Stewart Blusson
Quantum Matter Institute
THE UNIVERSITY OF BRITISH COLUMBIA

# ANNUAL REPORT **2017**

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Quantum Matter Institute
THE UNIVERSITY OF BRITISH COLUMBIA

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# Message from the director

2015 and 2016 were years of transformation for the Stewart Blusson Quantum Matter Institute (SBQMI). With the influx of funds received from Dr. Blusson, the Canada First Research Excellence Fund, and our other supporters and partners, we laid the foundation that now allows us to break new ground in our search for answers to some of the most challenging questions of our time.

In 2017, we worked hard to build on this foundation, literally, as we moved into our new building, capitalizing on the open design to increase collaboration and interdisciplinary exchange of ideas. We made exciting advances in fundamental and applied research, and reached out to partners who share our vision in research, education, and the flow of promising ideas to useful applications. This has been the year of great forward momentum.

At the core of this movement is the growth of our research and scientific team. We have been fortunate to add two new faculty members to our group, Dr. Ziliang Ye and Dr. Ke Zou, each of whom bring significant expertise in materials fabrication and characterization. We have also extended the capabilities of our support team by hiring scientists, research associates, postdoctoral fellows, and technicians from around the world to help us accelerate our research, generate promising ideas, and creating the applications and devices that form the basis of an emerging quantum industry.

We continue to sharpen our focus, channeling our resources to those questions that present the biggest challenges, best leverage our skills and expertise, and bring most benefit to society. We are designing materials with the ideal properties to serve as building blocks for future ultra-high-performance technologies by developing new experimental and theoretical techniques, and fabricating archetype devices to demonstrate their technological and commercial potential. This work will lead us to advances in clean energy, energy storage, quantum computing, communications, and atomic scale fabrication and characterization of new materials – advances that will result in new intellectual property, spark new industries, and accelerate the adoption of applied research results in Canada and abroad.

Since 2012, we have enjoyed a strong and fruitful partnership with the Max Planck Society of Germany, formally becoming one of the few international Max Planck Centres, and the only one fully dedicated to the study of quantum materials. This year, we signed an agreement that formalized our 2014 Memorandum of Understanding to expand this partnership by adding the University of Tokyo as a third pillar to the centre. I am thrilled by the learning opportunities that our joint workshops, schools, exchange programs, and research projects have brought to our faculty and students.

This year we broadened our industrial partnerships and are excited by the opportunities these provide to solve challenging quantum questions for the industrial world. In addition, we are working to form strong partnerships with other quantum research centres in Canada and the UK to promote the potential of this nascent field.

One of the most important pillars of our success is our academic programs. Our students and postdoctoral fellows come to us from around the world and are indispensable contributors to our Institute. While we provide them with the training needed to build rewarding careers, they provide us with the energy, enthusiasm, and new perspectives to tackle fundamental research questions.

Our approach to supporting our students and postdocs is a comprehensive one. In addition to broadening their academic experiences through interdisciplinary supervision, work on research projects, and opportunities to present their work at international conferences, we offer programs to develop the 'soft skills' that are so much in demand for success in academia and industry. Panel discussions with invited guests spanning academia, industry, and entrepreneurship give them the opportunity to explore potential career directions with experienced professionals; and our new mentorship program provides students and postdocs with the opportunity to explore these careers paths in depth. We are grateful to everyone who has given their time and wisdom so generously for these programs.

Our students have also had the opportunity to give back their time and wisdom. One of our core principles is to ensure that our collaborative and interdisciplinary culture is supported by a wide variety of perspectives and experiences. We do this by building a culture founded on equity and diversity – a difficult challenge given the under-representation of women and visible minorities in research in the physical sciences. Working with our equity committee, our students designed and delivered outreach programs to young women and people from visible minorities to introduce them to the excitement of quantum science and serve as mentors during their visits to our facilities.

This is only a brief snapshot of the many activities underway at our Institute over the past year, and it is an even smaller representation of all the new initiatives that we are designing and implementing for the year to come. We are fortunate to have creative and engaged faculty, staff, postdocs, and students, full of ideas about how to leverage the vast potential of our Institute to forge the future of quantum science and bring the world along with us as we take on this challenge. I am most proud of their effort and accomplishments, and would like to express my deepest gratitude to them all.

Andrea Damascelli
Scientific Director

# History

May 2010
**Quantum Matter Institute is Established**

Under the leadership and vision of Dr. George Sawatzky, a group of faculty at UBC establish the Quantum matter Institute. The group aims to break past the current boundaries of quantum material research through the collaborative effort of a multi-disciplinary team that brings together physicists, chemists, and material scientists—a team where theoreticians, experimentalists and engineers work closely together.

February 2012
**QMI Broadens its International Presence**

George Sawatzky and Bernhard Keimer, Director of the Max Planck Institute for Solid State Research in Stuttgart, lead the creation of the Max Planck-UBC Centre for Quantum Materials. It is the only international Max Planck Centre focused on quantum materials research and one of the few Max Planck partnerships outside of Germany.

January 2014
**QMI's International Partnerships Expand**

QMI and UBC sign a Memorandum of Understanding with the University of Tokyo. This collaboration expands the Max Planck partnership and results in the new Max Planck-UBC-U Tokyo Centre for Quantum Materials.

January 2015
**A New Scientific Director is Appointed**

Andrea Damascelli replaces George Sawatzky as the new director of the Quantum Matter Institute and as the co-director, with Bernhard Keimer, of the Max Planck-UBC Centre for Quantum Materials. His vision is to continue building an institute that will propel Canada to the forefront of quantum materials' science and technology.

