SCIENTIFIC NewsLetter

INTERDISCIPLINARY RESEARCH INSTITUTE OF GRENOBLE

October 2019 N°06

Press release

A new scanning tunneling microscope technique allows the study of topological electronic properties of materials

The ultra-relativistic nature of electrons in graphene relates to a topological property of their wave-functions. An international team of physicist, propose a new scanning tunneling microscope approach to measure this topological property in the electronic density near an hydrogen atom grafted on the surface. This method which is published in *Nature* magazine on September 30th could be applied to other materials in the search of new topological electronic sates.

Time zone is a useful way to represent time at the surface of the globe. However, it rises the following question: what time is it at the North pole where all the time zones meet? Within this representation, the North pole is a singular point where time is not well defined. A way to reveal this singularity is to send a traveler circumnavigating the globe to the East like Jules Vernes' Phileas Fogg in his book 'Around the World in Eighty Days'. The traveler crosses the 24 time zones during his journey.Switching his watch one hour forward each time he crosses a time zone, he will observe a time shift of exactly one day as his returns to the starting point compared to an observer who remained there. This difference which is the key to the final twist in Vernes' book is remarkable in that it does not depend on the details of the travel such as the latitude. It depends only on the number of turns around the north pole. Such a property is said to be topological.

In quantum physics, topological properties characterize new electronic states. For instance, low energy electrons in graphene behave as particle moving close to the speed of light. This ultra-relativistic behaviour is characterized by a topological singularity, some sort of North pole in an abstract space. Since electrons also have clocks (the phase of their wavefunction), the topological singularity has been revealed by forcing the electrons to loop around it with magnetic fields and by comparing their clocks. Under these conditions, the phase difference acquired after the navigation led to the observation of the anomalous Quantum Hall Effect, which confirmed the existence of ultra-relativistic particles in graphene.

Now, writing in *Nature* an international team of researchers presents a new approach to access the same topological property. The method is a conceptual leap as it does not require to force electrons around their north pole. Instead, the researchers have shown that it is possible to materialize the abstract singularity at the surface of graphene by grafting an hydrogen atom on it. This is unveiled by wavefront dislocations in the local density of electrons near the hydrogen atom observed in Scanning Tunneling Microscope images (*Figure*). They showed that the number of additional wavefronts is a measure of graphene's singularity. This discovery opens a new route to understand the topological state of matter, which determine the optical and electronic properties of materials.

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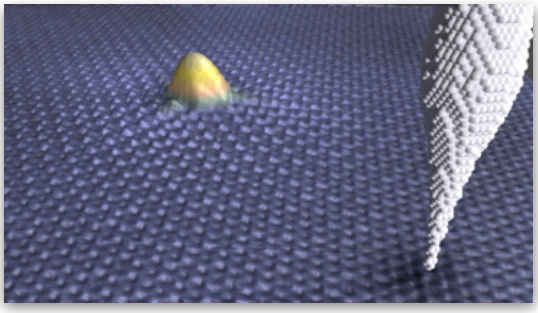
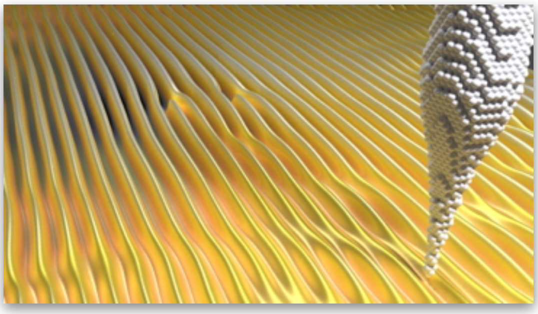




Left image: 3D reconstruction of the raw scanning tunneling microscope image. On the right is seen an artistic representation of the scanning tunneling microscope tip used to record the image. The dome corresponds to the hydrogen atom. Some of the oscillations seen in the image result from the rearrangement of electrons around the hydrogen atom.
The right image represents the corresponding signal selected from the original image and amplified. One observes additional wavefronts (dislocations) in electronic density which are real space manifestation of graphene's abstract singularity.

