theoretical work was done in collaboration with G. Volovik from Helsinki University of Technology.

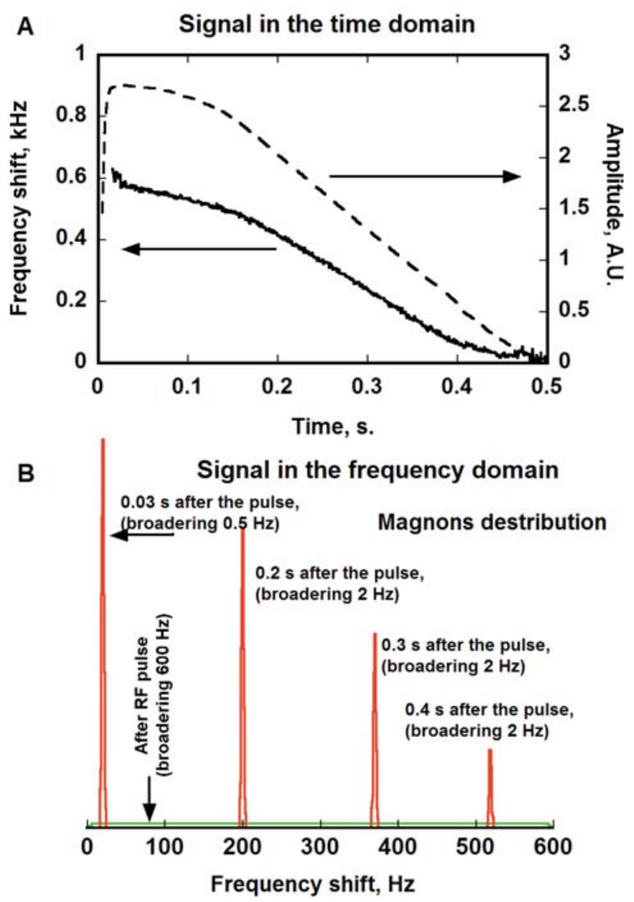

Fig. 1: Pulsed NMR experiment on superfluid ^{3}He in a magnetic field gradient corresponding to a 600 Hz broadening of the ^{3}He nuclear resonance frequency. (A) A short radiofrequency pulse at time t=0 tilts the magnetization approximately 110 degrees. After the pulse, the nuclear spins precess in their local field, dephasing with respect to each other in about 2 ms. The spin supercurrents then redistribute the magnetization. A Bose condensate of coherent magnons forms at 30 ms and manifests itself by a coherent precession of practically all the tilted magnetization (or number of magnons). The number of magnons and the dimensions of the condensed state slowly decay over a time of about a second. (B): The broadening measured in the BEC state is less than 0.5 Hz. This residual broadening is due to the dipole-dipole interaction. The number of magnons decreases slowly with time, and the resonance frequency and broadening change. The ratio of the 600Hz broadening before magnon condensation to the 0.5 Hz broadening in the condensed state shows that 99.9% of the magnons are condensed.

Contact

• Yuriy Bunkov, Email : yuriy.bunkov@grenoble.cnrs.fr , Telephone : +33 476881252.

Further reading

• "Bose-Einstein condensation of magnons in superfluid ^{3}He", Yu. M. Bunkov, and G. Volovik, Journal of Low Temperature Physics, 150, 135 (2008)
• "Magnon condensation into a Q ball in ^{3}He-B", Yu. M. Bunkov and G.E. Volovik, Phys. Rev. Lett. 98, 265302 (2007).
• "Strong orientational effect of stretched aerogel on the ^{3}He order parameter", J. Elbs, Yu. M. Bunkov, E. Collin, H. Godfrin, and G.E. Volovik, Phys. Rev. Lett. 100, 215304 (2008)

Origin of hysteresis effect in long Josephson junctions

In long Josephson junctions, the distance between the superconducting electrodes is such that the electrical capacitance is very low. One then expects a reversible behaviour of the Current-Voltage characteristic. However, systematically at sufficiently large superconducting current, significant hysteresis is observed in such junctions : the Josephson junction switches to the resistive state and the superconducting state reappears only when the current has been lowered to a significantly lower value.

In the framework of a collaboration with the Helsinki Low Temperature Laboratory, we have built and studied superconductor – normal metal – superconductor junctions with superconducting tunneling probes attached (see Fig. 1). These probes give the temperature of the electrons in the normal metal at the centre of the junction. We recorded the electron temperature as a function of the bias voltage applied to the junction, in both the reversible regime and the regime of non-zero hysteresis.

At the point where the device switches to the resistive state, the electrons in the normal metal reach a temperature of order 0.4 K, even though the substrate remains thermalized at 50 milliKelvin (Fig. 2). This electronic heating reduces the superconducting current strongly and does not disappear until a bias state well below the critical current, hence giving rise to the hysteresis effect.

Our results prove, for the first time, the thermal nature of the hysteresis in long Josephson junctions. The same mechanism is no doubt responsible for the hysteresis effects in Josephson junctions based on nanowires, on two dimensional electron gases, on carbon nanotubes or on planes of graphene.

This work was done with M. Meschke, J. T. Peltonen et J. P. Pekola of the Low Temperature Laboratory, Helsinki University of Technology (Finland).

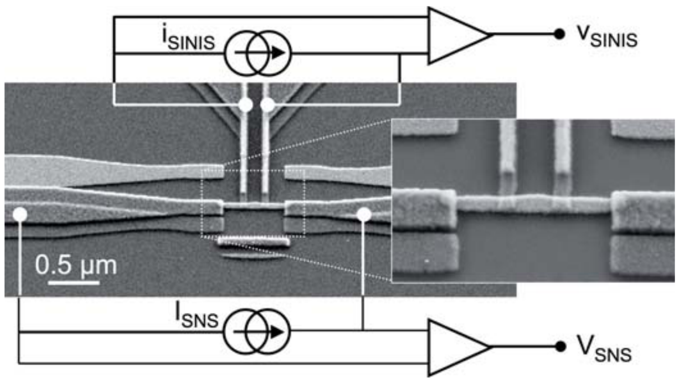

Fig. 1: SNS (Superconductor – Normal metal – superconductor) Josephson junction of length 1.5 microns with schematic of the measuring circuits. Two tunnel probes connected to the normal metal measure its electron temperature via voltage V_{SINIS}.

