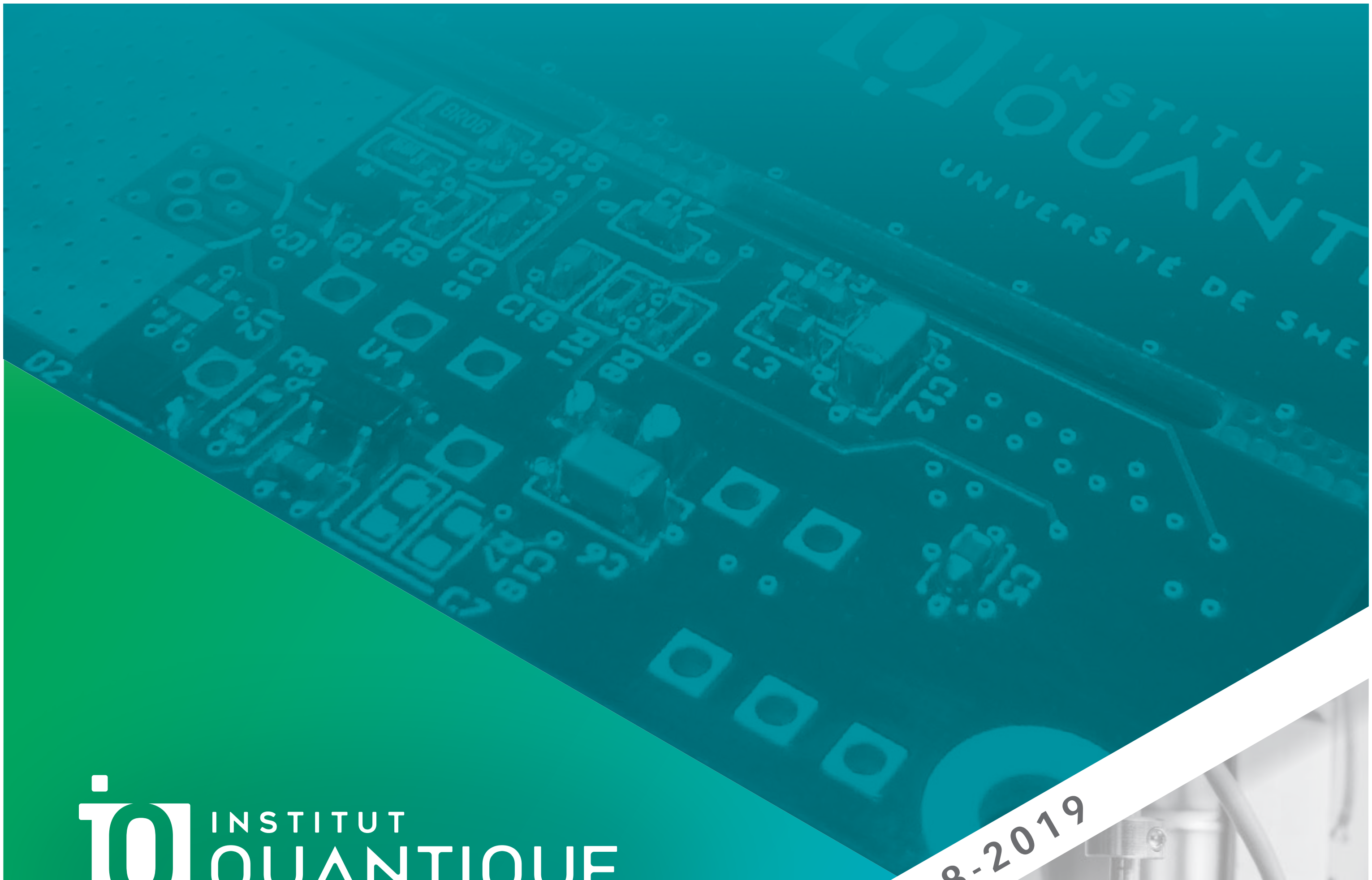
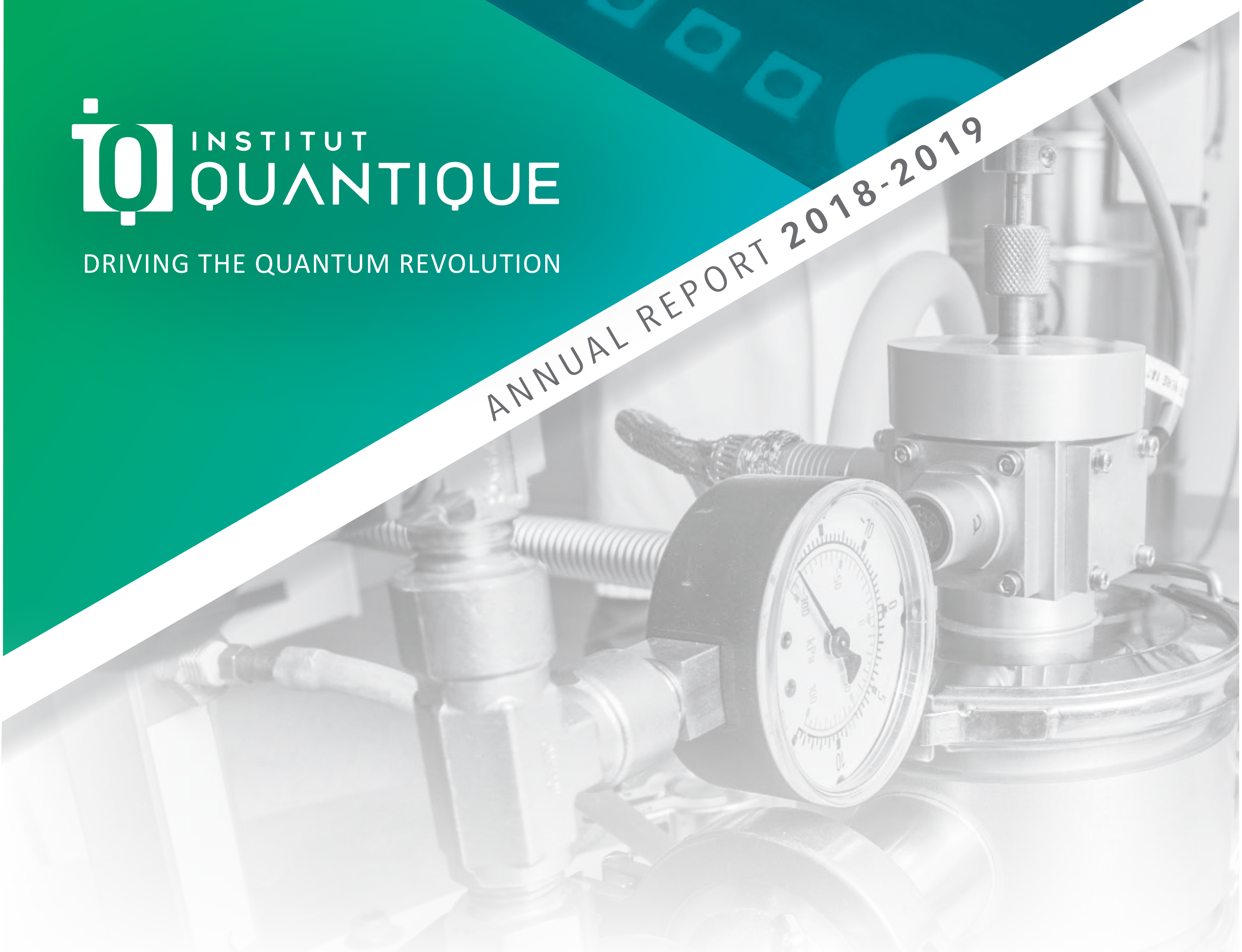


INSTITUT QUANTIQUE

DRIVING THE QUANTUM REVOLUTION

ANNUAL REPORT **2018-2019**



UNIVERSITÉ DE SHERBROOKE

OUR VISION

Quantum sciences will produce technologies that will transform our society. The Institut quantique at the Université de Sherbrooke is at the center of a dynamic ecosystem that is accelerating this quantum revolution.

OUR MISSION

Put students at the center of research in an open and collaborative environment to accelerate the transition from science to quantum technologies. We train leaders who have the skills and critical thinking essential to creating knowledge relevant to a changing society.

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DIRECTOR'S WORD

Another busy year for the Institut quantique and its researchers, where several decisions taken in the first years of the Institut's existence have materialized into tangible initiatives. A key example is the $20.5M grant provided by the Government of Quebec for the Integrated Innovation Chain project to which the IQ belongs. Another major success is the 3.6M funding over six years for the CREATE training program, which aims to reduce the gap between science and technology. At the national level, the Institut quantique has greatly contributed in the development of a national quantum strategy. The medium to long-term impact of this key effort could be decisive for the role played by our institute, Quebec and Canada in terms of quantum science and technology development.

Alexandre Blais, Scientific Director.
Photo: Michel Caron – UdeS

One of the Institut quantique's priorities is training students. This year, we have taken this mission to heart by offering them exceptional opportunities. The 7th edition Women in Physics Canada Conference organized by three female IQ students is an excellent example. During this event, more than 120 participants met at the Université de Sherbrooke to hear over 20 speaker, and took part in skills development workshops. Similarly, the QMSat project, which consists of future engineers and students from other faculties, led by postdoctoral fellow from Institut quantique, David Roy-Guay, won a grant from the Canadian Space Agency. The joint project aims at putting quantum technology developed by the team into orbit and will help expose more than 500 students from high schools, colleges and universities to quantum science.

You will also find in this annual report some of the key breakthroughs by IQ members in the fields of materials, engineering and quantum information, including discoveries at the interface of these research areas. The talent of our researchers was praised again this year at the University of Sherbrooke, as well as across Quebec, Canada and the rest of the world. The Radiation Instrumentation Early Career Award to Professor Jean-François Pratte and the Kamerlingh Onnes Prize to Professor Louis Taillefer come to mind.

Finally, among other exciting projects, the Institut quantique's new building is progressing. We are fortunate to work with Saucier + Perrotte Architects, one of the most recognized architectural firms in Quebec. We look forward to welcoming you to this new place of exchanges and collaborations.

ABOUT THE INSTITUTE

Institut quantique (IQ) of Université de Sherbrooke brings together internationally recognized leaders in research and interdisciplinary training in science and quantum technologies. IQ is a collaborative environment at the interface of quantum computing, quantum materials and quantum engineering offering students, its members and its partners exceptional scientific and professional opportunities.

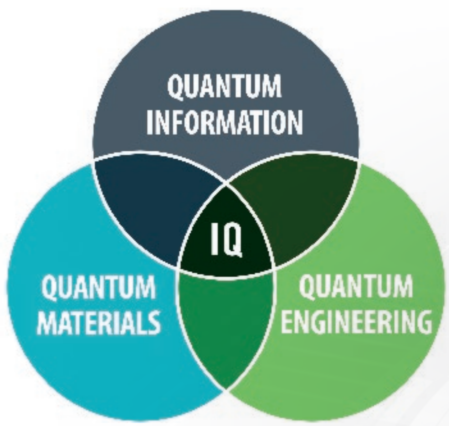
OUR ACTIONS

- Develop projects at the interface of our research areas
- Train the highly qualified staff who will be the driving force of tomorrow's economy
- Accelerate the development of quantum technologies, entrepreneurship and the marketing of these technologies
- Engage key players in the development of quantum technologies
- Foster social awareness in technological challenges emerging from quantum science

CFREF MAJOR GRANT

The Canada First Research Excellence Fund (CFREF) has awarded $33.5 millon over the next seven years to our researchers to support the "From Quantum Science to Quantum Technologies" project, an ambitious strategy to meet the needs of the 21st century digital age.

CANADA FIRST
RESEARCH EXCELLENCE FUND



KEY FACTS

FROM INNOVATION TO COMMERCIALIZATION: FUNDING THE INTEGRATED INNOVATION CHAIN.

The Quebec government made a contribution of $20.5 M to implement the *Chaîne d'innovation intégrée pour la prospérité numérique* (CII Integrated Innovation Chain for Digital Prosperity). This project, valued at $28.5 M, will support research in new industrial sectors, including quantum technology development.

The project will also be a key component in the transition from pure science to developing and upscaling quantum technology. The Institut quantique will be able to take advantage of this investment along with two other infrastructure projects that are part of the CII: The Interdisciplinary Institute for Technological Innovation (3IT), to develop and test prototype parts; and the the MiQro Innovation Collaborative Centre (C2MI).

Vincent Aimez, Vice-Rector, Partnerships and Knowledge Transfer and the President of the Université de Sherbrooke, Professor Pierre Cossette; The Honourable Dominique Anglade, Deputy Premier and Minister of Economy, Science and Innovation and Minister responsible for the Digital Strategy; Luc Fortin, Minister of Families and Minister responsible for the Estrie region ; and Normand Bourbonnais CEO of the MiQro Innovation Collaborative Centre (C2MI).

"By supporting this project, our government has reaffirmed its commitment, as stated in the Digital Strategy, to accelerate Quebec's transition into the economy of the 21st century. In addition, supporting the Université de Sherbrooke is a concrete expression of our wish to be a partner that is attentive to academic needs in terms of research infrastructure as we continue our investments in research and innovation," explains Dominique Anglade.

THE 2018 WOMEN IN PHYSICS CONFERENCE IN SHERBROOKE

The 7th edition of Women in Physics Canada (WIPC 2018) was held from July 17 to 20, 2018 for the first time in Quebec at the Université de Sherbrooke. It brought together 120 students, professors, post-doctoral researchers and industry professionals working in physics-related fields. Discussions were hosted by 21 speakers and panelists.

In addition to being able to learn about the work of world-renowned female researchers from Quebec, participants took part in workshops for professional skills development and discussion panels on the challenges that women and minorities face when pursuing a scientific career.

(Continued on next page)

WIPC 2018 conference participants.

Women in Physics: No small feat

While women account for less than 30% of the global community of researchers and collective efforts to change things has only brought modest results, WIPC supports and encourages young female physicists early in their careers to persevere.

By bringing this conference to Sherbrooke, the three organizers who are physics students and IQ members pulled off a true feat. “Until now, the event was held in Ontario or in one of the western provinces,” points out Sophie Rochette, a doctoral student in physics and co-organizer. By bringing it to Quebec, we were able to reach more participants coming from eastern provinces, which was not the case in previous years. Although the event was in English, all the materials related to the conference were bilingual, which made it more accessible [to french speakers].” Sophie worked with her colleagues Maude Lizaire and Marie-Eve Boulanger, both master’s students in physics, to make this event a success.

Sophie Rochette, Maude Lizaire and Marie-Ève Boulanger, event organizers. Photo: UdeS

Looking to the future

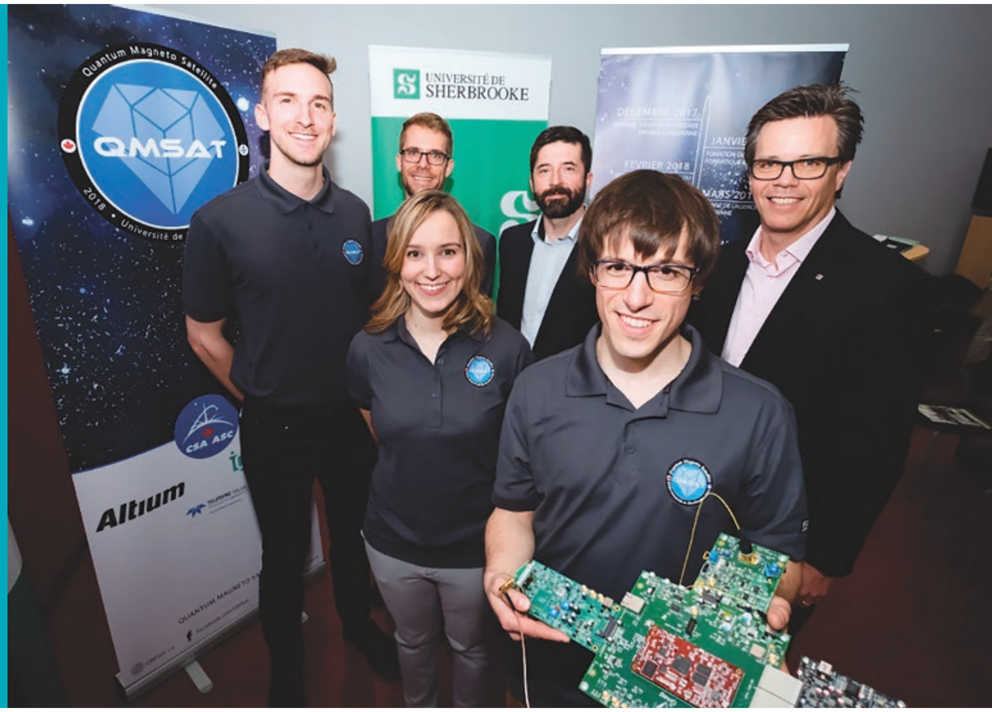
During the months leading to the conference, the trio was able to count on the cooperation of several of their male colleagues and the strong support of the Institut quantique, the main sponsor for the event. “The popularity of the activity demonstrates a need for networking,” says Maude Lizaire. Many people feel alone and isolated in what they experience. Some even think that this is unavoidable, that this is how things are and they must learn to live with it. A day like today proves that this is not true.”