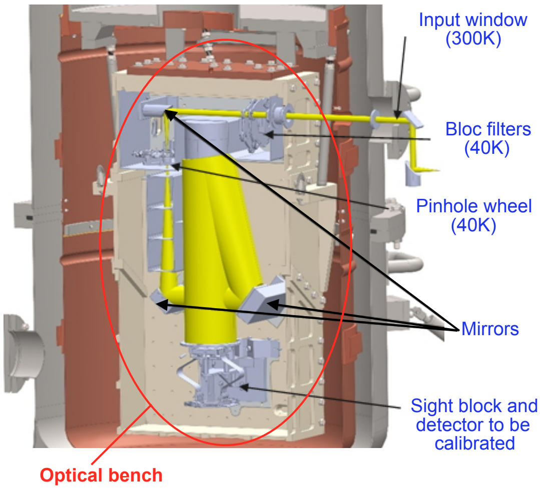
Contact: Vincent Renard
Pheliqs
Quantum Photonics, Electronics and Engineering

Intrapix - A one-of-a kind characterization device

In order to observe ever further with better resolution the stars and galaxies, highly sophisticated devices are designed. Thus, the performance of the sensors and their capability to detect the faintest signals are significantly improving over time. This is the case for the bolometer, a thermal detector whose general principle is to convert the energy of an incident radiation into heat which then raises the temperature of an absorber featuring a thermometer. Each detector has a few thousand pixels, each representing a square of about ten µm side. However, when a photon reaches a pixel, it seems that it would generate a different signal depending on the point of impact, edge or center of the pixel. Hence the Intrapix project is a cryostat designed to accurately characterize these bolometers.

Contact: Éric Ercolani
DSBT
Low Temperature Systems Department

The Low Temperature Systems Department (DSBT) of the IRIG institute has established itself over time as a reference within the space cryogenics community. As part of the Herschel mission, the largest telescope ever placed in orbit, DSBT designed the cryorefrigerators to cool the observation detectors of two instruments to about 300mK. ArTeMis, a sub-millimeter photonic camera operated by CEA-Saclay's Institute of research into the fundamental laws of the Universe (IRFU), has benefited from the Herschel legacy. Indeed, this camera composed of bolometers operating at 300 mK and installed at the focus of the large Apex telescope (Chile) is cooled by a cryogenic chain and a cryostat entirely designed by DSBT.
It is therefore natural that IRFU turns to DSBT to contribute to the Intrapix project, with the dual objective of designing an optical test bench to characterize these bolometers and developing a brand new cryostat to maintain this bench at low temperature. This cryostat includes a cryogenic part featuring a liquid nitrogen tank and a pulse tube for cooling the bench and the detectors. During the design phase, pre-dimensioning calculations (without optics) carried out by DSBT showed that no thermomechanical stress could generate significant deformations that could affect the path of the light beam (*Figure*). A special cryogenic heat treatment of the bench will be carried out to guarantee its dimensional stability over time.
The integration of the optical bench in the cryostat (*Figure*), with these different optical components, will allow the Intrapix project to serve the largest European astrophysics projects such as Euclid-VIS, JWST-Miri, Plato. Intrapix is unique in the world and will allow the intra-pixel characterization of matrix detectors, for visible or infrared in the field of astrophysics.



Intrapix operating diagram.
Cross section showing the inside of the cryostat designed and made by DSBT. The optical test bench features various components (mirrors, filter wheel, collimators, pattern test pattern, etc.) designed by the IRFU Astrophysics Department and made by Durham University.
In yellow: path of the light beam.