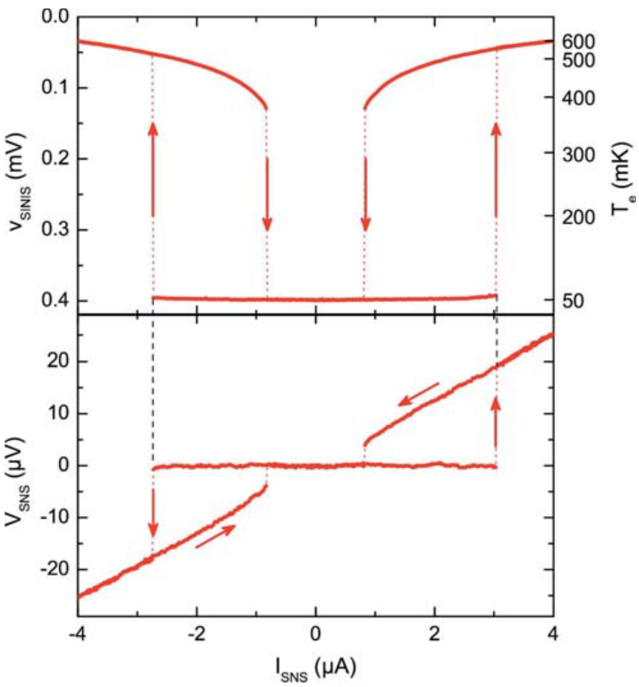

Fig. 2. At top : Temperature (right hand scale) of electrons in the normal metal and temperature of the substrate. At bottom, on the same current scale : Current-voltage characteristic of the Josephson junction showing hysteresis effect. The electronic temperature varies markedly as a function of the voltage V_{SNS} on the terminals of the Josephson junction, while the substrate remains thermalized at cryostat temperature 50 mK.

Contact

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Further reading

• "Origin of Hysteresis in a Proximity Josephson Junction", H. Courtois, J.T. Peltonen, M. Meschke, et J.P. Pekola, Phys. Rev. Lett. 101, 067002 (2008).

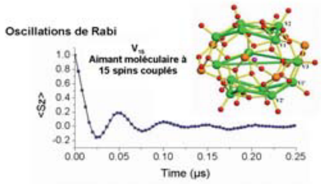
It is a great pleasure to highlight the exceptional harvest of prizes gathered during these first two years (2007-2008) of the Néel Institute's existence. The Institute is proud to honour seven members of our staff who have received scientific awards in this period. These awards were of course attributed for personal scientific achievements. Additionally, on behalf of our seven prize-winners, I would like to widen the spotlight for a moment to include all our research and technical staff and students : by their expertise, originality and commitment to excellence and cooperation, they have all contributed to the success of our laboratory. The awards also affirm the exceptional character of our local environment – an international scientific campus linking universities, laboratories and large instrument facilities – as an ideal site for fostering research of the highest quality. Further evidence of the dynamism of the Néel Institute is provided by the 280 articles published by our staff in international journals in 2008, 30% of these articles in co-authorship with teams in other countries.

Alain FONTAINE
Director of the laboratory

Bernard BARBARA

A. Joannidès Prize 2007
Gentner-Kastler GP 2008
B. Pascal Medal 2008

ernard Barbara's research has ranged over many branches of magnetism. In his recent work, he has shown how reversals of the magnetic moment for Single Molecule Magnets, and also for isolated Rare Earth ions, are governed by quantum tunnelling dynamics. He is using magnetic resonance of these systems to explore their potential as a new type of q-bits, the basic building blocks of quantum information and computation.



Bernard Barbara has been honoured by three awards in the last two years : the Grand Prix A. Joannidès (2007) of the French Academy of Sciences, for "research useful for the public and worthy of support"; the Blaise Pascal medal for Physics (2008), attributed by the European Academy of Sciences in recognition of an "outstanding personal contribution to science and technology"; and the joint German and French Physical Societies' Gentner-Kastler prize (2008), for "outstanding contributions to physics".

Yuriy BUNKOV

Fritz London Prize 2008

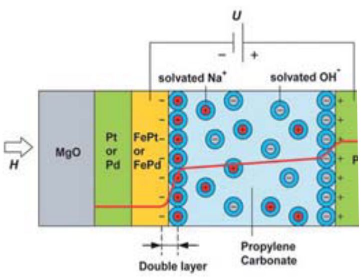
Yuriy Bunkov, formerly with Moscow's famous Kapitza Institute, joined the CNRS Grenoble labs in 1995. He brought to Grenoble his profound theoretical knowledge of quantum fluids and his expertise in ultra-low temperatures. Most recently, he has been investigating the quantum orientation of the ^{3}He order parameter by anisotropic impurities. He is also working on the low temperature aspects of the construction of the Dark Matter (WIMPs) detector installed under the French Alps.

For one of his discoveries, namely Spin Superfluidity and Coherent Precession of Magnetization, Yuriy Bunkov has been awarded the prestigious Fritz London prize. First awarded in 1957 and attributed every three years, this is the highest distinction in the field of low temperature physics (nine London Prize winners have gone on to win the Nobel Prize in Physics). Yuriy Bunkov shares the 2008 prize with Vladimir Dmitriev and Igor Fomin, both from the Kapitza Institute.

Dominique GIVORD

Louis Néel GP 2007

Dominique Givord is an expert in magnetism and magnetic materials. He has made important contributions in many fields of metallic systems such as the Invar effect, the de Gennes law, paramagnetic ordering, coercivity. In recent work with US and Spanish colleagues, he demonstrated blocking of the superparamagnetism of nanoparticles in an antiferromagnetic matrix. Most recently, he showed how magnetism of ultra-thin metallic films can be controlled by applying an electric field. He has multiple patents and collaborations with industry: his expertise in coercivity properties is currently helping development of magnets for hybrid electric cars.

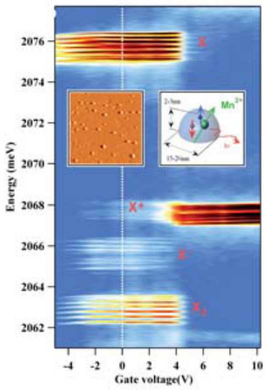


Dominique Givord was awarded the first Louis Néel Grand Prize (2007), created by a consortium of nine French scientific societies to reward achievement in applied physics.

Lucien BESOMBES

J. Herbrand Prize 2008

Lucien Besombes, Néel Institute researcher and member of Grenoble's joint CNRS/UJF/CEA team for nanophysics and semiconductor research, has developed sensitive spectroscopic methods to exploit the extremely rich field of semiconductor quantum dots. He achieved the first detection of the spin of a single Mn atom diluted in a single quantum dot. This and his subsequent experiments open a path to spintronics applications involving manipulations of a spin-based quantum system.



Lucien Besombes received the 2008 Grand Prix J. Herbrand of the French Academy of Sciences, awarded every two years to a young physicist aged under 35 whose work is judged "useful to the progress of the physical sciences or their peaceful applications".

Bertrand MENAERT

CNRS Crystal 2007

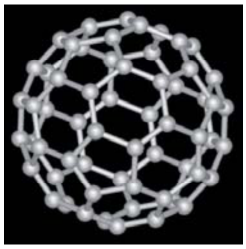
ertrand Ménaert joined the CNRS as a research engineer in 1993 and came to Grenoble in 2000. He specializes in crystal growth by the flux method from high temperature solutions. He grows single crystals for non-linear optics, especially compounds of the "KTP"($KTiOPO_4$) family. He has also developed patented techniques for cutting and polishing highly accurate, crystallographically oriented spheres and cylinders for optical measurements and laser devices. His current work concerns the growth of periodically-poled KTP crystals for quasi-phase-matched nonlinear optical frequency conversion.