The Chairholder for Women in Science and Engineering in Quebec, Professor Ève Langelier, praised the organizers’ commitment. “This initiative does much more than support the increase in the number of women in physics. It also contributes to a better inclusion of female physicists in their field so that they can feel more at ease. Equity, diversity and inclusion are much sought-after values in all fields. However, we must continue to put forward the major advantages of diversity in innovation, for instance.”

IQ IS LAUNCHING INTO ORBIT

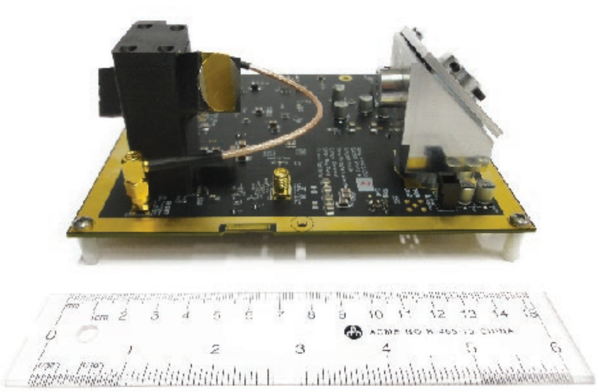
QMSAT PROJECT

In 2018, the QMSat team, which consists of future engineers working towards a bachelor's degree and students from other faculties at the Université de Sherbrooke, obtained one of 15 grants from the Canadian Space Agency. The three-year funding worth $200,000 is part of the Canadian CubeSat Project (CPP).



Participants presented during the announcement of the QMSat project. Standing from left to right: Claude Samuel Chrétien and Chloé Mireault-Lecourt, electrical engineering students; David Roy-Guay, postdoctoral student in electrical engineering; David Rancourt and Julien Sylvestre, professors in mechanical engineering; and Patrik Doucet, Dean of the Faculty of Engineering.

Photo: UdeS – Michel Caron



The aim of the QMSat project is to demonstrate a new sensor technology that measures magnetic fields in space and to improve the precision of solar storm measurements in radio communications, GPS and electrical networks.

"This satellite will be one of the first concrete applications of cutting-edge quantum technology developed at the Université de Sherbrooke's Institut quantique and one of the first quantum technology applications in space," explains project coordinator Professor Julien Sylvestre of the Faculty of Engineering and IQ member.

(Continued on next page)

After prototyping a large diamond-based quantum magnetometer in the laboratory, postdoctoral student in electrical engineering at the Université de Sherbrooke's Institut quantique, David Roy-Guay proposed miniaturizing the quantum sensor to students so it could be integrated into a CubeSat. "They will have to reduce the size of the current prototype, which is as big as a laptop to a 10 cm-wide cube. It is a tremendous challenge, but they can do it! This CubeSat enables us to be at the cutting edge of research and materials science education, computer science and quantum engineering," he points out.

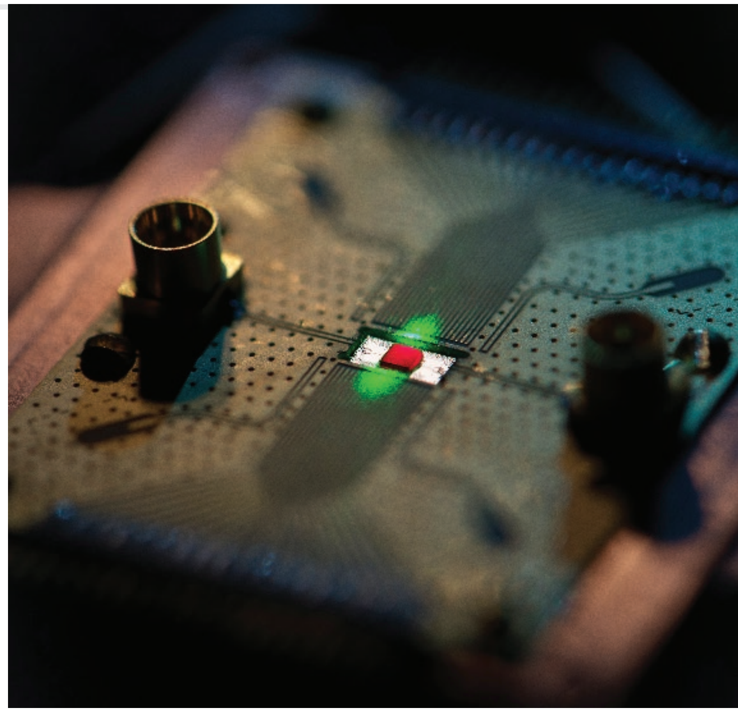
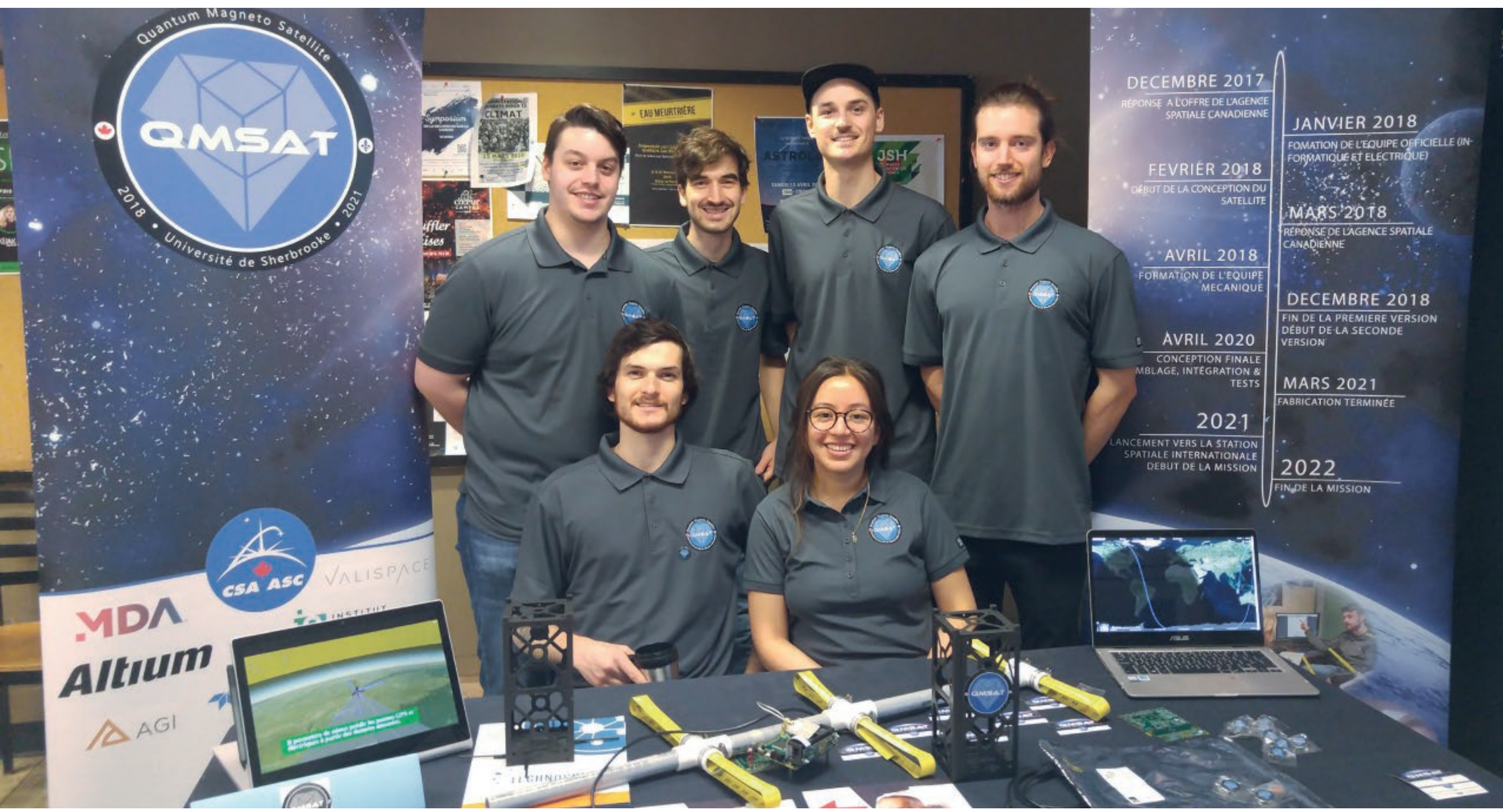


Photo: UdeS – Karine Couillard

ADDITIONAL INFORMATION:

www.qmsat.ca | www.asc-csa.gc.ca/fra/satellites/cubesat/default.asp



Standing from left to right: Antoine Beaudry, Thomas Roy, Jean-François Bilodeau, Charles-Olivier Jacques.
Seated from left to right: Philippe Gobeil, Wendy Édith Vasquez Gutierrez.
Photo: Provided

THE CREATE PROGRAM:
BRIDGING THE GAP BETWEEN SCIENCE AND TECHNOLOGY

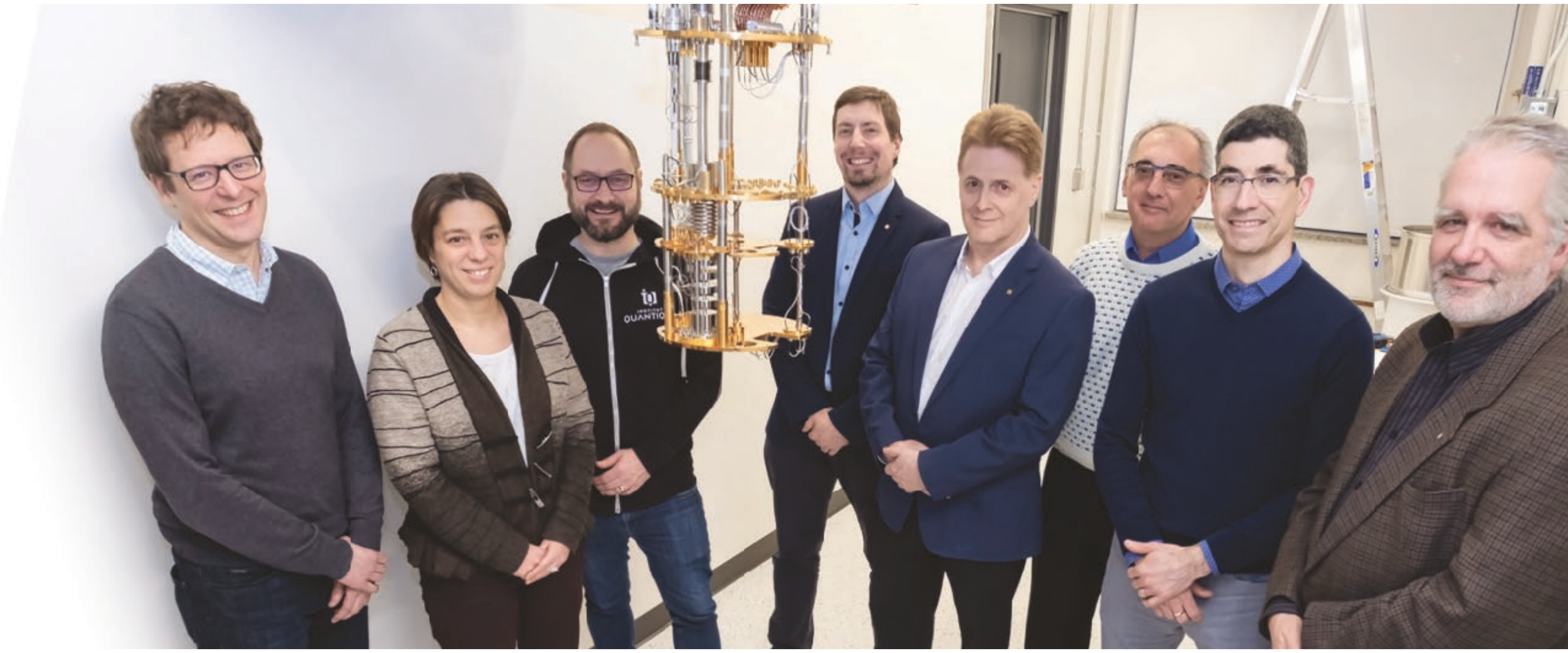
Training future professionals in the quantum industry

The Université de Sherbrooke, in collaboration with six university partners, will train qualified professionals with a global perspective on the quantum chain, from quantum science to engineering skills and methods, over the next six years. Quantum technologies are part of Canada's high technology economy, a key priority sector for the country.

Yves Bérubé-Lauzière, professor at the Université de Sherbrooke's Faculty of Engineering and member of the Institut quantique and the Interdisciplinary Institute for Technological Innovation (3IT), will be in charge of a Collaborative Research and Training Experience Program (CREATE) of the Natural Sciences and Engineering Research Council of Canada (NSERC). With this grant of $3.6 M over six years, professor Bérubé-Lauzière will coordinate state-of-the-art training activities for R&D in quantum technologies across the country.

(Continued on next page)

From the right: Marie-Claude Bibeau, Minister of International Development and La Francophonie and Kirsty Duncan, Minister of Science and Minister of Sport and Persons with Disabilities. They are in the company of physics researchers from l'IQ.
Photo: Provided



Researchers involved with the CREATE program - From left to right: Alexandre Blais, IQ Scientific Director; Eva Dupont-Ferrier, IQ Researcher; Michel Pioro-Ladrière, IQ Deputy Director; Christian Sarra-Bournet, IQ Executive Director; Patrick Fournier, Vice-Dean for Research, Faculty of Sciences; Marc Leclair, Research Assistant; Yves Bérubé-Lauzière, Director of the QSciTech Program and professor at the Faculty of Engineering; and Pierre Labossière, Vice-Dean for Research at the Faculty of Engineering. Photo: UdeS – Michel Caron

The aim of this program, known as "QSciTech – Bridging the gap between quantum science and quantum technologies," is to train the next generation of quantum scientists, engineers and entrepreneurs. The integrated training will allow physics students to learn the fundamentals of engineering and conversely, engineering and computer science students to be trained in quantum physics. These students from different backgrounds will also have common training activities to learn to work together towards developing quantum technologies.

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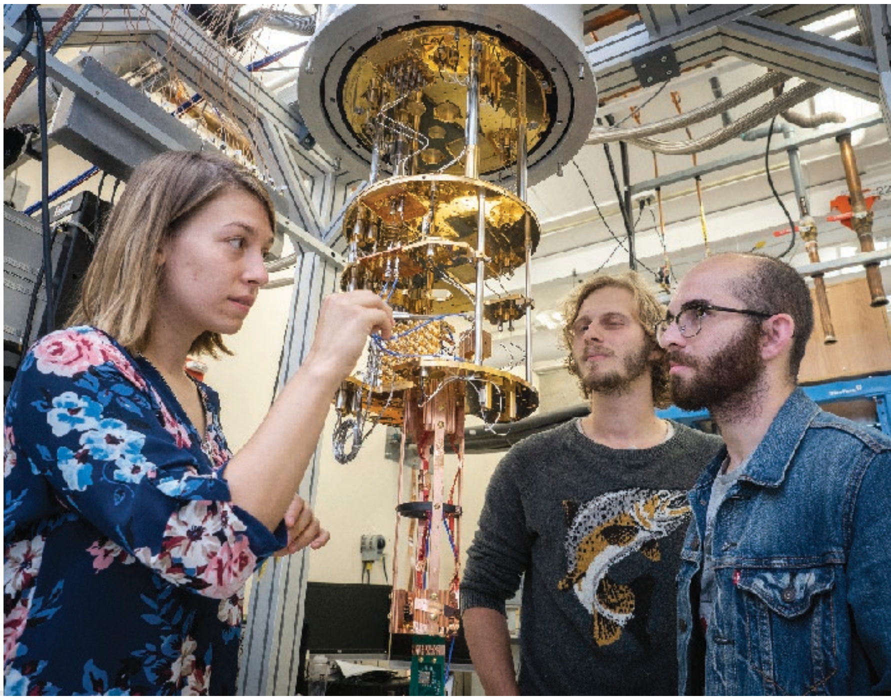

Photo: UdeS – François Lafrance

"This program is important because quantum technologies are mainly in the hands of physicists at the moment. Engineering is key to deploying these technologies on a larger scale and bringing these to the commercialization stage. On the other hand, engineers usually have limited knowledge about quantum sciences, which affects how they can contribute to quantum technologies. The aim of the QSciTech program is to facilitate understanding between these two communities and improve the way they work together," explains Yves Bérubé-Lauzière.