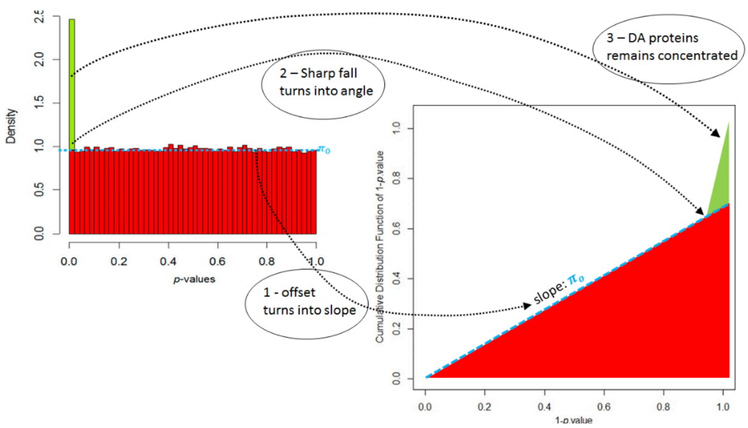
Unintentional p-value hacking
The risk of making the data lie, despite themselves

« There are three kinds of lies: lies, damned lies, and statistics ». This sentence by British Prime Minister Benjamin Disraeli originates from an inappropriate use of statistical tools to support an intuition or conviction. Although censurable, this practice unfortunately has its counterpart in research: p-value hacking. It consists in dredging the data until the desired significance is obtained for a hypothesis tested, to the detriment of some statistical rules that are violated. In most cases, this is done in good faith, since the objective is to get the best from the data while complying with publication requirements. Nevertheless, it is essential to limit this practice, which leads to many false discoveries.

Contact: Thomas Burger
BGE
Large Scale Biology laboratory

This is practically the case in proteomics, due to the intrinsic proteome complexity, but also to the rapid evolution of analytical technologies. This is one of the reasons why many bioinformatics and biostatistics tools regularly blossom in the literature [1], with the promise of overcoming the triple limit of big proteomics data: their large size, their big dimensionality, and their great complexity. However, the simplicity of these tools cannot hide the need for a minimum of theoretical understanding to use them correctly.

It is with this objective in mind that researchers at IRIG's Large Scale Biology laboratory have made a special effort in recent years to disseminate good practices in data science for proteomics [2-4]. They published an introduction to FDR theory (False Discovery rate, an ubiquitous quality control measure), they disambiguated a set of terms with different meanings in artificial intelligence and analytical chemistry, and also proposed five steps to improve the quality control of differential proteomic analysis between several samples.



Graphical construction allowing to visually estimate the quality of the p-values calibration.

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Modeling hole qubits to better unravel their secrets

Qubits are devices in which information is stored as a quantum superposition of two states "0' and "1'. The possibility of superimposing different configurations opens up many perspectives for information processing. These "0" and "1" states can be the "up" and "down" spin states of an electron placed in a magnetic field. CEA-Grenoble manufactures such spin qubits by trapping electrons under the gates of silicon-on-insulator transistors. It is also possible to store information in the spin of a hole left after removing an electron from silicon. The physics of these holes is very original, rich and complex. Numerical simulation improve our understanding of their behavior and show their potential.

Contact: Yann-Michel Niquet
MEM
Modeling and Exploration of Materials

In silicon qubits, the spin is manipulated by modulating the magnetic field in which the device is immersed. However, it remains difficult to control such modulations at the single qubit scale. This is why it may be advantageous to make qubits by using 'holes' rather than electrons. These are indeed subjected to a strong "spin-orbit coupling", *i.e.* the spin of a hole is intimately linked to its movement in space. It thus becomes possible to act on the spin of a hole by giving it an oscillatory motion thanks to a radio-frequency electric field directly created by the gate of the transistor (and much easier to control than a radio-frequency magnetic field).
However, the physics of holes is much richer and more complex than that of electrons. IRIG researchers recently analyzed experiments on hole qubits [1, 2] using numerical simulations that describe in detail these quantum devices down to the atomic scale if necessary. These simulations allowed them to access many quantities that are not experimentally measurable and therefore complete the "portrait" they were able to establish of these qubits. In particular, these simulations have allowed researchers to better understand the mechanisms of spin manipulation at the nanoscale [3]. They were then able to establish a "minimal" analytical model that incorporates the essential mechanisms highlighted by the simulation [4]. This analytical model describes the conditions to be met to optimize hole control and demonstrates that silicon is an ideal material for hole qubits despite its low spin-orbit coupling, due to its very anisotropic electronic properties (the dynamics of holes being very strongly dependent on the direction of their movement in the crystal).
This work paves the way for the optimization of hole devices and for a detailed understanding of the effects of spin-orbit coupling in silicon.