Bertrand Ménaert has received a "Crystal" award (2007), a distinction attributed by the CNRS every year to highlight the expertise and creativity of the engineers and technicians who contribute to scientific discovery.

Xavier BLASE

CNRS Silver Medal 2008

Xavier Blase, a CNRS researcher since 1996, has used simulation methods to explore varied fields in condensed matter physics and the nanosciences, ranging from the growth mechanisms of nanotubes, through the superconductivity of diamond and doped silicon, to electronic transport in molecular systems. Previously with the Laboratory for Condensed Matter Physics and Nanostructures in Lyon, he moved to the Néel Institute in March 2008. His research, which concerns both the development and the application of simulation methods, exemplifies the increasing role of ab-initio quantum simulations for understanding physical phenomena in all areas of condensed matter science.



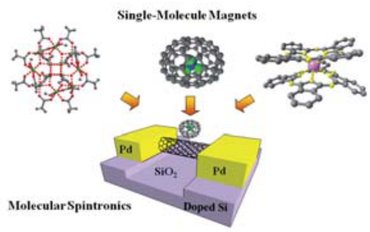
Xavier Blase has received a silver medal of the CNRS (2008) for his major contributions to the development of ab initio quantum simulation methods.

Wolfgang WERNSDORFER

ERC Call 2008

Wolfgang Wernsdorfer, a CNRS researcher since 1996, is a leader in the field of magnetism at the nanometre scale, and in the nanosciences generally. He developed the ultrasensitive micro-squid magnetometer that enabled the first measurement of the magnetization reversal of a single 1000 atom cobalt nanoparticle. He is presently doing pioneering work in molecular spintronics. Most recently his team detected a quantum phase transition at low temperature in a single C_{60} molecule.

Wolfgang Wernsdorfer has been awarded a grant in the European Research Council's "Ideas" programme, a recent initiative to fund the most creative, top level researchers. His research programme will target the single magnetic molecule as a component in the new field of molecular spintronics.



The topological Cooper-pair pump and its applications to metrology

Most physical systems depend on external parameters which, at special values, give additional symmetries to the system. At these points, quantum degeneracies may occur. When the parameters are easily tunable, one can explore quantum states not only at the degeneracy points but over the entire parameter space. Even when it is away from a symmetry point, the system is sensitive to the point's presence. The reason is simple: at a degenerate point absolute quantum phases cannot de defined. From a topological point of view, a degeneracy is a defect in the wavefunction phase. This topology has important consequences such as the quantization of physical quantities (e.g. the quantum Hall effect). For quantum circuits, the quantized quantity is the charge transferred when performing an adiabatic cycle by varying gate voltage and magnetic flux values. This quantization is geometric and does not depend on the precise shape of the cycles used. In this fashion, a quantized current can be generated. Such a current can be used in metrology as an electrical current standard, critical to the redefinition of the International System of Units.

The circuit studied here, a "Cooper-pair pump", represented in Fig. 1, has three Josephson junctions in series which separate two superconducting islands. The three tunable parameters are the two gate-induced charges n_{g1} and n_{g2} on the islands and the phase difference φ across the three junctions. The lowest quantum states are degenerate at isolated points T_{pq} (n_{g1}= 2/3+p, n_{g2}= 2/3+q, $\varphi=\pi[2\pi]$, where p and q are integers) in this three-dimensional parameter space. An integer topological charge can be associated with the phase defects at these points.

The most interesting consequence of this non-trivial topology is the quantization of the charge transferred during the adiabatic evolution of the circuit's ground state over any families of cycles which completely enclose the degenerate points. This is achieved using periodic cycles which cover densely a surface which encloses one or more degeneracies. The most convenient cycles are helices covering the surface of a cylinder of height 2π (the cylinder axis is the phase difference across the pump). Over one cycle, the charge transferred is an integer (the number of turns) multiple of 2e. When the

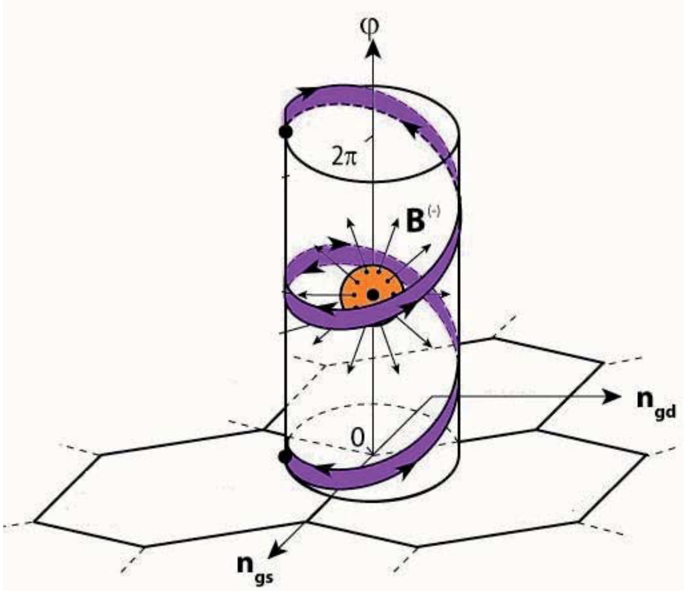


Fig. 2: A degenerate point in the three dimensional parameter space is represented at the center (φ=π) of the cylinder. The ellipses making p turns (p=2 in the figure) around the cylinder transfer p Cooper pairs through the pump.

cycles are repeated at a frequency ν, the current I_p generated is exactly $I_p=2ep\nu$. Thus, the current can be used as a metrological current source and ultimately as an absolute standard for the International System of Units.

There are several challenges to be met on the way to this goal. Since the current is generated by the adiabatic evolution of the circuit's ground state, the operating frequencies must be limited in order to remain adiabatic. This limits the pumped current to a few tens of pico-amperes. The "topological" nature of the current generated protects the circuit against low frequency noise sources. The effect of other noise sources is the subject of ongoing studies.

This research is part of a European Future and Emerging Technologies programme devoted to studies of the adiabatic evolution of electronic circuits.

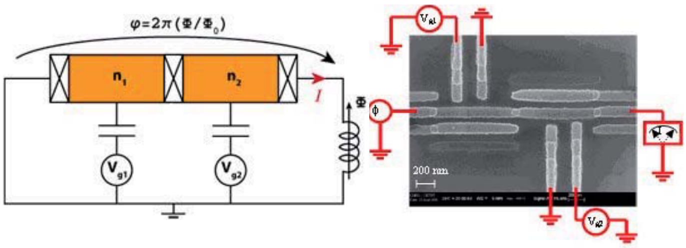


Fig. 1: A Cooper-pair pump has three Josephson junctions in series defining two islands whose electrostatic energies are tuned by two gate voltages. The phase difference across the pump is tuned by a an applied magnetic flux : the parameter space is here three-dimensional.