"This program can train future professionals to develop quantum technologies and help support the growing quantum industry. Training graduate students in quantum technology will contribute to boosting the job market with professionals who have an integrated vision of the discipline, which adds significant value," says Professor Jean-Pierre Perreault, Vice-Rector for Research and Graduate Studies at the Université de Sherbrooke.

Photo: UdeS – François Lafrance

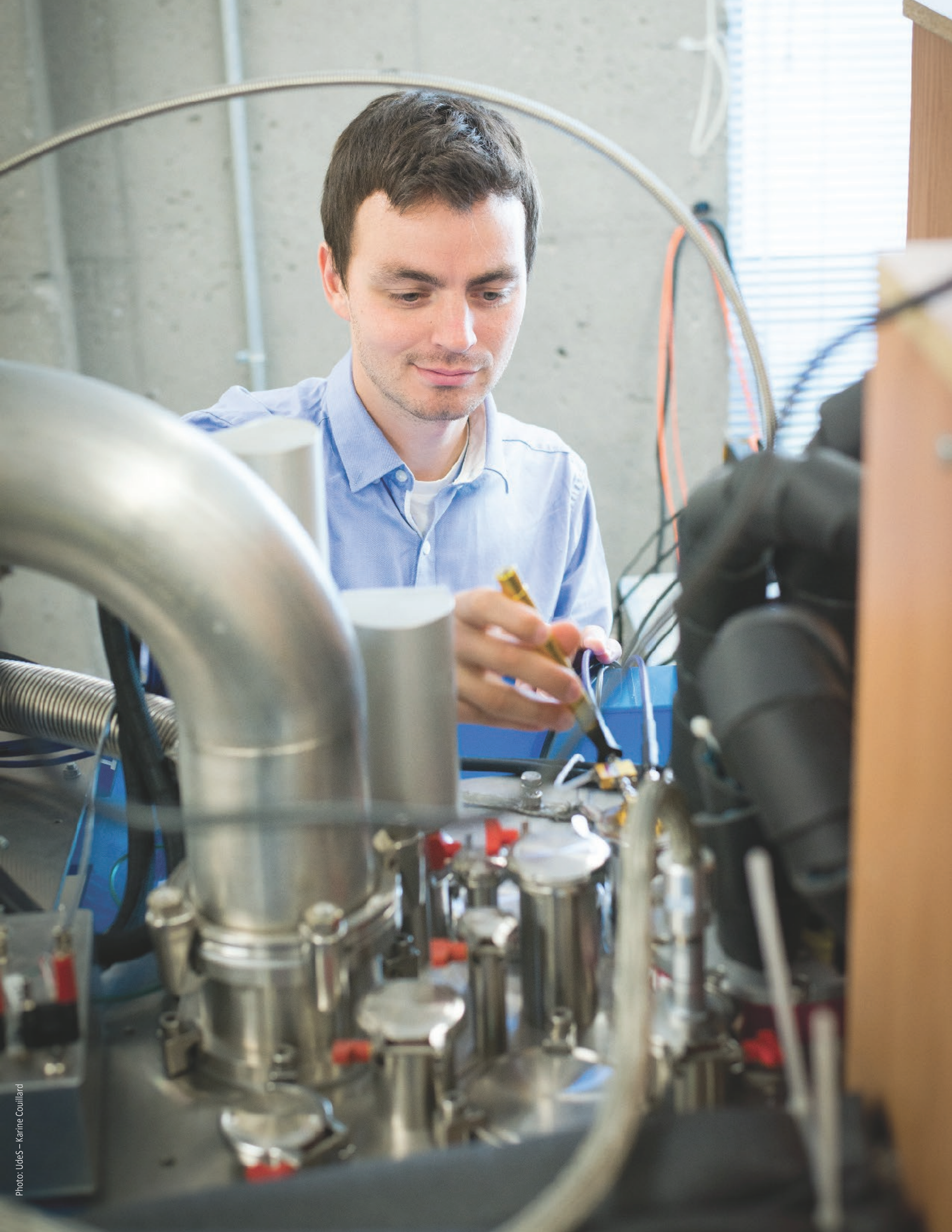
Photo: UdeS – Karine Couillard

SCIENCE AND TECHNOLOGY

MAX HOFHEINZ AND JOSEPHSON PHOTONICS


Photo: Provided

Professor Max Hofheinz is an applied scientist and expert in quantum superconductor devices, who adds to the theoretical work done by IQ experts in this field.

His research focuses on Josephson photonics, which enable simple quantum mechanisms powered by simple continuous tension to be implemented.

He is interested in the potential presented by these mechanisms for different uses such as the generation of quantum microwave states, quantum-limited amplification and the detection of single microwave photons.

In quantum superconductor circuits, the Josephson junction is the key element. It is the only nonlinear, dissipationless circuit element that is known. It is usually used in the superconductor state in which it acts as a non-linear inductor, for example in superconductor qubits or Josephson parametric amplifiers. A Josephson junction can also be non-linear and dissipationless when continuous and non-zero voltage is applied. In this case, a Cooper pair current can circulate in the junction when the 2eV energy of a Cooper pair that passes through the junction by tunnel effect may be dissipated in the surrounding linear circuit in the form of photons emitted by one or several of its modes. In this state, used in Josephson photonics, the junction works like an active non-linear element, which transforms energy supplied by the continuous source into microwave radiation.

Professor Hofheinz's team has adapted these physics to quantum microwave sources, such as single photon sources and measurement devices, quantum-limited amplifiers and microwave photomultipliers. Although these devices are likely to be less coherent than their counterparts using the Josephson junction in the superconductor state, they allow performances that are very close to the quantum limits, are easier to implement and able to function on high bandwidths.

The Yale Quantum Institute gave Professor Hofheinz the Yale Quantum Institute Distinguished Lecturer Award in January 2019 and on that occasion, he gave a presentation entitled: *Can we build quantum devices using the voltage state of Josephson junctions?*

COHERENT SPIN-PHOTON COUPLING USING A RESONANT EXCHANGE QUBIT

Researchers in the field of quantum sciences and technologies are motivated by the prospect of making substantial contributions to the development of quantum computers. Sharing this desire, Udson Cabral Mendes, postdoctoral fellow at Institut quantique, is studying how quantum bits and photons can interact strongly in a quantum chip.

Udson Cabral Mendes
Photo: UdeS – Karine Couillard

Increasingly, spin qubits are being considered as an approach in designing quantum computers. In fact, their long duration of coherence and their small size make them an interesting tool for solid-state quantum calculations. Meanwhile, the connection between different spin qubits inside a chip remains a major challenge. A first step towards the resolution of this problem was mentioned in *Science* and *Nature* articles both co-written by Udson Cabral Mendes.

As part of an international collaboration, Mr Cabral Mendes and Professor Alexandre Blais combined their theoretical expertise with the experimental teams of QuTech and ETH-Zurich to demonstrate, in proof-of-concept experiments, how to transfer information coded in a spin qubit to a microwave photon in a superconductor resonator. “While the idea behind the articles in Science and Nature is the same, the physics of quantum spin-photon coupling, devices and materials used in these experiments are very different,” says Mr Cabral Mendes.

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Science: Spin-photon coupling in silicon

In the experiment conducted by the QuTech group, led by Professor Lieven Vandersypen, spin qubits are formed in silicon by confining a single electronic spin in two quantum boxes – also known as double quantum points.

Thanks to a trick using magnetic fields proposed by IQ's Professor Michel Pioro-Ladrière and his team, researchers were able to couple the rotation of electrons with the photon's electric field.

ADDITIONAL INFORMATION

Samkharadze, N., Zheng, G., Kalhor, N., Brousse, D., Sammak, A., Mendes, U. C., … Vandersypen, L. M. K. (2018). Strong spin-photon coupling in silicon. Science, 359(6380), 11231127. www.doi.org/10/gc95x8

Nature: Spin-photon coherent coupling using a resonant exchange qubit

In the experiment conducted in collaboration with ETH-Zurich and Professors Andreas Wallraff, Klaus Ensslin and Thomas Ihn, the spin qubit is composed of gallium arsenide, in which three electronic spins are trapped in three quantum boxes forming an exchange qubit known as resonant. In this device, the coupling between the photon and the spin qubit is the result of a spin-to-charge conversion process mediated by the exchange interaction.

"In future quantum computers, microwave photons might be used to transmit quantum information between the spin qubits separated by a centimetre or more in a complex chip," adds Alexandre Blais.

Udson will continue his postdoctoral studies at IQ until 2019, where he will have other exciting opportunities to contribute to the development of quantum technologies.

ADDITIONAL INFORMATION

Landig, A. J., Koski, J. V., Scarlino, P., Mendes, U. C., Blais, A., Reichl, C., … Ihn, T. (2018). Coherent spin–photon coupling using a resonant exchange qubit. Nature, 560(7717), 179. www.doi.org/10/gdvnpf

SIMULATE WITHOUT TRYING TO IMITATE NATURE

If some philosophers once questioned themselves about the state of human beings before the emergence of society, physicists sometimes wonder about the ground state of a material. What would the material look like if it were in its lowest energy state? This question is particularly relevant for understanding certain materials or molecules whose exotic properties are only revealed at low temperatures.

"Using a quantum computer to simulate the dynamics of a material or a system as well as measure its evolution and its behavior, is a known and controlled process. On the other hand, placing the object of study in its initial condition is quite a challenge. "explains Professor David Poulin.

The quantum computer's tremendous estimating computing capacity allows us to consider many breakthroughs in areas such as drug research, transportation and finance. In physics, particularly in the search for new materials, one of the tasks that we want to give the quantum computer is to simulate the behavior of materials at low temperatures, also referred to as the ground state.

Professor Poulin and his co-authors, including world renown Professor Alexei Y. Kitaev from Caltech's Institute for Quantum Information and Matter (IQIM), explored the idea of mathematically simulating the ground state rather than following nature's path.

Professor Poulin explains. "All that has been tested before is to reproduce nature in an algorithmic way. For example, how do you cool a material in the laboratory? Just put it in contact with something cold, such as liquid helium, and the dynamics of the system will naturally cause it to cool down. In a quantum simulation, it is possible to imitate this dynamic of a system coupled to a cold tank, which allows us in principle to prepare it in its ground state. However, this simulation is very slow and expensive, which is a major obstacle to this type of application."

The discovery of Prof. Poulin and his co-authors is an algorithm that makes it possible to prepare the ground state of a system without having to imitate a cooling process. Instead, the method uses a much more efficient mathematical trick to do the same work. "What distinguishes our approach is that it is based on a process that does not occur in nature. It is a kind of algorithmic shortcut that allows us to simulate nature without physically imitating it."

One could think of adapting the same idea to go beyond the scope of the study of materials, for example to study complex molecules, or ongoing experiments in the large collider of CERN (European Council for Nuclear Research).

ADDITIONAL INFORMATION

Poulin, D., Kitaev, A., Steiger, D. S., Hastings, M. B., & Troyer, M. (2018). Quantum Algorithm for Spectral Measurement with a Lower Gate Count. Physical Review Letters, 121(1), 010501.

Professor David Poulin
Photo: UdeS – Karine Couillard

COMBINING CONCEPTS OF QUANTUM INFORMATION AND QUANTUM MATERIALS

QUANTUM CORRELATION AND PHASE TRANSITION

One only has to look at boiling water to see the spectacular changes in the organization of matter during a phase change. At the quantum level, changes in phase transitions can also be just as striking, particularly for a key quantum phenomenon: entanglement.

André-Marie Tremblay and David Poulin
Photo: UdeS – Michel Caron

In a recent article published in Physical Review Letters, a team of theorists from Institut quantique (Pr David Poulin and Pr André-Marie Tremblay), Royal Holloway in London (Caitlin Walsh, student and Pr Giovanni Sordi) and Brookhaven Laboratory in the United States (Patrick Sémon, research scientist) have combined concepts of quantum information and quantum materials to highlight quantum correlations during a phase transition that is fundamental for quantum materials.

The research initiated by Giovanni Sordi focused on a mathematical model where interactions between electrons transform a metal, where they can move freely into an insulator and where they are localized. This transition between metal and insulator, also known as the Mott transition, is a central phenomenon for the theory of quantum materials, such as high temperature superconductors.

Similar to the liquid-gas transition that we are familiar with, boiling water, this metal-insulator transition has two key characteristics: it is abrupt at low temperature and ends at high temperature at a critical point where there is no longer any difference between the two phases. The important discovery of this team showed that all these characteristics are manifested in key measurements of quantum correlations. In particular, they identified how electrons were entangled and how mutual information changes at the transition. Electrons are entangled when the measurement of the state of an electron instantly changes the state of other electrons. Mutual information informs us of the presence of correlations, regardless of their nature. These two quantities relate to generalizations of the entropy concept.

The results of this theory can be verified by advanced experiments using quantum simulators made of ultra-cold atoms, where it is possible to measure quantum correlations.

ADDITIONAL INFORMATION

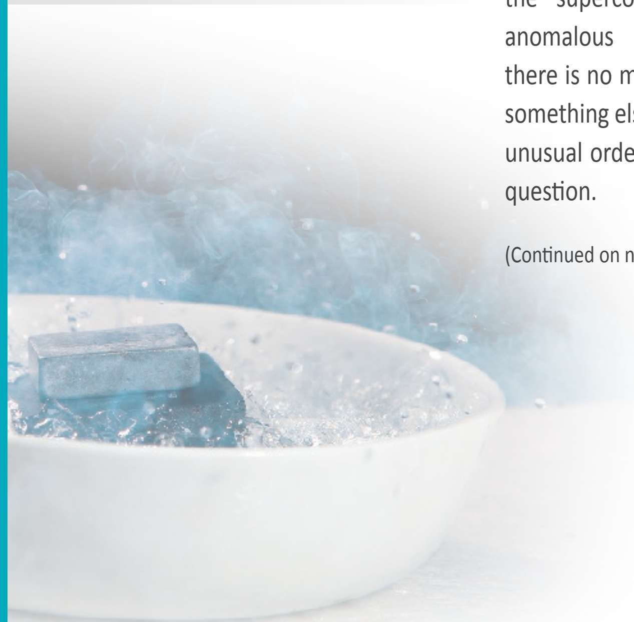
Walsh, C., Sémon, P., Poulin, D., Sordi, G., & Tremblay, A.-M. S. (2019). Local Entanglement Entropy and Mutual Information across the Mott Transition in the Two-Dimensional Hubbard Model. Physical Review Letters, 122(6), 067203.

A publication in Nature
AT THE HEART OF HIGH-TEMPERATURE SUPER- CONDUCTIVITY

Electrons in cuprate superconductors behave in remarkable ways. They conduct electricity without resistance at record high temperatures, and when they cease to superconduct, they do not comply with our usual expectations for how a metal should behave. Now, a team led by Sherbrooke Professor and IQ member Louis Taillefer reports in *Nature* a major finding that could explain these remarkable properties: a quantum critical point right at the heart of cuprate superconductors.

A time will come when superconductors will revolutionize our daily life, in areas as diverse as energy transmission, medicine, and communications. For this to happen, the critical temperature below which superconductivity occurs must first be increased up to room temperature. As of today, copper-oxide materials called "cuprates" are the most promising candidates for achieving that goal. However, these are materials where the weirdness of quantum mechanics seems to have created a wealth of spectacular and anomalous properties that defy our understanding.

The most puzzling feature of cuprates is the "pseudogap phase", a mysterious electronic phase of matter that coexists with superconductivity, and is considered one of the great enigmas in physics today. Elucidating the nature of that phase is thought to be the key to understand how electrons behave in these materials.



The team of researchers led by Taillefer and Thierry Klein at the Institut Néel in Grenoble, France, discovered a crucial ingredient for resolving the enigma: the pseudogap phase ends at a quantum critical point. This means that it harbours some kind of order, and that order is the key. In other materials, superconductivity has been found to spring from a quantum critical point where magnetic order ends, and magnetism is what causes the superconductivity and the other anomalous properties. In cuprates, there is no magnetic order, so it must be something else. Figuring out what type of unusual order is involved, is now the big question.