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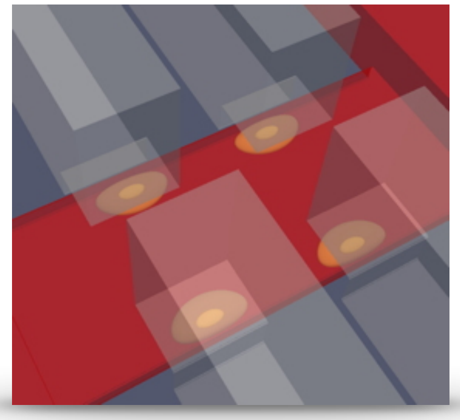


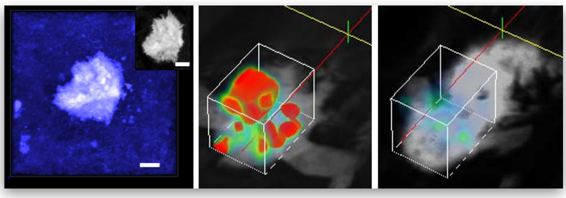
Modeling of four qubits along a silicon wire (red), each controlled by a gate (transparent grey). The iso-surfaces of electron density under each of these gates, which indicate where the holes are located, are shown in yellow.

Towards a new type of Alzheimer's diagnosis?

Amyloid fibers are self-assembling proteins whose fibrillar structure first attracted attention because their accumulation as amyloid deposits in the brain has been demonstrated in the case of neurodegenerative diseases (Alzheimer's, Parkinson's, mad cow disease). Their *in vivo* detection is an essential research axis for the diagnosis of diseases associated with the accumulation of amyloid deposits: amyloses. Indeed, in the case of Alzheimer's and Parkinson's diseases, a diagnosis is necessary not only for better medical care but also for the development of new treatments.

Contact: Vincent Forge
CBM
Chemistry and Biology of Metals

During a ***collaboration***, researchers from the IRIG's Chemistry and Biology of Metals Laboratory have highlighted the luminescence properties of amyloid fibers ranging from visible to near infrared. In blue, this luminescence makes it possible to detect amyloid deposits in a section of the human brain (*Figure*, left) without any labeling and to observe their three-dimensional structure.
In the near infrared, *i.e.* in the diagnostic window, this signal allowed the detection of amyloid deposits in the skulls of living mice that developed Alzheimer's disease (*Figure*, right). This observation could thus constitute a new tool for screening and diagnosis for Alzheimer's and other amyloid-deposited diseases such as type 2 diabetes and systemic amyloidosis.



Left image: Confocal microscopy image of an *ex vivo* amyloid deposition on a section of a brain of a person with Alzheimer's disease in the hippocampus region. 3D modeling of the amyloid deposit from 60 sections detected in the blue. (Boxed) A typical section of the amyloid deposit. The scale bars correspond to 5 µm.

Center and right images: Detection of amyloid deposits in live animals by 3D NIR imaging in "Alzheimer" mice (center) and in control mice (right).

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Collaborations: This work is the result of a collaboration between Grenoble-Alpes Université, Inserm, CNRS, INP Grenoble, Synchrotron Grenoble, University of Cergy-Pontoise and the Geneva Medical School (Switzerland).

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