Contact

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• Web site: http://www.neel.cnrs.fr/spip.php?rubrique50

Quantized vortices in polariton Bose-Einstein Condensates

Quantized vortices are observed in a Bose-Einstein condensate of excitonic polaritons in a semiconductor. They are visualized by phase-resolved imaging of a polariton gas condensed at 20 K in a CdTe-based microcavity. Here, in contrast to the case of the Bose-Einstein condensates in liquid 4He and dilute atomic gases, the vortices are generated in the condensate ground state, and are pinned at well defined positions.

Superfluidity, first reported in liquid ^{4}He, has received much attention in Bose-Einstein Condensates (BECs) produced in dilute gases of atoms. Quantized vortices, i.e. a quantized rotation of fluid around a singular point, are a fascinating manifestation of superfluidity. They have been generated by stirring three-dimensional atomic BECs or thermally activated in quasi two-dimensional atomic systems.

Recently, Bose Einstein Condensation has been produced in the solid state for polaritons in planar microcavities that incorporate quantum wells of the semiconductor material CdTe. Polaritons are composite bosons of mixed photon-exciton nature, resulting from strong light-matter coupling. Due to the ultra-light polariton mass (10^{-5} m_e), polariton gases created by optical pumping can condense at critical temperatures as high as 50 K. We have now probed the long range spatial coherence of polariton condensates by overlapping two images of the condensate's luminescence.

For a vortex free BEC, i.e. one where the phase is spatially homogeneous, a nonzero angle between the two image beams generates a system of perfectly parallel fringes. In the presence of vortices, forklike dislocations appear in the interferogram, as seen in the red circle in Fig.1. Since a single fringe is missing in the dislocation, the "topological charge" of the vortex, i.e. the integer number of 2π phase shifts around the vortex core, is unity. This is confirmed by doing a Fourier transform of the interferogram to map out the spatial phase of the condensate (inset of Fig.2). As shown in Fig. 2, the phase increases by exactly 2π along a closed loop around the vortex core, independent of the distance from the core. We could also verify that the polariton density is indeed lower at the vortex core.

In this system, the vortices are generated in the condensate *ground* state. Their positions and signs do not change from one experiment to another, ruling out spontaneous formation by thermal fluctuations (as occurs in the Berezinskii-Koster-Thouless phase of a 2D BEC). Our vortices result from the combined effect of the very short polariton lifetime (10^{-12} s, which has to be compensated by continuous optical pumping), and the photonic disorder due to microcavity irregularities. How these disorder-induced vortices relate to superfluidity in a non-equilibrium BEC is yet to be understood.

This work was done in collaboration with Benoît Deveaud's team at Ecole Polytechnique Fédérale de Lausanne (Switzerland).

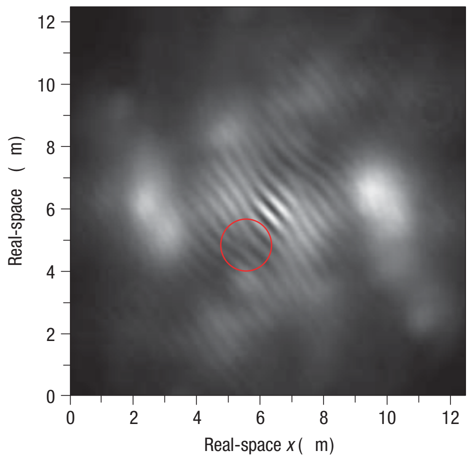

Fig.1. Interference pattern observed by overlapping condensate's image and its retro-reflected image. A vortex appears as a fork-like dislocation in the regular fringe pattern (inside red circle).

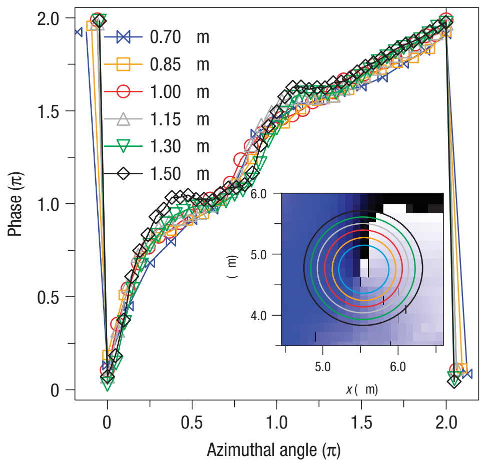

Fig.2. Phase of the polariton condensate along closed loops (cf. the circles in the inset) around the vortex shown in Fig.1, at various distances from the core. Inset displays the 2D spatial phase around the vortex as a colour-intensity map.

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Further reading

- "Bose–Einstein condensation of exciton polaritons", J. Kasprzak et al., Nature 443, 409 (2006)
- "Quantized vortices in an exciton–polariton condensate" , K. G. Lagoudakis et al., Nature Physics 4, 706 (2008).

Quantum forgetfulness of a Single Molecule Magnet

A step critical to the implementation of a quantum computer based on complex magnetic molecules (Single Molecule Magnets) is control of the decoherence mechanisms. Decoherence is the process by which a quantum system "forgets" its quantum nature and become classical when it interacts, even very weakly, with the random fluctuations of its environment. Simply speaking, a collective quantum system possesses an "internal clock" acting like a pendulum whose amplitude decreases progressively because of these environmental interactions. When the clock's motion stops, the system is effectively at rest and collapses to the classical regime.

This loss of coherence is a serious obstacle in the development of a quantum computer: any quantum calculation requires that the internal clocks of each single element of the computer (the quantum bits or "qubits") oscillate for a sufficiently long time for a quantum calculation to be carried out. This has turned out to be a particularly difficult problem with complex "Single Molecule Magnets" of large dimensions (each molecule contains several hundred atoms). In a Single Molecule Magnet, the electronic spins are coupled to the large number of nuclear spins present in their own environment, killing the quantum oscillations very rapidly.

Researchers from Néel Institute and the Institute for Nanoscience and Cryogenics of CEA-Grenoble have now been able to monitor the Rabi oscillations driven by microwaves for the famous low-spin molecular magnet V_{15}, see Fig. 1. This is a vanadium-based system containing 15 vanadium ions with their spins strongly coupled through oxygen atoms. The 15 spins ½ of vanadium are all coupled antiferromagnetically resulting in a mesoscopic spin ½ in the ground state. The use of big molecules such as V_{15} should facilitate individual addressing, especially since molecular chemistry methods can produce self-organization of such molecules in well ordered monomolecular layers, easy to address.

From pulsed Electron Paramagnetic Resonance ("spin-echo") measurements of coherence times, the different possible mechanisms of decoherence have been evaluated. In this system, the main source of decoherence comes from the vanadium nuclear spins. If it were not for the nuclear spins, this Single Molecule Magnet would stay "quantumly alive" for 100 µs, long enough to implement simple molecular quantum gates. Such long coherence times could be obtained in molecular magnets if nuclear-spin-free molecules are used.

This first demonstration of the Rabi oscillations of a Single Molecule Magnet has already generated several follow-ups using the same technique. Besides its potential applications in quantum computing, this result shows how robust quantum mechanics can be : A molecule with 2^{15} quantum eigenstates involving complex interactions (super-exchange, dipolar and Dzyaloshinsky-Moriya interactions), can "stay alive" for a fraction of a microsecond.