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The team's discovery came from measurements of the specific heat at very low temperature, having first suppressed superconductivity with very large magnetic fields, using the powerful magnets at the Laboratoire National des Champs Magnétiques Intenses in Grenoble. The long-term project was a collaboration between Sherbrooke and Grenoble, involving three researchers who are members of the *Laboratoire Circuits et Matériaux Quantiques*, at Laboratoire International Associé created by the French CNRS in 2017, linking the Institut quantique in Sherbrooke with several French laboratories. This Sherbrooke-France partnership is a good example of co-tutoring, whereby Taillefer and Klein jointly supervised PhD students Bastien Michon and Clément Girod, first and second authors on the Nature article.

Christophe Marcenat, Thierry Klein, Bastien Michon and Louis Taillefer.
Photo: Provided

"At Sherbrooke, we have explored the pseudogap phase with various probes, but to see the quantum critical point required the expertise of Thierry Klein and Christophe Marcenat in measuring specific heat in high magnetic fields", says Taillefer. "A great example of complementary teamwork."

The project is also an excellent illustration of the synergetic approach of CIFAR, whereby experimentalists, theorists and experts at materials synthesis are brought together to achieve a breakthrough. In this case, CIFAR's *Quantum materials program* enabled Taillefer to obtain precious cuprate samples from Bruce Gaulin and Hidenori Takagi, respectively member and advisor in that program. Theoretical calculations were carried out by Simon Verret, a postdoc in the group of IQ member André-Marie Tremblay, a long-term member of the CIfAR program.

"Being able to convince Bruce Gaulin and his group at McMaster to synthesise cuprate samples at very high doping was crucial", says Taillefer. "Thanks to CIFAR, a new collaborative axis between Sherbrooke and McMaster was opened".

The Gordon & Betty Moore Foundation contributed to funding this project, via a grant to Taillefer as part of its program on *Emergent Phenomena in Quantum Systems*.

ADDITIONAL INFORMATION

Michon, B., Girod, C., Badoux, S., Kačmarčík, J., Ma, Q., Dragomir, M., … Klein, T. (2019). Thermodynamic signatures of quantum criticality in cuprate superconductors. *Nature*, *567*(7747), 218.

QUANTUM AMPLIFIERS WITH VERY HIGH BANDWIDTHS

IQ's call for projects is an opportunity for collaboration and experience sharing that offers a great deal of independence to researchers. Sébastien Jézouin and Udson Mendes, IQ postdoctoral fellows, have seized this opportunity and submitted a project to build a quantum amplifier.

Sébastien Jézouin
Photo: UdeS – Karine Couillard

To survive ambient temperatures and contribute to the effective transmission of quantum information, an amplifier is required to boost a signal as weak as a single photon. At present, many amplifiers already work well but their bandwidths are narrow and they amplify signals on low frequency ranges, which is not optimal. There are only a handful of examples of effective amplifiers with a large bandwidth. However, these are difficult to build because of the complexity of the technical feat required to produce them.

The two researchers have combined their expertise to design a quantum-limited amplifier, equipped with a bandwidth of several GHz, with a relatively simple architecture. They have dedicated the first portion of the project to develop design scenarios and find solutions to experimental problems caused by theoretical constraints. Sébastien Jézouin, the experimenter, and Udson Cabral, the theorist, have taken advantage of the opportunity to spend time together daily to drive the project forward.

The result: with a bandwidth of 3-dB reaching 4.3 GHz, they demonstrated a gain of 20 dB, corresponding to the kind of performances expected at the start. All this was the subject of an article in *Physical Review Applied*.

This project has also enabled the two researchers to explore intellectual property, supported in their efforts by IQ.

Although the postdoctoral fellowship was coming to an end for Sébastien Jézouin and Udson Cabral, the project has generated enough interest at IQ for it to be extended.

ADDITIONAL INFORMATION

Mendes, U. C., Jezouin, S., Joyez, P., Reulet, B., Blais, A., Portier, F., … Altimiras, C. (2019). Parametric amplification and squeezing with an ac- and dc-voltage biased superconducting junction. *Physical Review Applied*, *11*(3), 034035.

STRONG INTERACTIONS AND THE FERMI-HUBBARD MODEL

A recent publication in Science perfectly illustrates how teamwork is essential to scientific research. Members of IQ Reza Nourafkan, Alexis Reymbaut, Charles-David Hébert and Simon Bergeron, all part of Prof. André-Marie Tremblay's research group, provided the theoretical part to *Bad metallic transport in a cold atom Fermi-Hubbard system*, while the experiments were done in Princeton by Prof. W. S. Bakr team. Prof J. Kokalj from Ljubljana also provided complementary theoretical work.

Reza Nourafkan - Photo: IQ

Electrical resistivity determines if a material is a conductor or an insulator, depending on whether it transports electrical current or not. Electrons carry current, but they usually scatter from one state to another, which causes electrical resistivity, ρ. The average distance covered by electrons between scatterings is called mean free path, l.

According to the Mott-Ioffe-Regel limit (MIR limit), this mean free path cannot become shorter than the distance between two atoms. When this happens, resistivity should saturate and reach its limit. However, a wide variety of materials, including cuprate superconductors, do not meet the above expectations: resistivity is linear in T and keeps rising with increasing T, which violates the resistivity bound imposed by the MIR limit.

In real materials, electrons interact not only with each other but also with vibrations of nuclei and with impurities. In order to simplify the problem, Prof. W. S. Bakr team created a quantum simulator from cold atom systems, which can be described by a simple model, the so-called Hubbard model. This model is widely used to describe cuprate superconductors as well. The Princeton group also found an ingenious way to measure electrical conductivity despite the fact that the carriers are neutral in this case.

The results from the quantum simulator show that resistivity exhibits a linear temperature dependence and shows no evidence of saturation, similar to what is seen in the strange metal phase of cuprate superconductors.

However, the T-linearity of ρ does not come from the Planckian limit of the scattering rate. Indeed, the scattering rate saturates in agreement with MIR limit.

Intuitively, the T-linearity of ρ is attributed to the strong interaction between carriers, which may destroy the conventional quasiparticle picture and invalidate its predictions. However, a quantitative understanding of this problem requires theoretical simulation of the electrical conductivity of the Hubbard model, a subject where Prof. Tremblay's group has extensive expertise.

Reza Nourafkan used a state of the art method, dubbed dynamical mean field theory (DMFT) and its extension, to solve the Hubbard model and calculate the resistivity. This was complemented by the work of postdoc Alexis Reymbaut, undergraduate student Simon Bergeron and PhD student Charles-David Hébert. The calculated scattering rate does saturate and the compressibility depends on temperature like 1/T, in excellent agreement with experimental data.

This would be due to an unexpected behaviour of compressibility, which decreases rather to 1/T at high temperature, which was also observed by the Princeton group. Thus, the T-linearity of ρ would come from this characteristic of compressibility. This conclusion would have been difficult to reach without the participation of these three research groups.

INFORMATIONS COMPLÉMENTAIRES

Brown, P. T., Mitra, D., Guardado-Sanchez, E., Nourafkan, R., Reymbaut, A., Hébert, C.-D., … Bakr, W. S. (2019). Bad metallic transport in a cold atom Fermi-Hubbard system. *Science, 363*(6425), 379 382.

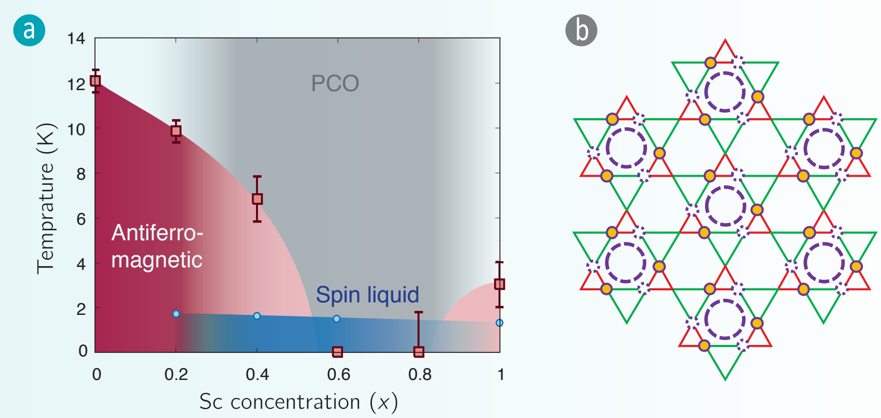
EXOTIC STATES : QUANTUM SPIN LIQUIDS

Quantum mechanics enables the emergence of many exotic states of matter. One of them, quantum spin liquid, is a fundamental state of a magnetic system where spins are highly entangled and give rise to emerging magnetic excitations. Several types of spin liquids have fractional quasi-particles called spinons: fermionic excitations that carry a spin-1/2 (such as a electron), but which do not carry any electrical charge.

Arash Akbari-Sharbaf, Aimé Verrier and professor Jeffrey Quilliam participated in the study of a series of materials, $Li_2In_{1-x}Sc_xMo_3O_8$, including an example of this surprising phase. In this case, spinons have a metallic behaviour according to the specific heat measurements, although these materials are electrical insulators.

Having studied these materials with a set of experimental techniques, the researchers suggest that it is the interaction of the degrees of spin freedom and charge on a highly frustrated network - the kagome network – that is at the origin of the spin liquid. More precisely, this family of materials can be considered as a "breathing" kagome network of molybdenum ions, where the ascending and descending triangles have two different sizes. In $Li_2In_{1-x}Sc_xMo_3O_8$ compounds, the respiratory parameter (λ), defined as the ratio of long and short binding lengths, changes non-monotonously with the concentration of Sc (x), allowing the system to change from a conventional antiferrometer for large λ to a quantum spin liquid for small λ. When λ is large, electrons are confined to small triangles forming spin-1/2 clusters on a triangular array with an antiferromagnetic exchange interaction between them, leading to a long-range antiferromagnetic order. On the other hand, when λ is small, electrons are no longer confined to individual triangles but can resonate around a hexagon, leading to a new plate charge order (PCO). Thermodynamic and spin muon rotation measurements (µSR) suggest that the PCO phase coincides with a high degree of spin frustration leading to a liquid spin. Thus, by playing on the degrees of charge freedom, it is possible to increase or decrease the magnetic frustration and thus adjust the system between a conventional state and an exotic state, i.e. the quantum spine liquid.

This research, conducted in collaboration with two research groups located in China and the United States, resulted in a paper in the journal Physical Review Letters in May 2018.



a Phase diagram for $Li_2In_{1-x}Sc_xMo_3O_8$. The dark red region shows antiferromagnetic ordering, whereas pink regions are a mix of magnetic ordering and quantum spin liquid. (b) The breathing Kagome lattice, where the triangles that point upward (red) are slightly smaller than those that point downward (green). Represented here is the plaquette charge order (PCO) which implies resonating electrons around specific hexagons.

ADDITIONAL INFORMATION

Akbari-Sharbaf, A., Sinclair, R., Verrier, A., Ziat, D., Zhou, H.D., Sun, X.F., & Quilliam, J.A. (2018). Tunable Quantum Spin Liquidity in the 1/6th-Filled Breathing Kagome Lattice. *Physical Review Letters, 120* (227201).

TECHNOLOGY TRANSFER

PHYSICIST BY TRAINING, ENTREPRENEUR BY PROFESSION

David Roy-Guay and the SB Tech team have big ideas

Most students attend Institut quantique for graduate studies or postdoctoral fellowships with the ultimate aim of a career in research or academics. Others decide to take the road less travelled: Entrepreneurship. Having completed his university studies recently, David Roy-Guay is among those who dare to launch a business project: he started SB Tech. The company specializes in the development of magnetometers based on diamond colour centres.

David Roy-Guay and his team

Photo: UdeS – Martin Blache

The technology

David Roy-Guay and his team are working on a new magnetometer, which is also known as a magnetic field sensor. Its use is widespread in the field of security, medical imaging, geology and navigation. The technology developed by SB Tech may find its use in the quality assurance of materials used in leak detection, whether in pipelines or landfills. In addition, magnetometers can also accelerate rescue operations and facilitate precise underwater navigation.

SB Tech's preferred technology is based on diamond colour centres. The founder of the business talks about its benefits: "It's a quantum technology that is appreciated because it keeps its quantum properties at room temperature. There is no need for a large dilution refrigerator to be able to use it. I'm now approaching the question of technology from the angle of an entrepreneur: cutting-edge laboratory research is unquestionably relevant, but when we take stock of what already exists, we realize that there are sensors that currently work very well. What determines the choice of a technology is how it will be used, its usage scenario. The advantage of our technology comes from the fact that it can be miniaturized while remaining very stable. It can be easily integrated into other platforms such as drones or independent robots."

David Roy-Guay
Photo: UdeS – Martin Blache

The path to entrepreneurship

According to David Roy-Guay, starting his business would not have been possible without Institut quantique's assistance and its team of engineer in the first round of prototyping. "From a strategic point of view, IQ invited me to national meetings." Not only does IQ represent a good collaborative partner to generate ideas and initiatives bringing together the expertise of physicists and engineers, but it also enables its members to open up to different professional avenues other than careers in a university setting by triggering meetings with other participants in the field, whether still studying or in business.

Counting on local entrepreneurship

One of the distinctive characteristics of SB Tech is the range of expertise of its team members. Engineering students such as Olivier Bertrand, Pierre-Luc Côté, Marc-Antoine Lalonde and Vincent Halde, contributed to the creation of magnetometer prototypes. David Roy-Guay hopes that some master's students in electrical engineering will also be part of SBTech's future.

A promising future for SBTech

As for the future of the young company, David wants to expand his team by recruiting specialists who are passionate about their fields. In the longer term, the entrepreneur would like to use his innovative technology to protect the environment while taking part in the democratization of the magnetometer in yet undeveloped fields of application.

At the end of 2021, the team will work with QMSat, in partnership with the Canadian Space Agency, to launch a miniature satellite into space. For the moment, David has put all his energy into building an agile and innovative team to continue developing new technologies while having fun doing it!

TO FIND OUT MORE
www.sbquantum.com

GENERATING RANDOM NUMBERS AND CREATING A BUSINESS

Professor Bertrand Reulet's research is focused partly on fluctuations, more commonly known as "noise." Typically, noise is seen as an element that is detrimental to the detection of a signal. It is reduced to a minimum through several consecutive measures. However, noise is not completely useless. It can, for example, provide information on particles involved in electric transportation or allow the generation of random numbers. This second property is the basis of a device developed by Pr. Reulet for commercial use in collaboration with Quantum Numbers Corporation (QNC).

This is where the technology developed by Bertrand Reulet comes into play. It directly uses the quantum property of electronic noise, a random phenomenon which allows the generation rate (in GHz) to increase very quickly.

Marketing such technology requires different types of expertise. With the help of TransferTech Sherbrooke, the Université de Sherbrooke`s technology transfer firm, Professor Reulet found a promoter to develop a win-win agreement. This led to the recruitment of Jean-Charles Phaneuf, now CEO of QNC. "As far I know, QNC is the first public high-tech company to have bought not a patent, but a Patent Cooperation Treaty (PCT), which offers applicants patent

Professor Bertrand Reulet
Photo: Michel Caron – UdeS

protection internationally. The objective is to structure technology and bring it to a high maturity level. Since then, QNC has turned this PCT application into two patents in the United States and will soon have two other patents that are the result of a patentability study in many other countries. This major accomplishment will ensure the intellectual property protection of the technology developed by QNC for years to come," explains Mr Phaneuf.

Professor Ghyslain Gagnon, who is a member of the LACIME Communications and Microelectronic Integration Laboratory at the École de technologie supérieure in Montreal, is in charge of technology development. His team is in the process of changing over from a random quantum noise generator to a random number generator. An initial application will be unveiled in the near future. A second version has already been developed and is in the debugging phase. QNC representatives hope to have the first pilot mechanism by the end of summer 2019.

"Our goal is to produce devices that can enter the global mass market. For the time being, our competitors offering "true" quantum random number generators mostly use photonics-based technology while QNC's is electronic-based. This gives us several advantages: the small size of our devices, which means potentially lower cost, excellent energy efficiency (due to advances in the field of semi-conductors) and a much easier integration with micro-electronic devices already on the market," adds Mr Phaneuf.

Marketing this technology will bring many benefits for Professor Reulet and IQ, including increased collaboration with ÉTS, several patents and many projects for graduate students.

How is a random number generated ?