This work was done in collaboration with T. Mitra and A. Müller of the Faculty of Chemistry of Bielefeld University (Germany) and B. Tsukernblat of the Chemistry Department, Ben-Gurion University, Beer-Sheva (Israel).

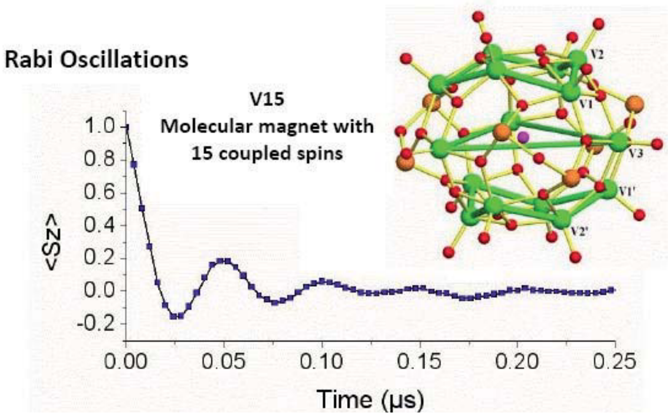

Fig. 1 : Schematic representation of the Single Molecule Magnet V_{15} (green=Vanadium, orange=Arsenic, red=Oxygen (there are many other atoms that are not represented). The curve shows the observed Rabi oscillation of the magnetization, excited by a pulse of 9.7 GHz microwaves in an EPR cavity in a 0.35 Tesla field at 2.5 K. The damping of the oscillation is caused mainly by interaction with the vanadium nuclear spins.

Contacts

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Further reading

• "Quantum Oscillations in a Molecular Magnet" , S. Bertaina, S. Gambarelli, T. Mitra, B. Tsukerblat, A. Müller, and B. Barbara, Nature 450, 203 (2008)

• See also the "News and Views" article highlighting this paper, by P.C.E. Stamp (same issue, p.167).

Wavefunction symmetry in graphene at the nanometre scale

Graphene is an unconventional two dimensional system with fascinating electronic properties. These properties - for example the half integer Quantum Hall Effect - come from the honeycomb crystal structure, which imposes special symmetry relations on the electronic wavefunctions, corresponding to the so-called "electronic chirality". A priori, this chirality is specific to the ideal graphene plane, but was found to be preserved for graphene on a SiO_2 substrate, as shown by magnetotransport measurements. We have found that the property of electronic chirality is also preserved in a single plane of graphene grown epitaxially on a silicon carbide (0001) substrate.

We have studied a SiC (0001) sample that was graphitized at the Néel Institute. It shows alternating terraces of monolayer and bilayer graphene. The two types of layer are weakly doped with electrons and have almost identical Fermi surfaces consisting of small circular pockets of radius $q_F \approx 0.6\ nm^{-1}$, centred on the corners of the Brillouin zone. To probe the electronic chirality we measured the local density of states of the surface using a low temperature (4.2 K) Scanning Tunneling Microscope at Max Planck Institute, Stuttgart. Native surface disorder elastically scatters the electrons of the graphene layer, creating quantum interferences. We obtained 4.2 K STM images at low bias voltage (i.e. at the Fermi level) on monolayer and bilayer terraces of graphene (Figs 1a and 1b).

Comparing these images, we observe that certain quantum interferences are not detected for the monolayer case. Specifically, these are the "$2q_F$" interferences (i.e. of wavelength $\pi/q_F \approx 5.2$ nm), associated with intravalley backscattering processes (coupling between electron states with wavevectors q_F and $-q_F$).

The absence of such processes in the monolayer is seen more markedly in the Fourier Transforms (Figs 1c and 1d). A circle of radius $2q_F \approx 1.2\ nm^{-1}$ is present at the centre of the FT for the bilayer (d) but absent for the monolayer (c). The absence of this circle for the monolayer is a direct consequence of the electronic chirality. This result was predicted theoretically but never demonstrated experimentally until now. It shows clearly that the characteristic symmetry of a graphene monolayer inhibits formation of quantum interferences at $2q_F$.

This work was done in collaboration with Klaus Kern's group at MPI Stuttgart and with Christina Bena of the Laboratoire de Physique des Solides, Orsay.

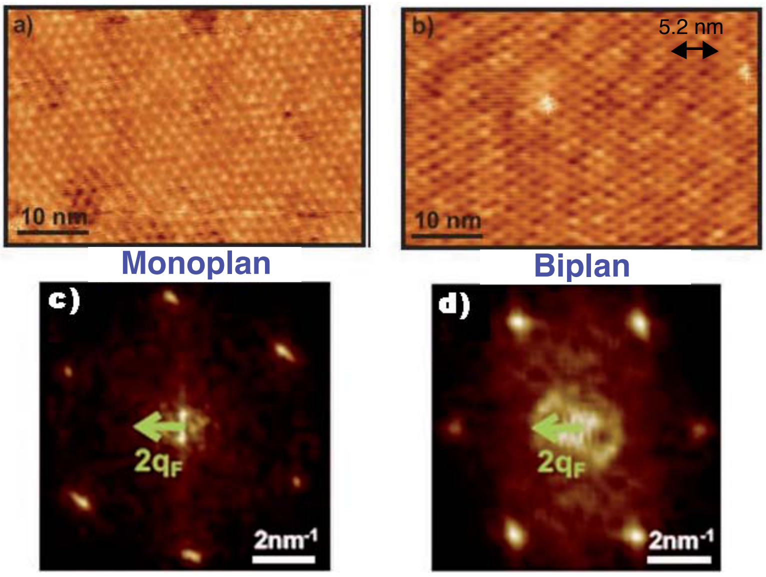

Fig. 1: STM images at very low bias voltage (a few mV) of (a) a monolayer and (b) a bilayer of graphene on SiC(0001). Such images are maps of the local electronic density of states at the Fermi level. Quantum interferences of wavelength π/q_F (5.2 nm), generated by disorder, are observed on the graphene bilayer but never on the graphene monolayer. Figs (c) and (d) show the central regions of the 2D Fourier transforms of STM images (a) and (b) respectively. A ring of radius $2q_F \approx 1.2\ nm^{-1}$ associated with the λ= 5.2 nm quantum interferences is present for the bilayer (d) but absent for the monolayer (c). These results show the absence of certain elastic scattering processes for low energy electrons, due to the symmetry of the electronic wavefunctions.

Contacts

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• Jean-Yves Veuillen, Email: jean-yves.veuillen@grenoble.cnrs.fr , Telephone: +33 476887461.

Further reading

• "Quasiparticle chirality in epitaxial graphene probed at the nanometer scale", I. Brihuega, P. Mallet, C. Bena, S. Bose, C. Michaelis, L. Vitali, F. Varchon, L. Magaud, K. Kern and J.Y. Veuillen, Phys. Rev. Lett. 101, 206802 (2008) .

“VOYAGE DANS LE CRISTAL”

“Voyage dans le cristal” is a major exhibition, now on display in Grenoble before touring other French cities. The exhibition presents to a general public the science and the beauty of matter in the crystalline state. The initiative came from physicists of the Institut Néel, Grenoble and the IMPMC , Paris, two laboratories with a long tradition of research in crystallography and solid state physics. The exhibition was mounted with the contribution of numerous partner laboratories under the management of the Grenoble Museum of Natural History and the French Association of Crystallography. “Voyage dans le cristal” recounts humanity’s interaction with crystals, through art and science, from prehistoric times to the present day. It invites the public on a voyage to discover crystals in their many aspects:

- *their wonder and mystery*
- *their place in the history of science*
- *their use in multiple contemporary applications.*

The following prospectus illustrates the scope and variety of the exhibition.

Crystals provoke wonder, become symbols, inspire study

JOUVENCE pendant, with ghost quartz generated by growth faults. Jean Vendome ®

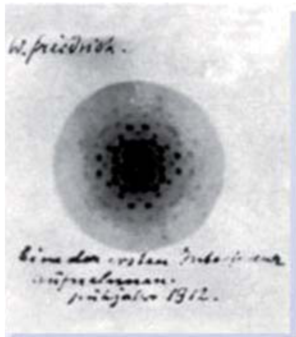
Already in prehistoric times, in the search for wealth under the earth’s surface, Man had discovered multiple faceted stones. Such stones provoked wonder and admiration; from Antiquity onwards, they became subjects of philosophical and scientific enquiry. Their colours and multiple geometries inspired mysticism and fascination: crystals became symbolic objects, often associated with virtues or supernatural powers. Their transparency, their rarity and their apparent inalterability led early to their use as ornaments. Man learnt to cut them skillfully, to enhance their sparkle and light.

Crystallography: the birth and triumph of a science

In the 16th and 17th centuries, natural philosophers held two opposing points of view about crystals: did they grow facetted from inert matter, or were they sculpted solids? In the 18th century, with no techniques yet available for probing deep into a crystal, scientists began to deduce their internal structure from observations of their external geometry.

Thus, the discovery of the invariance of the angles between the facets for a given type of crystal led scientists to define a crystal as a regular stacking of elementary building blocks. The work of Romé de l’Isle, of abbé Haüy and many others gave birth to a new science : “crystallography”. Together with astronomy, mechanics and optics, crystallography is one of the oldest of the physical sciences.

In the mid 19th century, still without any proper tool for seeing a crystal’s structure, the concepts of periodicity and molecular order gave the explanation of their shape and symmetry. The 1895 discovery of the mysterious “X-Rays” inspired the work of Laue and the Braggs, father and son, who used crystals in order to understand these new rays. In return, their “diffraction” experiments showed how crystals were indeed made of regular arrays of atoms, finally making it possible to “journey” into the heart of a crystal.



Historic X-Ray diffraction photograoh obtained in 1912 by Friedrich, Knipping and Laue

ENCOUNTERS ENCOUNTERS ENCOUNTERS

“If there is one word that I would retain after thirty years with the Natural History Museum of Grenoble it is this: “Encounters”. My encounters with scientists, many of them working behind the scenes, with an openness and lack of pretention that reconciles us with human nature, who recount for us marvellous stories from the regions where Life and the Sciences meet. “Voyage dans le Cristal” was born from such an encounter. It had then to be written, and given shape and form as an exhibition. Over thirty French scientists participated in that task.»

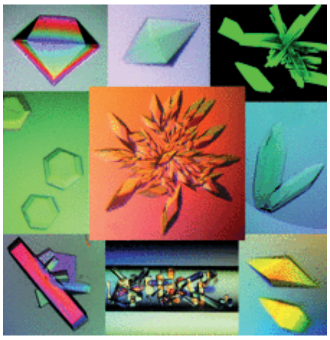
Armand Fayard,
Chief Curator of the Museum of Natural History of Grenoble

A JOURNEY INTO THE CRYSTAL

Exhibition from 25 avril to 27 septembre 2009
at the former Palace of the Dauphiné Parliament,
Place St André, Grenoble

Crystals for research and applications : scientists "grow" crystals

From the beginning of the 20th century, the birth of crystal chemistry enabled chemists to "grow" crystals, to "visualize" their structure, and thus to invent new materials. The same methods have spread through the sciences of pharmacy and biology, where fundamental research leads to synthesis of new pharmaceuticals.



Researchers crystallise proteins to study their properties. ©IUCr

Crystals are at the heart of metallurgy. Metals and alloys are made up of a multitude of crystals, and crystal defects determine the mechanical properties of metal objects and play a key role in forging, laminating, milling.

Crystals for microelectronics need to be nearly perfect, and either very pure or with minute concentrations of impurities purposely added for tuning their properties. Crystals also become solid state lasers or light sources in displays, or "LEDs" for traffic signals or Christmas decorations...

View of an exhibition room with crystal model (Magnetite) made with corks and iron wire by Louis Néel.

By its composition, its structure, its density, a natural crystal is a messenger from the heart of the earth. This messenger role of crystals is useful also in archaeology and in studies of heritage objects.

Many applications are based on the two classic crystals, quartz, which marks time in our watches, and diamond, symbol of wealth but just one member of the carbon family. That family gives us graphite, the fullerenes (a "nano football"), carbon nanotubes and graphene- a single plane of hexagons of carbon atoms where all the electrons propagate at the same velocity.

Crystals are an everyday object, found everywhere

The discoveries of the 20th century have dispelled the mysteries concerning the atomic structure and the physical properties of crystals, giving them "a new place at the heart of modern civilization". Crystals are now research tools used in investigations that cover an immense range, from the composition of our planet Earth to the microscopic structures of materials and the molecules of Life.

ENCOUNTERS *ENCOUNTERS* *ENCOUNTERS*

"Finally, this exhibition was built by the combined efforts of more than a hundred people in a number of laboratories in France. At the Néel Institute, the following persons (listed by alphabetical order) contributed: Murga Michelle Alvarez, Michel Anne, Caroline Bartoli, Anne-Marie Bonnot, Christophe Bouchard, Pierre Brand, Oana Bunau, Valérie Chaumont, Jérôme Debray, Catherine Dejoie, Eric Dooryhee, Sabine Douillet, Stéphanie Fort, Houmed Garad, Stéphanie Garaudée, Isabelle Gautier-Luneau, Jean-Louis Hodeau, Simon Joly, Yves Joly, Holger Klein, Olivier Leynaud, Céline Lourdel, Bernard Maire-Amiot, Florian Martin, Sylvain Martin, Pauline Martinetto, Bertrand Menaert, Pierre Molho, Philippe Plaindoux, Alain Prat, Aline Ramos, Patricia Segonds, Marcio Soares, Yan Suffren, Denis Testemale, Emmanuel Verloop, Julien Zaccaro. We thank them all here."