Random number generation is the basis of the most common communications encryption system: The RSA cryptosystem. The RSA algorithm uses two prime numbers generated randomly, from which two keys – one public and one private – are calculated. The strength of the encryption depends directly on the nature of the random prime numbers. Many devices can generate random numbers. They fall into two categories: pseudo random number generators, based on algorithms, and "true" random number generators, based on physical phenomena. Pseudo random number generators produce number sequences that only appear random.

A pattern or repetition appears when a large enough quantity of numbers generated are considered. This pattern is completely determined by a single number – referred to as a random seed – which is used to initiate the generator. On the other hand, a "true" random number generator measures a physical phenomenon, which is thought to be random, and then compensates for possible biases in the physical measurement. Two problems must be considered in this case. The majority of phenomena used are not really random and can therefore be tackled from different angles. The random number generation rate is often very low given the measurement process.

HONOURS AND DISTINCTIONS

2018 RADIATION INSTRUMENTATION EARLY CAREER AWARD

Prestigious international recognition for Professor Jean-François Pratte

In 2001, he attended the same conference in San Diego as a master's student. This time, the conference took place in Australia and despite the years gone by, his passion remains the same. It all started in a lab where he saw human body scans for the first time accompanied by the person who would later become one of his mentors, Professor Roger Lecomte. For Professor Pratte, it's engineering to change lives and make a difference.

This prestigious prize recognizes the significant and innovative technical contributions of a young researcher who obtained his doctorate less than 10 years ago in radiation measurement and instrumentation techniques.

Professor Jean-François Pratte, with his team.
Photo: UdeS - Michel Caron

Professor Pratte's research by and large focuses on integrated circuit design, photonic detectors, electronic microsystems and 3D integrated circuit assembly for medical imaging and instrumentation for radiation detectors.

According to Jean-François Pratte, this Early Career Award "is probably the most prestigious prize that I could have won at the point where I am in my career!" The award carries a cash grant of $1,500. But it is the recognition that comes from the award that makes it so significant for the researcher.

KAMERLINGH ONNES PRIZE 2018

Professor Louis Taillefer receives a new international accolade

Louis Taillefer, professor in the Université de Sherbrooke's Department of Physics and a member of Institut quantique, is the first Canadian to receive the Kamerlingh Onnes Prize for 2018. Professor Taillefer was awarded the prize for "illuminating the nature of superconductivity in unconventional superconductors," during a ceremony held in Beijing on August 21, 2018. This honour is shared with Professor Yuji Matsuda of Kyoto University. The committee selected Professor Taillefer for "his seminal magneto-transport studies of heavy fermion and cuprate superconductors."

These seminal findings by Professor Taillefer and his colleagues advance our understanding of what makes superconductors more robust, with the ultimate aim of achieving superconductivity at room temperature, which would be a major technological revolution.

The KAMERLINGH ONNES Prize was established in 2000 by the organizers of the International Conference on the Materials and Mechanisms of Superconductivity (M2S), in honour of Professor Heike Kamerlingh Onnes, who discovered superconductivity in 1911. The prize is sponsored by Elsevier, publisher of the *Physica C – Superconductivity and its Applications* magazine. This prize is awarded in recognition of outstanding experiments which illuminate the nature of superconductivity and consists of a €7,500 cash award.

Photo: Provided

THE ROYAL SOCIETY OF CANADA PRESENTS ITS AWARDS

The Rutherford Memorial Medal in Physics for Alexandre Blais

Professor at the Physics Department and Scientific Director of the Institut quantique at the Université de Sherbrooke, Alexandre Blais is the recipient of the Rutherford Memorial Medal in Physics awarded annually by the Royal Society of Canada (RSC) in recognition of eminent research projects in any area related to physics.

"It's a great recognition and I'm honoured to see my name added to the list of people who've contributed significantly to the progress of physics. They would undoubtedly tell you the same thing as me, which is that the work leading to this distinction is not done alone. It's the sum of all the efforts of an entire team. So, this Rutherford medal is also for my team members," says Professor Blais.

Professor Blais' scientific achievements are many, but the most striking is his contribution to the development of *circuit quantum electrodynamics* as he is an author of the seminal article in the field, *Cavity quantum electrodynamics for superconducting electrical circuits: An architecture for quantum computation*.

Rutherford Memorial Medal of the Royal Society of Canada

The Rutherford Medal is awarded annually by the Royal Society of Canada in memory of Professor Ernest Rutherford. A physicist and chemist born in New Zealand, Professor Rutherford spent part of his career at McGill University. Since his discoveries were made when he was relatively young, the RSC favours young researchers for this award in recognition of outstanding research in any field of physics.

RELÈVE ÉTOILE AWARD LOUIS-BERLINGUET MARCH 2019

Baptiste Royer
Photo: IQ

Baptiste Royer

Award-winning publication:
Itinerant microwave photon detector

Published in:
Physical Review Letters

At the turn of the last century, Albert Einstein argued that light is made up of clearly defined packets of energy: photons. A few decades later, the ability to detect single photons revolutionized several aspects of modern physics, from the infinitely small to the infinitely large. In his paper, Baptiste Royer sets out an innovative method to measure single microwave photons, which was previously only possible for photons of visible light. The detector will serve a range of applications, from quantum computing to dark matter detection.

ADRIEN-POULIOT AWARD

Laurence Haguenauer, Consulate General of France in Quebec, and Louis Taillefer, recipient of the ACFAS Adrien-Pouliot 2018 Award
Photo: ACFAS – Hombelhne Duma

The ACFAS highlights Louis Taillefer's collaborations with France

This year, the Adrien-Pouliot Award from the ACFAS (Association francophone pour le savoir) highlighting the scientific cooperation with France was awarded to IQ member Professor Louis Taillefer of the Physics Department at the Université de Sherbrooke. The award was presented at the 74th Annual Gala held in Montreal on November 13, 2018. Recognized for his work on superconductors and other quantum materials, Louis Taillefer has increased collaborations with French researchers and research centres since his arrival in Sherbrooke in 2002. He has also contributed to the training of several young researchers from French institutions.

"This award," adds the researcher, "highlights the importance of research collaboration and the fruitful partnerships we have here at the Université de Sherbrooke with French researchers." The collaboration between Cyril Proust and Louis Taillefer is at the heart of the CNRS's 2017 creation of a new International Associated Laboratory (LIA) between Sherbrooke and several laboratories in France.

SCIENTIFIC POPULARIZATION AWARD

Sekou-Oumar Kaba
Photo: UdeS - Michel Caron

Sekou-Oumar Kaba, recipient of the Scientific Popularization Award from the ACFAS

Interest in scientific popularization is at the heart of Sekou-Oumar's passion for science. His long list of contributions includes hosting "Les Débrouillards" for a summer, co-hosting a radio program on CFAK and CISM—UdeS and UdeM's university radio stations, organizing various conferences, and creating an audio segment on the extraordinary properties of superconductors. This last project was awarded the Scientific Popularization Award by the ACFAS during its 2018 congress. Masters student under the supervision of David Sénéchal, Sekou-Oumar probes the superconductivity of strontium ruthenate using state-of-the-art numerical methods. Explaining his research in a short audio format that is accessible to all is a feat in itself. We congratulate him greatly for his well-deserved award!

2018 INSPIRATION AWARD

Christian Sarra-Bournet with Vice-Rector for Human Ressources, Pr Jean Goulet and the President, Pr Pierre Cossette.

Photo: UdeS

Christian Sarra-Bournet, Executive Director of IQ, recipient of the Professional Engagement Award in the University Community

The UdeS community is invited every year to submit nominations for the Inspiration Award. These nominations celebrate staff members who are charitably involved and have a major impact in the university community.

The awarding of the Professional Engagement Award in the University Community to the Executive Director of the Institut quantique underlines the growing place of our institute within the UdeS, and its influence at a local, national, and international level.

TEACHING AWARD

Pr Garate with the Dean of Sciences, Pre Carole Beaulieu, the Vice-Rector of Studies, Pre Christine Hudon and the President Pr Pierre Cossette.

Photo: UdeS - Michel Caron

Professor Ion Garate, recipient of the Recognition Award for Teaching Quality from the Faculty of Sciences

Professor Ion Garate, from the Department of Physics and member of the Institut quantique, received the Recognition Award for Teaching Quality from the Faculty of Sciences. Professor Garate has distinguished himself in many ways within university education. He has taught at all three university levels and his evaluations by his students are exceptional in each of his courses.

Professor Garate is also recognized for his training of highly qualified research personnel. Since the beginning of his academic career in 2013, he has supervised the research work of many students and fellows at the undergraduate, graduate, and postdoctoral levels. Many students under Professor Garate's supervision consider him a mentor, and have obtained competitive scholarships from large organizations.

COLLABORATIONS AND PARTNERSHIPS

OPENING OUR DOORS TO OTHER PLAYERS IN THE CANADIAN ECOSYSTEM – NRC

National Research Council Canada | Conseil national de recherches Canada

The National Research Council of Canada (NRC) and UdeS have signed a Memorandum of Understanding to explore potential collaborations and develop research projects under four themes: quantum information; correction of errors and algorithms; photonic integration; and photonic quantum sensors. Similarly, both partners want to improve their training offerings as well as their awareness activities in quantum and photonic science.

This partnership is yielding tangible results. The first is the appointment as an adjunct professor of four NRC researchers, including three women: Alicia Kam, PhD (nanofabrication); Madeline Lee, PhD (magnetic detection); Li-Lin Tay, PhD (sensors); and Louis Gaudreau, PhD (electronics and quantum photonics).

This partnership has also given way to a collaboration of the Institut quantique within the Quantum Security Technology Access Centre (QSTAC). This centre was established by the NRC, Defence Research and Development Canada and the Communications Security Establishment to help coordinate and strengthen the government's internal research efforts in quantum science and technology related public policy issues.

PARTICIPATING IN INTERNATIONAL EFFORTS – OPENSUPERQ

IQ's Scientific Director Alexandre Blais has been named co-chair of the OpenSuperQ basic science group, one of 20 projects funded by the European Quantum Flagship. This consortium of 10 international academic and industrial partners aims to design, build, and operate a 100 qubit quantum processor on the cloud. This quantum information processing system, physically located at Forschungszentrum Jülich (FZJ) in Germany, will be made available to external users via a central website.

The European Quantum Flagship was launched in 2018 and is one of the most ambitious research initiatives put forward in the European Union. With a budget of one billion euros over 10 years, this project aims to consolidate and expand Europe's leadership in the quantum field, as well as drive the transition of science to the market through commercial applications and disruptive technologies.

COLLABORATIVE QUANTUM PROJECTS

Joint research initiative undertaken by the Université de Sherbrooke, the University of British Columbia, and the University of Waterloo

Three of Canada's most recognized research centres for information and quantum materials undertook five joint research projects starting in March 2019.

Projects were solicited and selected in a concerted effort by the Stewart Blusson Quantum Matter Institute (SBQMI) at the University of British Columbia, the technology development program Transformative Quantum Technologies (TQT) at the University of Waterloo, and the Institut quantique (IQ) at the Université de Sherbrooke. The three centres are all recipients of funding from the Canada First Research Excellence Fund.

Each quantum research projects aims to accelerate scientific breakthroughs by leveraging highly specialized equipment and expertise from institutions over the next two years.

Opportunities through complementarity

“There are amazing opportunities at the interfaces of research efforts,” said Professor David Cory, Principal Investigator of TQT. “These joint research projects build on the complementarity of the three quantum CFREF programs, extending the reach of their accomplishments and speeding development. Through these projects we will see new quantum materials connected to quantum devices, new theories of quantum control leading to broader quantum applications, and the expertise of all three centres directed at solving the challenge of noise, which stands in the way of useful, general-purpose quantum computation.”

Final proposals were selected based on scientific significance and timelines with results expected within two years. Headed by collaborative networks of investigators among the three centres, each proposal makes use of knowledge, technical resources, and infrastructure unique to each centre.

Uniting forces

The breadth and range of investigative approaches highlights future potential for advanced research among collaborating institutions across Canada. The model offered by this joint-institutional effort is potentially one that could be used to map networks of resources among quantum institutions around the world.

“I am very excited about these new collaborative efforts,” said Professor Andrea Damascelli, Scientific Director at SBQMI. “Bringing together our strengths will advance Canada’s position as a global leader in quantum materials and technologies.”

Professor Alexandre Blais, Scientific Director at IQ agrees, “Working together on breakthrough quantum science benefits not only the scientific outcomes but also the training of the quantum technology leaders for Canada and the world.”

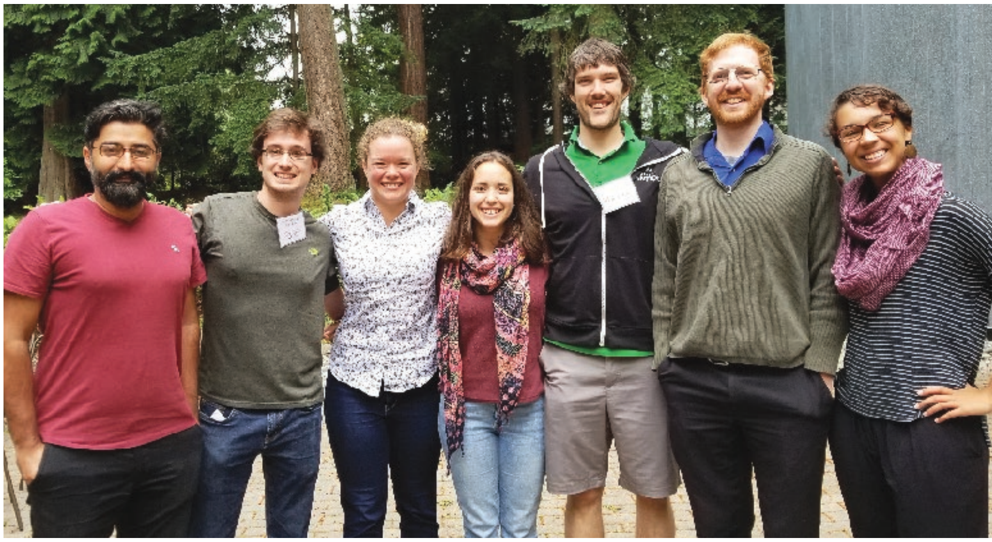
The three CFREF institutions plan to cooperate on future endeavours together, including the making of a quantum collaborative laboratory in support of a proposed national quantum strategy.

OUTREACH AND TRAINING

CANADIAN GRADUATE QUANTUM CONFERENCE - CGQC

June 20 to 22, 2018

The very first edition of this student conference—which aims to connect Canada's quantum communities and promote scientific collaborations and networking—took place on the UBC campus last summer. The conference was co-hosted by student members from three institutions via the Canada First Research Excellence Fund: *Institut quantique (IQ), Stewart Blusson Quantum Matter Institute (SBQMI), and Transformative Quantum Technologies (TQT)*. Participants had the chance to meet some of Canada's quantum industry leaders, as well as share their work with their peers. This first edition is an important step in the creation of a quantum research ecosystem in Canada. The organizing committee wants this conference to become a staple and evolve to reflect the needs of the quantum student community.



CGQC 2018 Organizing Committee: Mohamad Nikman, Étienne Lantagne-Hurtubise, Madelaine Liddy, Sara Turcotte, Karl Thibault, Thomas Baker, Maude Lizaire

Photo: Provided

A GREAT SUCCESS FOR A UNIFYING WORKSHOP

An International Scientific Workshop - New directions in quantum error correction

April 2018, Professor David Poulin organized a workshop on *New Directions in Quantum Error Correction*. This workshop brought together leading international experts in theoretical quantum information, who teamed up with IQ researchers to address some of the field's many challenges. More than twenty participating students were able to take advantage of these moments to discuss with the visiting researchers.

In addition to this research component, the event offered a series of educational courses on cutting-edge topics in theoretical quantum computing.

Presenters and topics included:

Michael Beverland (Microsoft) — Color quantum codes

Benjamin Brown (Sydney) — Self-correcting quantum memories

Guillaume Dauphinais (Madrid) — Decoding topological codes

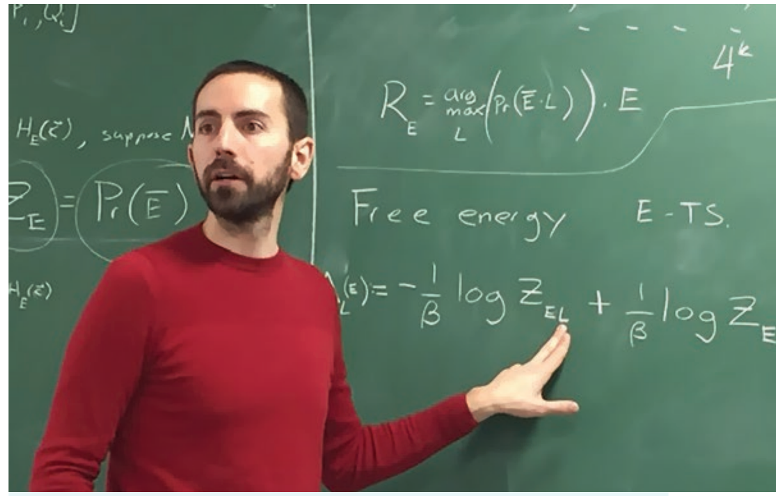
Steven Flammia (Sydney) — Statistical physics of quantum error correction

Tomas Jochym-O'Connor (Caltech) — Scattered quantum codes

Aleksander Kubica (Perimeter Institute) — Topological order stability

Fernando Pastawski (Berlin)— Quantum holographic codes

Theodore Yoder (IBM) — Approximate error correction



Steven Flammia
Photo: David Poulin

In the course he presented, Steven Flammia discussed the connection between statistical physics and quantum error correction – the physics of large numbers of interacting systems and the science of fixing bugs in quantum information processors. "These types of events are important for at least two reasons. First, the students benefit from interacting with and learning from experts. Having several experts lecture on topics inevitably leads to ideas being explained in several different ways, and in my experience, this is invaluable to enhancing student understanding. Second, having a small number of experts together to have a focused workshop is great because we all speak a common language. My favorite part of the workshop has been meeting some of the bright students and postdocs that work on topics in quantum information at Sherbrooke."

SCIENTIFIC WORKSHOP: SPIN CANADA

The second edition of the Spin Canada workshop was held in Calgary in July 2018, bringing together more than 40 people, including Canadian researchers, industry and government members with a research interest in quantum devices based on spin. Spin qubits are prime candidates for the quantum computer race and Canada has renowned expertise in the field.

Several activities were organized during this gathering, including scientific presentations, an industrial round table, and small thematic group discussions. A Canadian vision of research in this field is emerging thanks to these events, so don't miss the next one in 2020!

Participants at the Spin Canada workshop.
Photo: Provided

INTERNATIONAL SUMMER SCHOOL ON COMPUTATIONAL QUANTUM MATERIALS

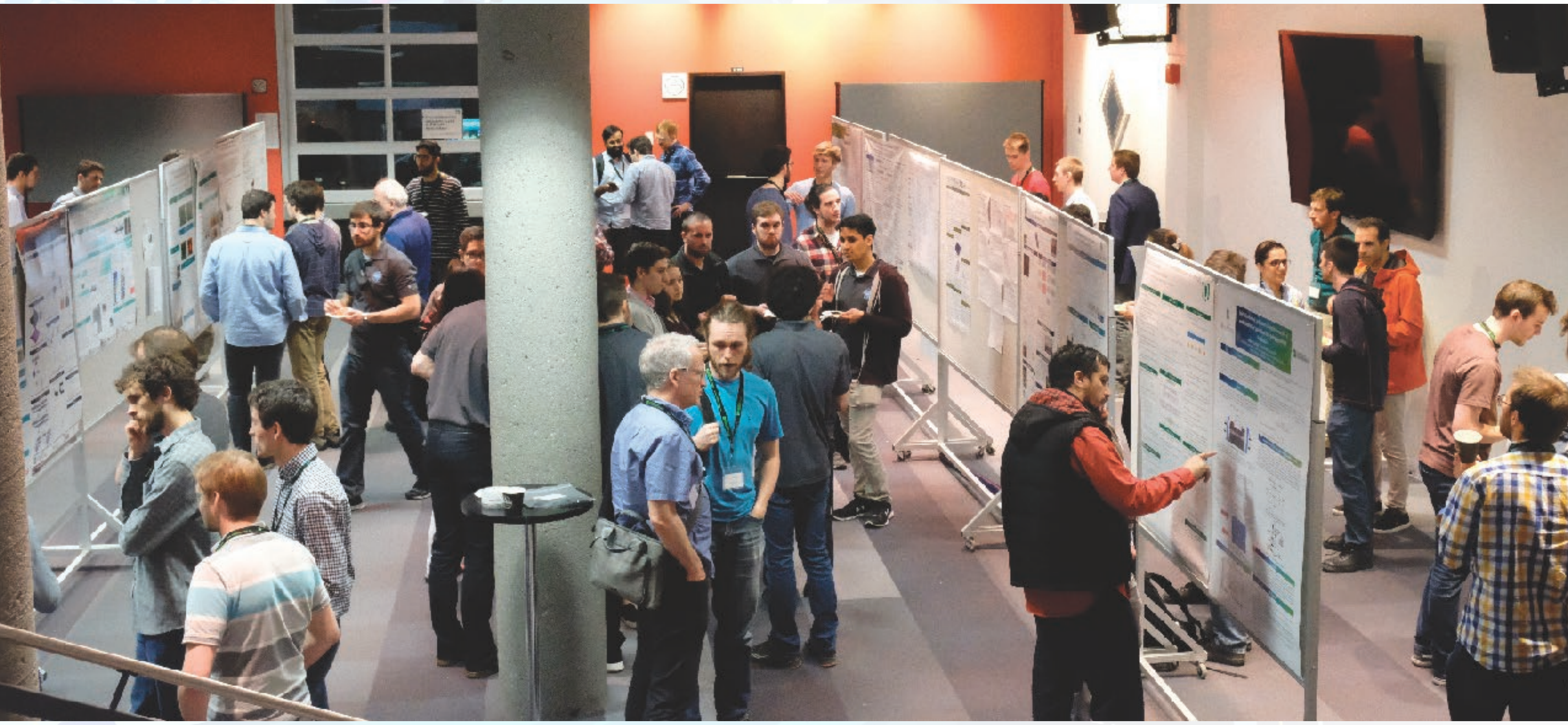
May 27 to June 8, 2018 - Centre de villégiature Jouvence - Quebec

The Second Edition of the International Summer School on Computational Quantum Materials was held at Jouvence's enchanting site, near the Institut quantique. World-renowned professors—many of whom invented the methods taught at school—and their students were brought together to increase participants' ability to apply numerical methods to their research problems. 60 participants took part in the event and shared a memorable learning experience.

Summer School Workshop
Photo: Provided

ANNUAL COLLOQUIUM 2018 – MAY 4, 2018

The second edition of this annual conference, organized by Eva Dupont-Ferrier, Ion Garate, and André-Marie Tremblay, took place on May 4, 2018. Institut quantique hosted close to 150 participants from the student community, faculty, and administrative staff. The event focused on sharing information and provided updates on both past and ongoing projects. Participants had the opportunity to present research projects, announce student initiatives, discover new IQ initiatives, and learn about job offers and fellowships.



2018 Annual Colloquium
Photo: IQ

IQ POSTDOCTORAL FELLOWSHIP PROGRAM

CLÉMENT GODFRIN

Clément Godfrin is a postdoctoral fellow at IQ under the direction of Professors Eva Dupont-Ferrier and Michel Pioro-Ladrière. His academic career began in Brest, France, where he was born. He moved to Paris for a master’s degree, and then Grenoble for a doctorate at the Institut Néel.

At IQ, he focuses on spins in silicon-based structures, specifically on the interaction between these spins and photons, to produce quantum information protocols. He is enthusiastic about experiments based on theories of precursors such as Einstein, Schrödinger, or Planck: "Thanks to the development of experimental techniques (cryogenics, nanofabrication, electronics, etc.), it is now possible to create systems that strongly resemble the thought experiments devised by the founders of quantum mechanics over a hundred years ago. I like to carry out these so-called toy model experiments which involve a very small number of components (atom, photon, etc.) and gain an in-depth understanding of the fundamental mechanisms of quantum mechanics."

Why choose Sherbrooke?

Clément Godfrin explains that a combination of several factors led him to choose the Institut quantique. His first contact with Sherbrooke happened seven years ago through a fellowship in Michel Pioro-Ladrière's group. During this first visit, Clément Godfrin noticed a working atmosphere that pleased him, an aspect he views as important to research. Later, during a visit to the Institut quantique, he got better acquainted with the team and was impressed by their expertise and skills in quantum physics.

"After a doctorate, it is essential to find a dynamic place in which we can enjoy great freedom, and that's what I found here," he says. Quebec's wide-open natural spaces was the final argument that convinced the outdoors enthusiast to settle in the Estrie region.

What’s next?

When asked "What are your professional intentions after your stay at the IQ?," Clément Godfrin answers without hesitation: "I would like to continue in research. I'm thinking of doing another postdoctoral fellowship to continue learning experimental techniques to probe and play more efficiently with quantum systems. Many teams around the world are currently working on systems that link spin and superconducting circuits, and I would like to continue on this path."

ALEXANDRU PETRESCU

Starting a research career is sometimes synonymous with displacement. Alexandru Petrescu, a postdoctoral fellow at IQ, went through this at 18. He moved from Romania to New Jersey to study Physics at Princeton University on a scholarship he obtained by taking part in Physics Olympiads. He had to shift from Romanian to English, a language he learned in his pre-university studies.

He then pursued doctoral studies at Yale University under the supervision of Professor Karyn Le Hur. Following Professor Karyn Le Hur's departure for the École Polytechnique, Alexandru Petrescu decided to finish his PhD in co-supervision, Paris–Yale. It was the first French immersion for the postdoctoral fellow who adamantly practiced the language on a daily basis during his PhD. It is as if, from that moment on, the path towards Sherbrooke began to reveal itself to him little by little. Professor Le Hur discussed the University of Sherbrooke with her student, sharing her personal experience of becoming the first woman to hold a position as Professor of Physics there. "I also knew that Sherbrooke is a very prominent university centre in our field. Excellent publications come from Sherbrooke. For example, I had the opportunity during my PhD to study articles written by Professors Blais, Sénéchal, and Tremblay. Moreover, I met Professor Garate when he was a postdoctoral fellow at Yale," says Alexandru Petrescu.

On a personal level, the arrival in Quebec was just as natural. "My wife and I are Europeans, and for us, there are obvious commonalities with Quebec, with the region, particularly in terms of culture. It is a very welcoming environment, nature is nearby, we are really fortunate."

From a scientific point of view

By obtaining the prestigious IQ Postdoctoral Fellowship, Alexandru joined Professor Blais' group. "I mainly work on the dynamics of quantum systems in superconducting circuits. Our goal is to find analytical methods to better understand the sources of decoherence in these systems and to know how to maintain quantum information in order to give experimenters guidance on the best way to manipulate their systems. Under the guidance of Alexandre Blais, I also became interested in quantum states called "Schrödinger's cats" for quantum error correction. All these projects are interrelated and that's what makes my stay in Sherbrooke so stimulating."

Attracted by IQ because of the possibilities of collaborating and being at the interface of various fields of physics, the postdoctoral fellow is involved in different research projects. "I also contribute to research projects with Professor Garate and Professor Le Hur in a completely different field, dealing with quantum simulation. We tackle a problem posed by Richard Feynman 40 years ago, that is to say, the impossibility of using conventional tools to simulate and understand a complex quantum system and the need to use quantum systems to do so. How does one duplicate a physical system to study its properties, a copy that can give information on the original? This is what I do with Ion and Karyn by studying Majorana fermions in quantum scales."

After the postdoctoral fellowship?

Alexandru Petrescu believes that so far, he has achieved his professional goals by doing his postdoctoral fellowship at the IQ, both because of the freedom that is afforded to him and of the quality of the people with whom he collaborates.

Although the fellowship is not over yet, he must still think about the next step, "My goal is to stay in academia, I hope to teach and do research. I am fascinated by our field, by the quality of the work that is done. I like playing with ideas, sharing them with colleagues, whether theorists or experimenters. For researchers, ideas are a bit like our currency. And who knows, maybe we'll see practical applications take shape thanks to our research." We wish him the best, and hope he will one day see applications derived from his work.

RYAN FOOTE

The path that leads to Sherbrooke

Originally from Bedford, New Hampshire, Ryan Foote is currently a postdoctoral fellow at the Institut quantique. After completing his undergraduate degree at the Massachusetts Institute of Technology (MIT) in Cambridge, Ryan spent a year working in a laboratory as a technical instructor. He then pursued higher education at the University of Wisconsin–Madison from 2012 to 2018. He arrived in Sherbrooke in August 2018 to work in Professor Michel Pioro-Ladrière's group.

How does one go from Wisconsin to the Estrie region? "During my studies, I met many people who worked here and read their publications—I even read Professor Pioro-Ladrière's publications before he was a professor. Even though my knowledge of the university and city was limited, I knew that there was something interesting happening in terms of quantum science," explains Ryan Foote, who also appreciates the fact that being in Sherbrooke means he is only 300 km from a meal with his family.

New challenges

During his graduate studies, Ryan Foote focused his research on quantum computing in silicon/silicon-germanium heterostructures. As a postdoctoral fellow, he is now working on silicon. As the physicist himself says:

"I'm trying to gather and simplify all the knowledge and expertise that the semiconductor community has accumulated over the years to different kinds of microchips that work very quickly and to see what we can do to integrate that into the development of a quantum computer. My research project fits in by focusing specifically on the co-integration of classical hardware with quantum systems. As my project progresses, I try to develop different small circuits to enable more advanced measurements while operating at extremely low temperatures."

This project will pioneer the construction of a mini-computer that could fit in a quantum computer to enable it to process information faster and send a higher-level signal in a refrigerator.

Diversified expertise

Once the measurements of Ryan's experiments begin, the physicist will start to benefit from his collaborative work with the electrical engineers at the Interdisciplinary Institute for Technological Innovation - 3IT. The main advantage of doing research in Sherbrooke is the proximity and variety of experts and resources.

"I'm pretty sure that once I start getting results and integrate these devices, my engineering friends will be quite useful. Similarly, when I try to go from the first to the second version of my chip, all the expertise available here will be a huge advantage. Without all this additional support, I might not have been able to start this project or it probably would have taken me three times longer."

Ryan goes on to add: "We cannot manufacture quantum computers without integrating fields other than physics. What I like about IQ is that this philosophy is widely shared by its members."

This multidisciplinary approach is precisely what attracts so many on the path that leads to Sherbrooke.

MATHIEU MASSICOTTE

Playing quantum Lego blocks

Originally from Drummondville, Mathieu Massicotte travelled a long way to get to Sherbrooke. From labs in Montreal to Barcelona, including an incursion into the world of start-ups, he finally chose to come at the Institut quantique to do a postdoctoral internship. Fascinated by 2D materials such as graphene, Mathieu is exploring their potential in the field of quantum technologies. To achieve this, he says, “You have to learn to play with Lego blocks the size of an atom”.

From Montreal to Barcelona

First hesitating between engineering and physics, Mathieu decided to choose engineering physics at Polytechnique Montréal, where he completed his bachelor’s degree. He then went on to complete a master’s degree in physics at McGill University, where he began to study graphene, a material with exceptional physical properties. “And of great beauty!” adds Mathieu, referring to the flakes he synthesizes on copper.

He then moved to Barcelona, Spain, where he completed his PhD in photonics at the Institute of Photonic Sciences (ICFO). During his thesis, he sought to understand how graphene and other 2D materials convert the light they absorb into electricity. “This process is extremely fast; it takes only a few picoseconds,” says Mathieu. This work, he hopes, will pave the way for a new generation of ultra-fast photodetectors based on 2D materials.

A passion for two-dimensional design

Mathieu is passionate about everything related to 2D materials. “The exciting thing about these materials is that they can be stacked on top of each other, one atomic layer at a time, to create artificial materials with completely new properties. For the physicist, the design of these heterostructures is similar to playing with a quantum and atomic version of Lego blocks. “At this scale, the blocks interact in a complex way and under the right conditions, new properties can emerge,” explains Mr Massicotte, who cites the example of superconductivity in graphene offset by a magic angle. “A heterostructure is more than the sum of its layers”.

An entrepreneurial detour

Since he completed his doctorate, Mathieu Massicotte has been exploring other avenues outside of academic research. He is interested in the process of commercializing innovations, that is, “how an invention moves from the laboratory to the marketplace”. Back in Quebec, he joined the team at TandemLaunch, a start-up business incubator that helps researchers identify promising technologies to launch companies. Alongside his team, Mathieu co-founded Edgehog, a company specializing in anti-reflective solutions for displays and other opto-electronic devices.

A return to the source

For the moment, Mathieu is mainly working on two projects combining 2D materials and quantum technologies. “The first is to use 2D materials to develop a quantum light emitting diode capable of emitting unique photons, while the second uses quantum technology, superconducting resonators, to study 2D materials,” he explains.