Alain Fontaine,
Director of the Néel Institute, CNRS-UJF

Absorption and fluorescence in monoclinic laser crystals

Efficient use of new laser crystals requires a full characterization of their absorption and fluorescence properties. For hexagonal, tetragonal, trigonal and orthorhombic crystals, these properties are described by the imaginary part of the complex second rank linear permittivity tensor which is diagonal for three principal axes. These axes are the same for the real and imaginary parts of the linear permittivity tensor and form an orthonormal frame called the dielectric frame. For such crystals, measurements of absorption and fluorescence for light propagating along the dielectric frame axes provide their complete characterization. We have demonstrated, however, that this approach is not appropriate for monoclinic crystals.

We have designed an experimental method that allows us to measure the complete distributions of absorption and fluorescence over all angular space. It uses a sphere cut and polished in a single crystal of the material to be studied. The sphere is oriented by X-rays and then placed on a Kappa circle, see Fig. 1. Due to the spherical geometry, a focused laser beam can be propagated in any crystal direction by rotating the sample on itself. The absorption of the laser beam and the fluorescence it generates are observed for each of these directions.

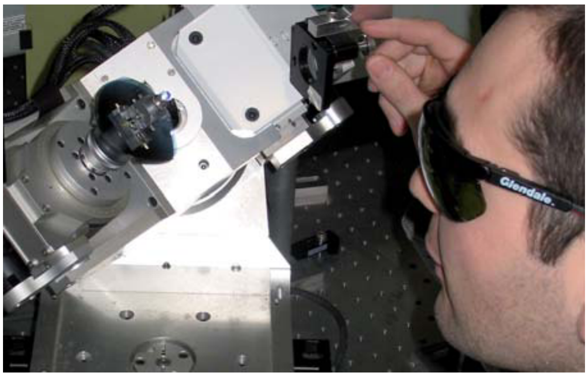


Fig. 1 : Spherically cut crystal mounted on a Kappa circle for study of angular distributions of absorption and fluorescence.

We studied a 7.44 mm diameter sphere of Nd:YCOB, an Yttrium Calcium Oxoborate doped with fluorescent ions Nd^{3+}. It belongs to the monoclinic crystal class *m*. As an example, Fig. 2 shows a scan of the Nd^{3+} absorption coefficient at 0.812 µm, given in polar coordinates as a function of the direction of propagation in the mirror plane *m*. It was recorded separately for the perpendicular and parallel components of polarization of a laser beam (the "ordinary" and "extraordinary" absorption coefficients respectively). The angular distribution of the ordinary absorption coefficient is isotropic while the extraordinary one exhibits a bi-lobal pattern whose symmetry axes X'_{abs} and Z'_{abs} do not coincide with the X and Z axes of the dielectric frame. Fig. 2 also shows that the ordinary and extraordinary absorption coefficients are equal for two crystal orientations we call the "absorption axes" (axes AA in Fig. 2). The angular variation of the ordinary and extrordinary polarized Nd^{3+} fluorescence at 1.061 µm shows two similar patterns, but with axes X'_{fluo} and Z'_{fluo} at a different orientation in plane *m*.

Interpretation of such experiments required a general analysis with a complex linear permittivity tensor whose real part, defining the refractive index surface, is diagonal in the dielectric frame. However, the imaginary part describing Nd^{3+} absorption and fluorescence is diagonal in two new axis frames called absorption frame and fluorescence frame. They are different from each other and from the dielectric frame.

While extending basic knowledge in the field of crystal optics, this work is of prime importance for achieving optimum use of low symmetry crystals (monclinic and triclinic) as materials for laser devices.

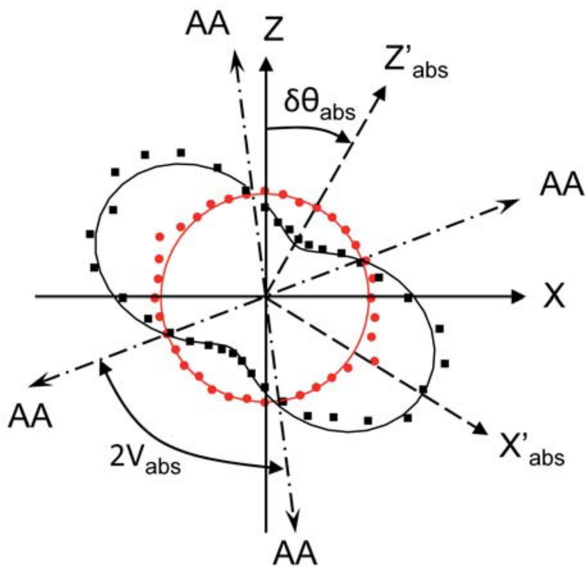


Fig. 2 : Angular distributions of the absorption coefficient measured in the mirror plane of the monoclinic crystal Nd:YCOB. Red circles are intensity of the perpendicular (ordinary) polarization, black squares are for the in-plane (extraordinary) polarization. The pattern for in-plane polarization is found to be rotated with respect to axes X and Z of the dielectric frame.

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Further reading

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Interstitial LaFeSi materials for magnetic refrigeration

Magnetic refrigeration, based on the magnetocaloric effect, has great promise for domestic and industrial use and is attractive for reasons of both economics and ecology. Compared to conventional refrigeration techniques, it should have higher power efficiency (60% compared to at best 40%), thus reducing energy consumption. Furthermore, it would reduce the use of greenhouse-effect gases such as Hydrofluorocarbons (1 kg HFC is equivalent to several tons of CO_2). This technology requires optimization of magnetic materials having high magnetocaloric performance, for use in the high fields available with new, powerful permanent magnets such as Neodymium-Iron-Boron alloys, as well as development of fast magnetization/demagnetization techniques, efficient thermal exchanges, and high corrosion resistance.

"Giant" magnetocaloric effects result from the property of ferromagnetic instability in certain compounds having very high magnetization densities. When such a material is moved into a high magnetic field at temperatures near the Curie temperature, the magnetic moments tend to align. This ordering corresponds to a reduction of the magnetic entropy S_m. Under adiabatic conditions, i.e. no heat exchange with the environment, the total entropy of the material is constant. The entropy of lattice vibrations (phonons) and of conduction electrons increases to compensate the fall of S_m, raising the temperature of the material. Inversely, the material is cooled if it is moved rapidly out of the magnetic field.

To apply these properties to refrigeration, a Carnot type cycle is set up : Heat is transferred to a heat sink during the magnetization phase, and heat is withdrawn from the volume to be refrigerated during the demagnetization phase. Various harmless fluids can serve as the heat exchange medium.

In the framework of a Grenoble consortium involving the Néel Institute and the CRETA (Consortium de Recherche pour l'Emergence de Technologies Avancées), we are studying various families of high performance materials, with the aim of using them in the refrigeration systems being developed at the G2ELab, Grenoble Institute of Technology. We have demonstrated that the family of compounds of the formula type $LaFe_{13-x}Si_x$ have exceptional magnetocaloric performances whose ranges of operating temperature can be controlled by inserting a light interstitial element such as H, C or N into the metallic lattice. This insertion dilates the lattice, reinforcing the Fe-Fe exchange forces and moving the Curie temperature to the desired range.