SANGHITA SENGUPTA

Sanghita Sengupta saw an offer for a prestigious postdoctoral fellowship from the Institut quantique. She submitted her candidacy and was subsequently invited to present her research at IQ in Sherbrooke. She made the trip in February 2018 to present Quantum Many-Body Interaction Effects in Two-Dimensional Materials to IQ members.

She then received a positive response from the selection board for the postdoctoral fellows. For Sanghita Sengupta, IQ`s research environment perfectly met her expectations. "I was very interested in this scholarship because it emphasizes independence and also allows you to collaborate with other teachers to learn."

During her first visit to Sherbrooke, she also had the opportunity to meet Professor Ion Garate. "I liked him very much; he is humble and very aware of the recent developments in physics, which convinced me to join his group when I learned that I had been selected." Our postdoctoral fellow is confident she made the right choice, "Professor Garate has excellent leadership qualities."

Accustomed to changes

Our postdoctoral student was born in Calcutta where she completed her undergraduate studies and her masters degree in physics. Always curious about how things work, Sanghita travelled 12,000 km from Calcutta to Burlington, Vermont, where she pursued her doctoral studies at the University of Vermont.

Her initial project was to become an experimentalist and develop thin layers in materials such as graphene, a relatively new field of science that earned André Geim and Konstantin Novoselov, both from the University of Manchester in the United Kingdom, the Nobel Prize in Physics in 2010. "That's why I came to Vermont - there was a teacher I really wanted to work with. In the year that followed my doctoral studies, I went from experimentation to theory. I did not plan for this but I ended up becoming a theoretical physicist. I think that my professors from the University of Vermont found me well suited for theory because I always asked too many questions in the experiments. At first, the transition from experimentation to theory was very difficult because I had to put a mathematical structure to the questions I asked. In retrospect, what I found difficult at the time is now something that I enjoy," Sanghita Sengupta says.

Current projects

Always ready to explore new paths, she set out to discover topology. "Most of my doctoral work was on quantum materials related to 2D materials, such as graphene. Professor Garate is conducting a project where he wants to hear the sound of the topology of electrons. This is a new field for me. This project is very interesting because we are developing a theory that combines ideas from semi-classical physics, statistical physics, and quantum field theory. I can also contribute to this project with some of my knowledge on phonon physics; this is a quantum of vibrational energy in a crystalline solid."

Future projects

Sanghita Sengupta would like to pursue a university career but she is well aware that only a small minority of people ever get there. "From this perspective, I know that the coming year will be crucial, and I will put all my energy and efforts into making the most of the expertise available at IQ and the great opportunities for collaboration."

IQ IN NUMBERS

April 1, 2018 to March 31, 2019

26 Professors-Researchers

138 Graduate Students

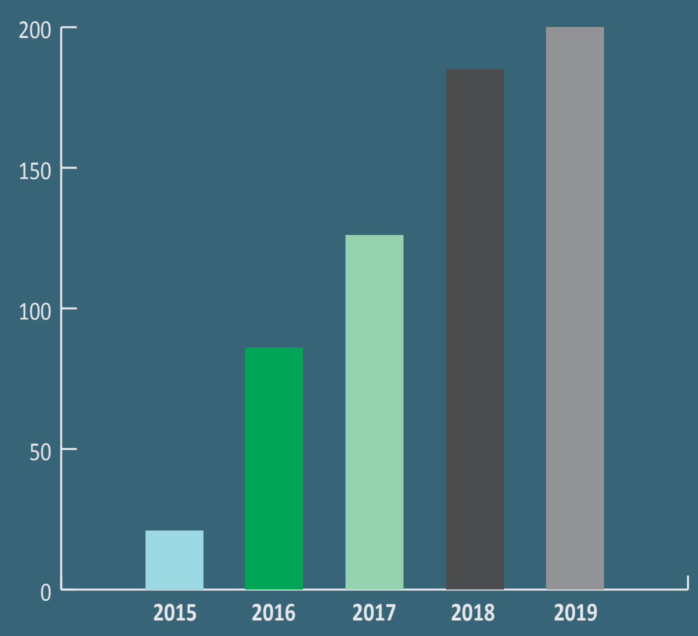
37 Postdocs

22 Research Staff

67 Publications

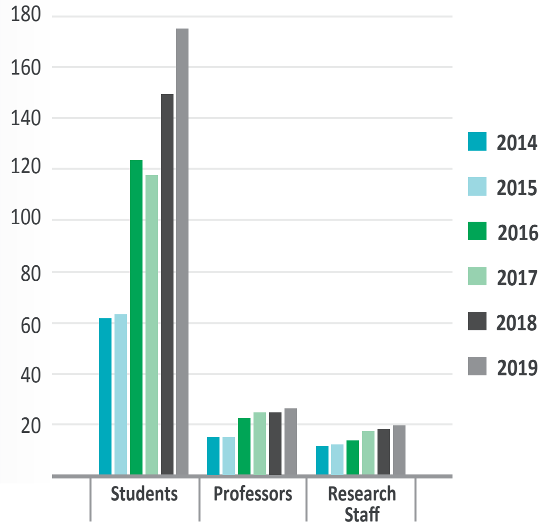
6 Adjunct Professors

Seminars



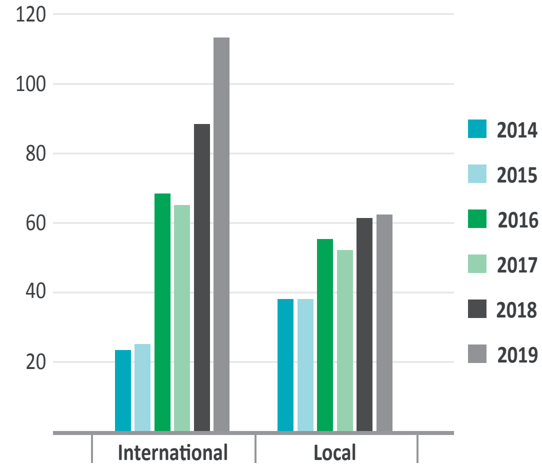
Recruiting and retaining the best researchers in the world is a priority for the Institut quantique. The chart shows the increase in all types of researchers for the fiscal years 2014 to 2019.

IQ workforce



Number of professors, technical and professional staff, postdoctoral fellows, and students

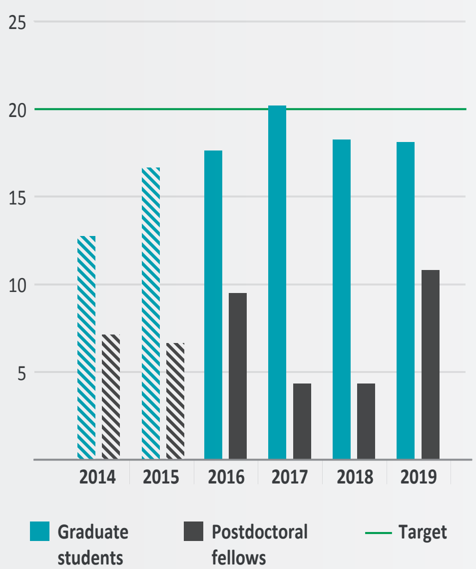
IQ students



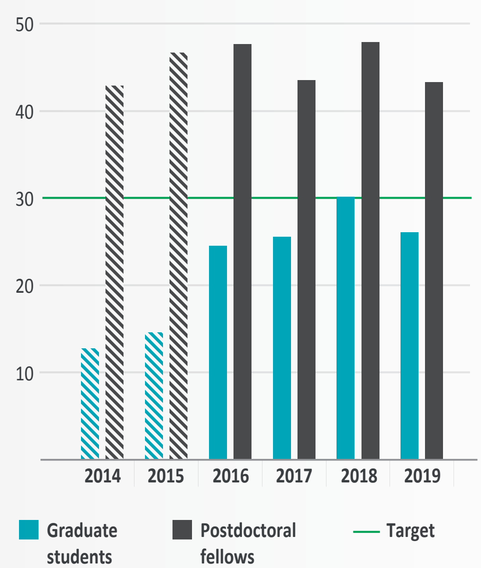
Students' origins

EQUITY, DIVERSITY, AND INCLUSION AT IQ

% of women

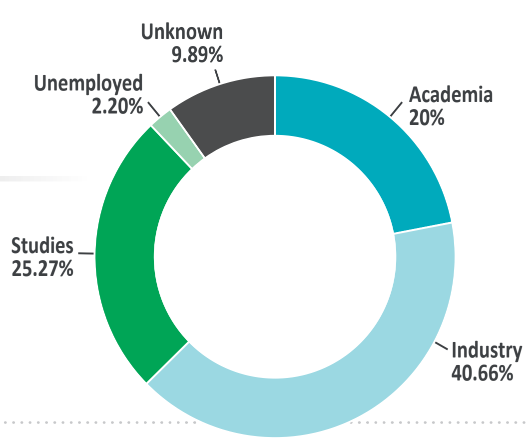


% of visible minorities at IQ

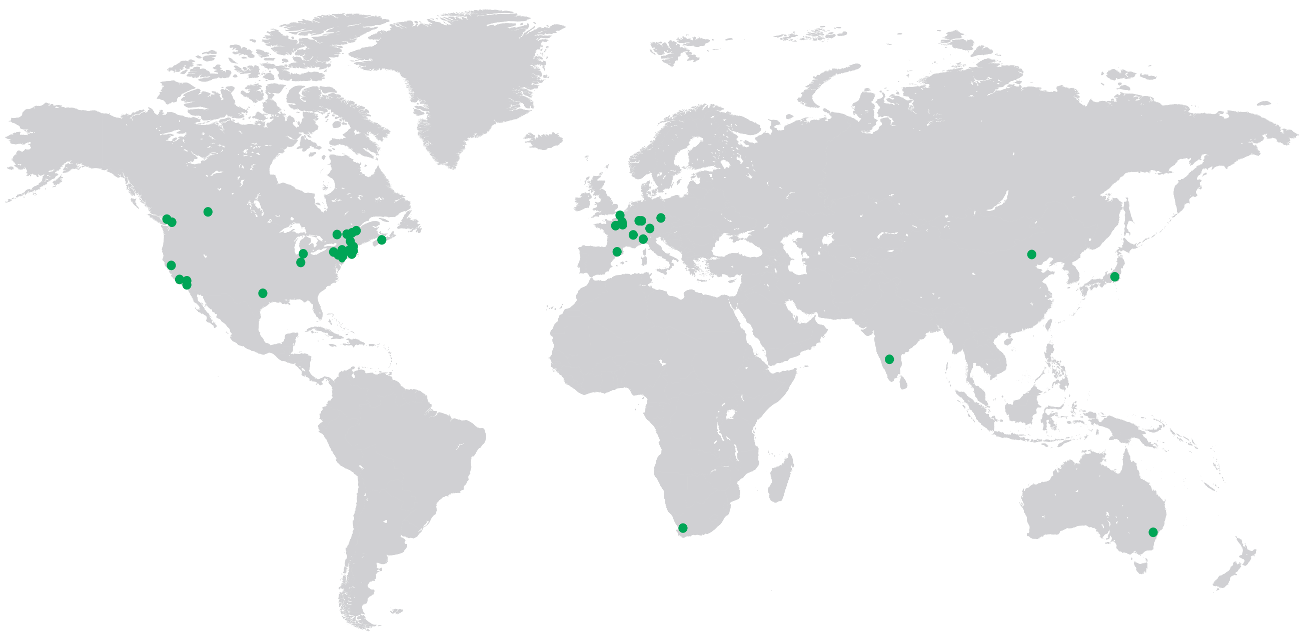


Alumni occupation

(166 students in 3 years)



VISITORS AT IQ



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Alex Maloney, Dept of Physics, McGill University, Canada

MEMBERS - RESEARCH THEMES AND OBJECTIVES

Alexandre Blais
Physics Department
Scientific Director
Quantum Information

- Large bandwidth single microwave photon detection
- Development of novel high-fidelity entangling gates for superconducting qubits
- Development of a superconducting quantum computer architecture based on cat-state encoding
- Development of novel applications for small-scale quantum computers
- Machine learning-aided design of quantum devices

Michel Pioro-Ladrière
Physics Department
Deputy Director
Quantum Information

- Develop a spin qubit using an industrial solution
- Create a one-dimensional semiconductor of atomic size
- Measure the influence of synthetic spin-orbit coupling on the gyromagnetic factor
- Characterize the consistent control of a set of spins operating at room temperature
- Produce a CCD device in the quantum limit
- Study the feasibility of a new approach for efficient quantum computation in material resources

Yves Bérubé-Lauzière
Department of Electrical and Computer Engineering
Quantum Engineering

- Develop a protocol for feedback control of the state of a double quantum dot spin qubit
- Complete the development of a feedback control protocol to prepare and stabilize cavity quantum state superpositions
- Develop optimized excitation pulses for ultra-sensitive magnetic resonance characterization of quantum materials
- Develop a quantum circuit compiler for an ion trap computer

Claude Bourbonnais
Physics Department
Quantum Materials

- Publication of work on the application of the renormalization group to low-dimensional quantum critical systems under the influence of doping
- Publication of work on the Seebeck effect theory in strongly correlated low-dimensional systems

Vincent Aimez
Department of Electrical and Computer Engineering
Quantum Engineering

- Development of advanced micro-nanofabrication methods for heterogeneous materials

François Boone
Department of Electrical and Computer Engineering
Quantum Engineering

- Design, fabrication, and characterization of micro-machined passive components
- Design and development of MMIC
- THz component
- Characterization of concretes via microwave measurements

Serge Charlebois
Department of Electrical and Computer Engineering
Quantum Engineering

- Quantum cryptography: exploitation of high temporal resolution to increase the reliability of quantum communication protocols
- Production of VUV-visible entangled photons for the characterization of photodetectors in the VUV range

Paul Charrette
Computer Science
Quantum Engineering

- Production of nanoplasmonic antennae coupled to NV centres
- Production of devices exhibiting surface acoustic waves for coherent optomechanical coupling of microwave photons to telecom photons
- Production of ultra-low-loss waveguides for embedded quantum photonics on a chip

René Côté
Physics Department
Quantum Materials

- Study of collective electron states in graphene multilayers
- Study of the phase diagram of the electron gas in a spatially modulated potential
- Study of topological optical properties of Weyl semimetals
- Study of orbital skyrmions in the graphene bilayer

Dominique Drouin
Department of Electrical and Computer Engineering
Quantum Engineering

- Automatic detection of the electronic regime for a spin qubit using artificial intelligence
- Development of a manufacturing process for spin qubits on silicon at 3IT.nano
- Control spin qubits using cointegration of resistive memories

Éva Dupont-Ferrier
Physics Department
Quantum Information

- Establishment of quantum protocols with microelectronic devices
- Develop MOS qubits with microelectronic transistors
- Interfacing dopants with superconducting circuits
- Develop spin qubits with dopants in MOS transistors
- Manufacturing of single dopant MOS transistors with the 3IT platform

Patrick Fournier
Physics Department
Quantum Materials

- Study of the nonlinear Hall effect in cuprates and related materials
- Study of the Little–Parks effect in high temperature superconductors
- Develop selective epitaxy on substrates for oxides
- Interfaces in oxide-based heterostructures
- Development and study of the magnetocaloric properties of quantum materials
- Demonstration of the rotating magnetocaloric effect

Ion Garate Aramberri
Physics Department
Quantum Materials

- Find new optical and acoustic signatures of topological invariants in quantum materials
- Develop optimization algorithms for devices exhibiting Majorana modes
- Design new quantum devices based on manipulation and control of topological invariants

Max Hofheinz
Department of Electrical and Computer Engineering
Quantum Engineering

- Development of a microwave photomultiplier
- Demonstration of a limited quantum microwave amplifier with dc power supply
- Development of a theoretical framework for Josephson photonic devices
- Exploration of non-reciprocal devices based on Josephson photonics
- Realization of low noise dc bias circuits (nV rms)

Denis Morris
Physics Department
Quantum Materials and Quantum Engineering

- Study of spin defects in wide-gap semiconductor materials such as AlN, h-BN and diamond
- Study of coupling between plasmonic structures and photon emitters associated with luminescent defects in semiconductor materials with wide-gap
- Study of electronic transport properties in nanowires and other semiconductor structures with volume or surface defects (porous structure, graphene, implanted materials, etc.)
- Ultrafast dynamics of superdiffusion and heat transfer phenomena in plasmonic structures

David Poulin
Physics Department
Quantum Information

- Discover a new quantum algorithm
- Strengthen our industrial links
- Discover new error-correcting codes using a smaller number of qubits
- Deepen our fundamental knowledge of physics

Jean-François Pratte
Department of Electrical and Computer Engineering
Quantum Engineering