Fig. 1 shows the performance as concerns entropy variations for various materials of this family that can now be produced in a well controlled manner by physico-chemical treatments developed at the Néel Institute. Numerous other materials are studied in our laboratory but these LaFeSi materials seem to have the best properties in view of magnetic refrigeration applications.

This research is done in cooperation with researchers at AGH University of Sciences and Techonology, Krakow (Poland) and Perm State University (Russia). Our industrial partners are Arcelor-Mittal as concerns the industrial development of the materials, McPHy Energy for powder treatments, and Cooltech Applications for the engineering of magnetocaloric systems (refrigeration, air conditioning, wine cellars), with support from the ADEME and other national and regional energy research agencies and from PSA Peugeot Citroën. The first commercially designed systems should appear in 2009.

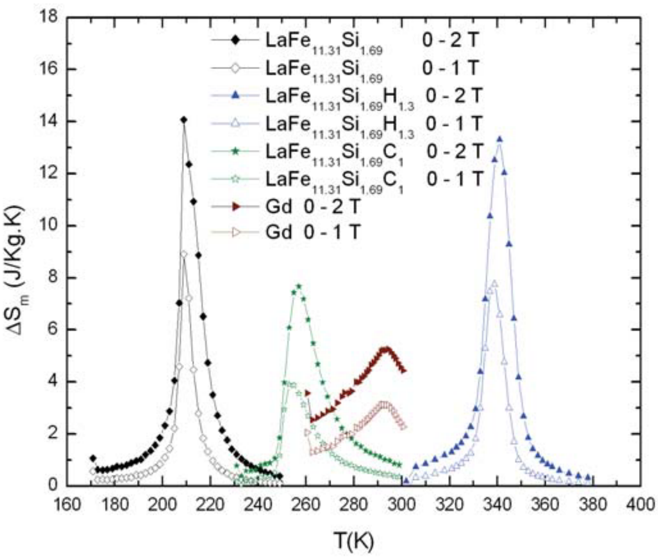

Fig. 1: Variation of magnetic entropy for compounds of the formula $LaFe_{13-x}Si_x$, pure and with insertions of interstitial elements H and C (Nitrogen, not shown, gives a ΔS peak at 230 K). Curves for the classic magnetocaloric material Gadolinium are given for reference. Curves were obtained by applying the Clausius-Clapeyron equation to data from isothermal magnetization measurements in 1T or 2T fields. They show the exceptional amplitude of the entropy variation of LaFeSi materials. The desired range of refrigeration temperatures (e.g. near 300 K) could be achieved by composite materials with continuously overlapping curves.

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Further reading

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Structure of heterogeneous materials by diffraction tomography

The advent of the nanosciences calls for the development of local structural probes to characterize real, ill-ordered or heterogeneous materials. Furthermore, properties of materials are often related to their heterogeneity or to the presence of a minor constituent and/or to a hierarchical arrangement of their structure or of their order. This is the case for materials as diverse as alloys, cements, nano-components, bones, pigments or mineral products.

The analysis of such materials requires going beyond the usual powder X Ray diffraction (XRD) techniques to develop new structural probes appropriate for both local and global quantitative analyses. Although it is one of the best quantitative global probes available, XRD suffers from a relatively low detection threshold (a few percent). On the other hand, electron diffraction/microscopy is very effective locally but not good for global analysis, and the sample preparation is destructive.

Using apparatus installed at the European Synchrotron Radiation Facility (ESRF), Grenoble, we have shown the potential of Computed Tomography applied to X-ray diffraction, for analysis of compounds or unknown phases in nanomaterials and powders. We demonstrated its usefulness first on the product of a high pressure experiment where a fullerene (C_{60}) was transformed into amorphous or crystalline diamond. As a second example, we studied a polycrystalline quartz-chalcedony sample containing iron pigments and we reconstructed three-dimensional maps of the different phases present in this heterogenous material, see Fig. 1.

Our X-Ray Diffraction Computed Tomography (XRD-CT) method provides a tool for (i) reconstructing selective images of each phase in the structure using direct spectral analysis (ii) extracting diffracted and scattering diagrams of each phase using an inverse analysis. The sensitivity of this non-destructive structural analysis method is better than 0.1%. The spatial resolution can range down to 1 micron.

Furthermore, the Diffraction-Tomography experiment can be coupled with absorption or fluorescence tomography to give a "multimodal" non-destructive analysis with applications in fields as diverse as materials science, chemistry, geology, environmental and medical sciences, palaeontology and art-related materials.

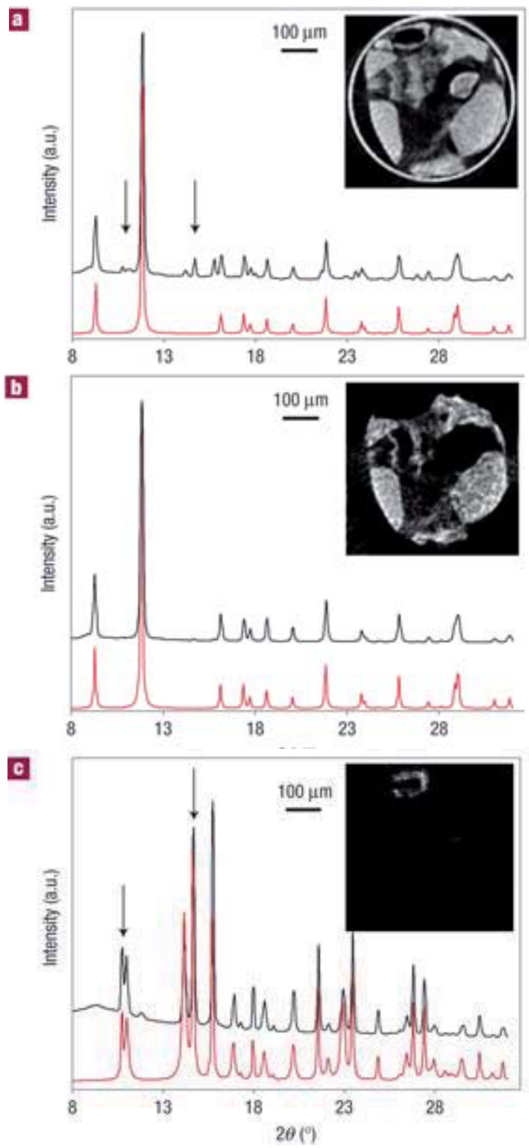

Fig. 1: Phase selectivity of the X Ray Diffraction–Computed Tomography technique illustrated for a heterogenous material : a quartz-chalcedony based iron pigment. Insets are images reconstructed by direct analysis of the data and black curves are experimental diffraction spectra from inverse analysis. Red curves are calculated spectra for different phases, from Rietveld powder diffraction modelling. Fig. 1(a) shows total image and compares total experimental XRD spectrum (black) to a calculated spectrum (red) of pure chalcedony. Fig. 1(b): image and spectra for the predominant quartz-chalcedony phase. Fig 1(c): image and spectra for minority haematite phase (Fe_2O_3).

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