- Implement vertically integrated (3D) single photon avalanche diodes
- Production of an integrated circuit for the temporal distribution of quantum keys
- Development of a very low power acquisition and control system for electronic spin qubits

Jeffrey Quilliam
Physics Department
Quantum Materials

- Reveal Majorana fermions in spin liquids
- Use hydrostatic pressure to induce new magnetic states
- Develop new measurement techniques that allow us to study thin layers or surfaces
- Study Weyl semimetals with NMR and ultrasonic velocity measurements
- Discover and understand new phases of frustrated magnetic materials

Bertrand Reulet
Physics Department
Quantum Information

- Generate non-Gaussian quantum signals using electronic quantum noise
- Develop theoretical and experimental tools for broadband quantum optics
- Develop new experiments to probe quantum matter

Jean Rouat
Department of Electrical and Computer Engineering
Quantum Engineering

- Study the role of noise and spontaneous activity as revealing neuronal topologies within formal neural networks with discharges and neural microcircuits of the brain
- Study of deep neural networks with discharges
- Criticality study for recurrent neural networks
- Study the link between quantum physics and neural networks with discharges

David Sénéchal
Physics Department
Quantum Materials

- Publication of public software for quantum cluster calculations based on exact diagonalization
- Development of public software for tensor network calculations
- Study of the charge order in high critical temperature superconductors in the case of the Hubbard one- and three-band models
- Study of BCS-BEC and pseudogap phase in high-temperature superconductors as part of the three-band Hubbard model
- Study of superconductivity in misaligned graphene bilayers (twisted bilayer graphene) using mean-field theory

Julien Sylvestre
Department of Mechanical Engineering
Quantum Engineering

- Thermomechanical modelling and reliability of microsystems (microelectronics, MEMS, photovoltaics, etc.)
- Manipulation of information by micro and nanometric mechanical systems, high speed acoustic microscopy (entrepreneurship)

Louis Taillefer
Physics Department
Quantum Materials

- Study of quantum materials, where the correlations between electrons are strong, such as cuprates, unconventional superconductors, metals near a quantum critical point, and some topological materials

Dave Touchette
Department of Computer Science
Quantum Information

- Discover new information processing tasks with quantum advantage
- Adapt abstract protocols with quantum advantage for concrete architectures
- Develop our understanding of the limits of quantum information processing
- Development of a cost framework for quantum information
- Development of an interactive quantum encoding scheme

André-Marie Tremblay
Physics Department
Quantum Materials

- Clarify the physical phenomena appearing in the vicinity of the metal-insulator transition induced by interactions (Mott transition)
- Determine whether the superconductivity of Sr_2RuO_4 is topological or odd in frequency
- Accelerate material discovery and computational algorithms using artificial intelligence methods
- Discover in theoretical terms what determines the transition temperature of copper-based high temperature superconductors
- Generalize the two-particle self-consistent approach to include the effect of spin fluctuations in realistic calculations of quantum materials

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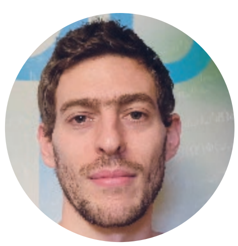

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The IQ is supported by two entities: a steering committee and a scientific council. These entities identify the broad research directions and emerging areas of interest for the development of the Institute, and identify opportunities for scientific collaboration with external partners. Furthermore, they support management in its search for collaborators and act as ambassadors in the activities to which they are invited. They are composed of members from the industry, academia, and the government with extensive experience in administration and science policy.

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École Polytechnique de Paris, France

ETH Zurich, Switzerland

Flatiron Institute, CCQ, United States

G2ELab/CNRS, Grenoble, France

ICTP Trieste, Italy

INL-Lyon, France

INRIA Paris, France

INRS-Énergie, Matériaux et Télécommunications, France

INSA Lyon, France

Instituts Fraunhofer, Germany

Institute for Experimental Physics, Innsbruck, Austria

Institute of Photonic Sciences, Barcelona, Spain

Institute of Physics, Chinese Academy of Science, China

Konstanz University, Germany

Laboratoire de Physique des Solides Orsay, France

Ljubljana, Slovenia

LNCMI – Grenoble, France

LNCMI – Toulouse, France

LTM, Grenoble, France

Max Planck Institute, Germany

MIT, United States

Northwestern University, United States

Oak Ridge National Laboratory, United States

Princeton, United States

Rice University, United States

Royal Holloway, University of London, United Kingdom

Rutgers University, United States

Stellenbosch University, South Africa

Technical University of Isfahan, Iran

The University of Sydney, Australia

TU Delft, Netherlands

UC Berkeley, United States

UCL, United Kingdom

UCLA Physics and Astronomy, United States

Universität Karlsruhe, Germany

Universität Stuttgart, Germany

Universität Ulm, Germany

Université de Bordeaux, France

Université de Lyon 1, France

University of Genoa, Italy

University of Ghent, Belgium

Université de Grenoble, France

Université des Sciences et Technologies de Lille 1, France

Université Paris-Diderot, France

Université Pierre et Marie Curie, France

Université Tahar Moulay, Saida, Algeria

University of California, Santa Barbara, United States

University of Fribourg, Switzerland

University of Indiana, United States

University of Leipzig, Germany

University of Notre Dame, Indiana, United States

University of Texas at Austin, United States

University of Tennessee, United States

University of Tokyo, Japan

Xiamen University, China

Yale University, United States

CANADIAN INSTITUTIONS

Canada's particle accelerator centre (TRIUMF)

Carleton University

Dalhousie University

Institut Transdisciplinaire d'Information Quantique (INTRIQ)

McGill University

McMaster University

Memorial University

Polytechnique Montréal

Regroupement québécois en matériaux de pointe (RQMP)

Regroupement stratégique en microsystèmes (RESMiQ)

Simon Fraser University

Université de Montréal

Université Laval

University of Alberta

University of British Columbia

University of Manitoba

University of Waterloo

Western University

INDUSTRY AND GOVERNMENT

Anyon Systems, Inc., Canada

Army Research Office, United States

BlueFors Inc., Finland

CIFAR, Canada

Calcul Québec

Compute Canada

D-Wave, Canada

Google AI Quantum Hardware Team, Santa Barbara, California, United States

Gordon & Betty Moore Foundation, United States

IBM Canada

IBM, Watson, United States

IBM Yorktown, United States

Keysight Technologies Canada Inc., Canada

Microsoft Research, United States

JILA Science, United States

MiQroInnovation Collaborative Centre (C2MI), Canada

National Research Council Canada (NRC), Canada

Raytheon BBN Technologies, United States

Sandia National Laboratories, United States

STMicroelectronics, France

Teledyne Dalsa Semiconductor, Canada

AWARDS AND DISTINCTIONS

INTERNATIONAL AWARDS

Radiation Instrumentation Early Career Award
Jean-François Pratte

Kamerlingh Onnes Prize
Louis Taillefer

NATIONAL AWARDS

The Rutherford Memorial Medal by the Royal Society of Canada
Alexandre Blais

NSERC Undergraduate Student Research Awards
Léo Caussan
Simon Bergeron
Catherine Éthier
Clovis Farley
Maxime Chagnon
Alexandre Dumont
Marc-Antoine Gauthier
Charles Richard
Olivier Trépanier

NSERC Graduate Scholarships– Master's
Lucas St-Jean
Gregory Brookes
Alexandre Choquette-Poitevin
Chloé-Aminata Gauvin-Ndiaye
Thomas Gobeil
Jean-Michel Parent
Sara Turcotte

NSERC Graduate Scholarships– Doctorate
Simon Bolduc Beaudoin
Frédéric Nolet

CRSNG Bourses Vanier
Baptiste Royer

PROVINCIAL AWARDS

Acfas Adrien-Pouliot
Louis Taillefer

ACFAS Scientific popularization Award
Sékou-Oumar Kaba

FRQNT Master's Scholarships
Julien Rossignol
Jessica Lemieux
Maude Lizaire
Alexandre Bédard-Vallée
Gregory Brookes
Chloé-Aminata Gauvin-Ndiaye
Thomas Gobeil
Mathieu Lachapelle
Jean-Michel Parent
Lucas St-Jean
Maxime Tremblay

FRQNT Doctoral Research
Samuel Boutin
Charles-David Hébert
Anirudh Krishna

FRQNT Postdoctoral
Mathieu Douhard

FRQNT BMP Innovation Scholarships
Samuel Parent

CGQC 2018

Best presentation
Sékou-Oumar Kaba

Best poster
Priyanka Brojabasi

INTRIQ – CONFETI

Best intro presentation Award
Maxime Tremblay

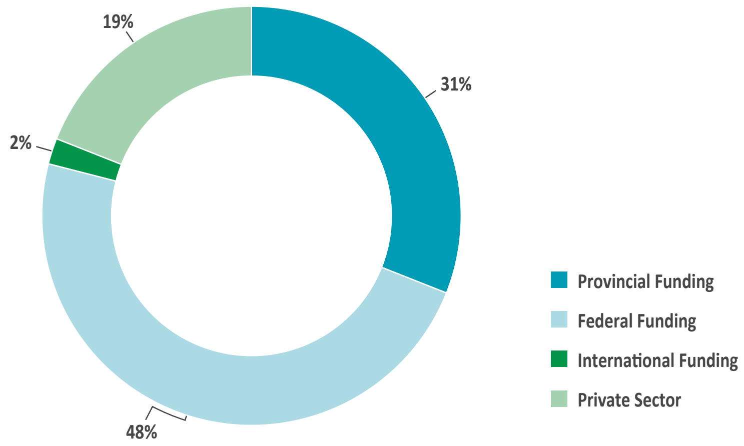
Best specialized presentation Award
Thomas Baker

UNIVERSITÉ DE SHERBROOKE

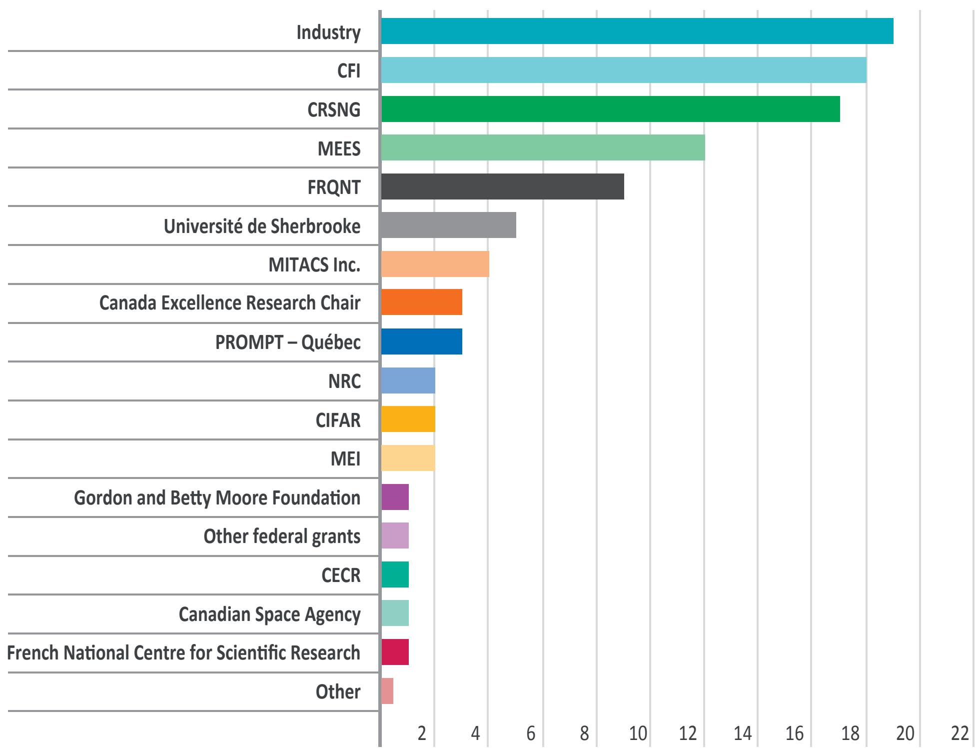
Prix Inspiration – Profesional commitment in the university community
Christian Sarra-Bournet

Prix Reconnaissance de la qualité de l'enseignement de la Faculté des Sciences
Ion Garate

FINANCES



Research Grants and contracts (unaudited) Total Revenue: 16 M$



Research grants and contracts (unaudited) Total Revenue: 16M$ (By Funding Agency)

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CONFERENCE PRESENTATIONS

Guests

Blais, A. (2018a, janvier). *Quantum computing with superconducting circuits*. Présenté à Department of Physics and Astronomy Colloquium, University of Calgary, Calgary, AL.

Blais, A. (2018b, février). *Itinerant microwave photon detector*. Présenté à Frontiers of Circuit QED and Optomechanics, Vienna, Austria.

Blais, A. (2018c, mars). *Qubit parity measurement in circuit QED*. Présenté à Aspen Winter Conference on Advances in Quantum Algorithms and Computation, Aspen, CO.

Blais, A. (2018d, juin). *Itinerant microwave photon detector*. Présenté à WQED18, Mazara del Vallo, Italy.

Blais, A. (2018e, juin). *Qubit parity measurement in circuit QED*. Présenté à Quantum Fluids of Light and Matter, Les Houches, France.

Blais, A. (2018f, juillet). *Quantum computing with superconducting circuits – Plenary talk*. Présenté à 9th International Conference on Spontaneous Coherence in Excitonic Systems (ICSCE9), Montreal, QC.

Blais, A. (2018g, juillet). *Superconducting quantum circuits*. Présenté à CIFAR Fundamental interactions workshop, Ontario.

Blais, A. (2018h, septembre). *Quantum Engineering of Superconducting Qubits*. Présenté à European microwave week, Madrid, Spain.

Bourbonnais, C. (2018, juillet). *Quantum criticality in low dimensional organic superconductors*. Présenté à International Conference on Synthetic Metals (ICSM2018), Busan, South Korea.

Côté, R. (2018a, février). *The world according to quantum mechanics*. Présenté à Champlain College Conference, Lennoxville,QC.

Côté, R. (2018b, avril). *NMR spectra of charge-density-wave states in GaAs/AlGaAs quantum wells and ^{13}C-enriched graphene*. Présenté à Physics at the nanoscale, Winnipeg, MA.

Dupont-Ferrier, E. (2018a, juillet). *Cool transistors : When devices from microelectronics industry become quantum!* Présenté à Women in Physics Canada 2018 / Femmes en physique Canada 2018, Sherbrooke, QC.

Dupont-Ferrier, E. (2018b, juillet). *Key role of dopants for quantum information with foundry-based transistors*. Présenté à LN2 colloque, Autrans, France.

Garate, I. (2018, avril). *An efficient algorithm for the optimization of Majorana devices*. Présenté à Workshop on interacting systems in low dimensions, Vancouver, BC.

Hofheinz, M. (2018, mai). *Quantum microwave devices based on inelastic Cooper-pair tunneling*. Présenté à INTRIQ Spring Meeting 2018, Bromont, QC.

Quilliam, J. (2018, mai). *Inducing quantum spin liquids with the interplay of charge and spin degrees of freedom*. Présenté à la Grande conférence du RQMP.

Reulet, B. (2018a). *Current/voltage fluctuations in nanodevices: From thermal and shot noise to quantum optics*. Présenté à IEEE 13th Nanotechnology Materials & Devices Conference, Portland, OR.

Reulet, B. (2018b). *Panel Discussion: QRNG Outlook*. Présenté à 6th Annual International Cryptographic Module Conference, Ottawa, ON.

Sénéchal, D. (2018, mai). *Dynamical Mean Field Theory*. Présenté à International Summer School on Computational Quantum Materials, Jouvence, Orford, QC.

Tremblay, A.-M. (2018a, juin). *Mott transition as an organizing principle for high-temperature superconductivity*. Présenté à Canadian Association of Physicists Congress, Halifax, NS.

Tremblay, A.-M. (2018b, juillet). *Being a physicist*. Présenté à Women in Physics Canada 2018 / Femmes en physique Canada 2018, Sherbrooke, QC.

Tremblay, A.-M. (2018c, novembre). *Perspectives on d-wave superconductivity and the pseudogap*. Présenté à Fall meeting of the Quantum Materials program of the Canadian Institute for Advanced Research, Toronto, ON.

OTHER

Acha, M. B., Robles, R., Charette, P. G., Bechou, L., & Sylvestre, J. (2018). Imaging based on low-coherence interferometry in the visible spectrum. *Photonics North*. Présenté à Montreal, Canada. Consulté à l'adresse www.hal.archives-ouvertes.fr/hal-02093409

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