July 2015
**QMI Wins Support to Begin its Transformative Growth**

Selected through a competitive process, QMI receives a $66.5-million investment from the Government of Canada via the Canada First Research Excellence Fund (CFREF) to support the program entitled "Quantum Materials and Future Technologies".

The CFREF award allows QMI to become quantum materials' science and technology institute, with a mission to broaden research, foster learning, and strengthen our translational effort.

March 2016
**QMI Becomes Stewart Blusson Quantum Matter Institute**

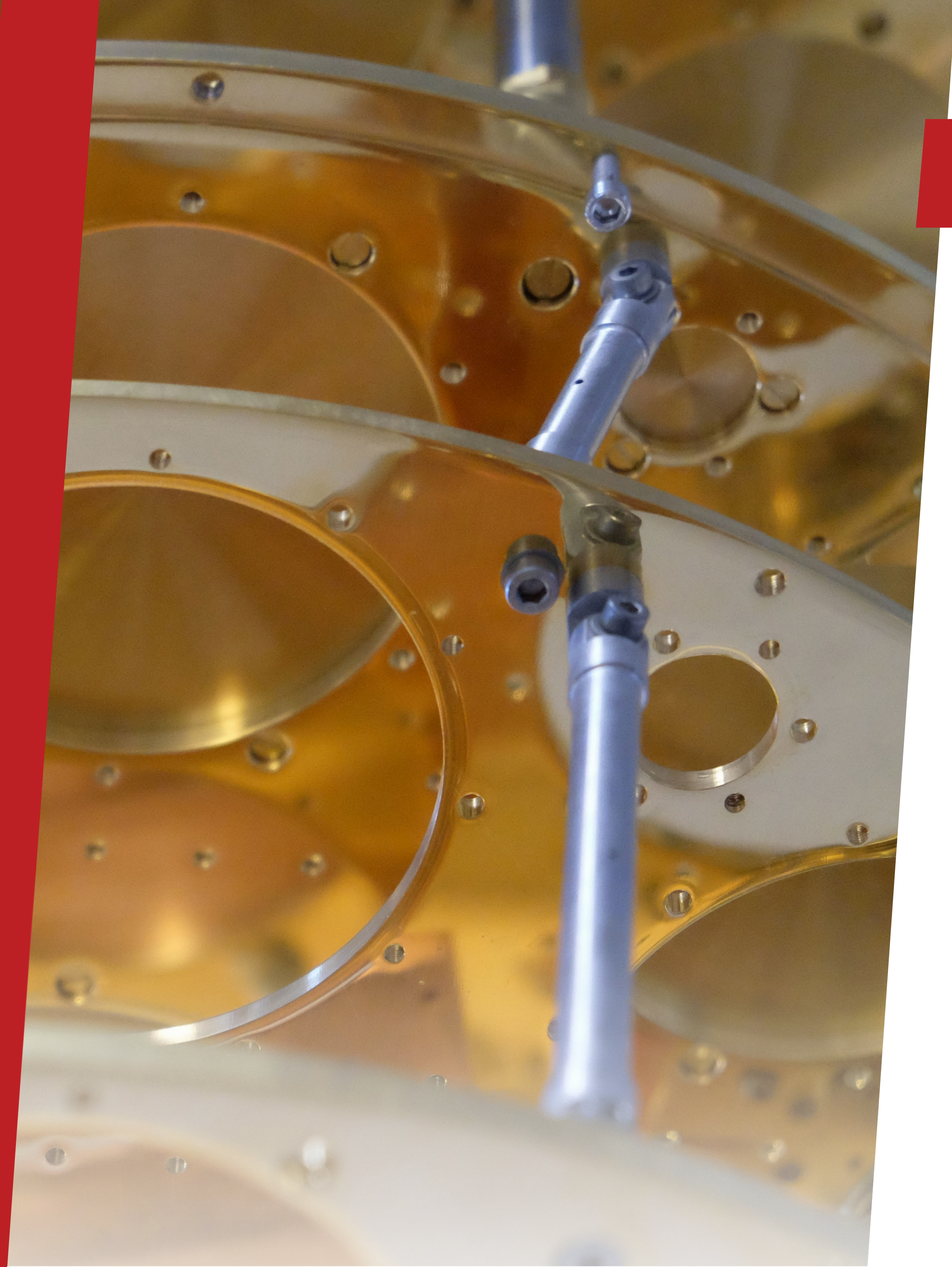
Vancouver-based diamond pioneer and philanthropist Stewart Blusson and his wife Marilyn donate $11M to quantum materials research at UBC, enabling the Institute to further broaden and deepen its research capabilities.

April 2017
**Max Planck — UBC — UTokyo Centre for Quantum Materials**

A signing ceremony in Tokyo formalizes a 2014 MOU to engage in a 3-way partnership amongst the University of Tokyo, Max Planck Society, and UBC, opening new possibilities for scientific collaboration through workshops, conferences, joint research projects, and student exchanges.

May 2017
**New Building Opens**

After moving into its new, purpose-designed building, SBQMI expands its materials synthesis, characterization, and device development capabilities and embarks on a major expansion and upgrade of its nanofabrication facilities, and electron microscopy and lithography infrastructure.



# Evolution and identity

SBQMI coalesced initially around a group of researchers at UBC focused primarily on transition metal oxide materials. The group collaborated closely to develop new measurement techniques and specialized world-class equipment to study these quantum materials, and closely wove together experimental and theoretical research to understand their properties and guide future directions. This successful research model attracted additional UBC scientists, who joined SBQMI and have applied the same approaches and infrastructure to study a broader set of materials and systems involving different types of correlations or artificially engineered structures at the atomic scale. Quantum materials defined in the narrow sense of highly correlated electron systems remain a core competency of SBQMI but not an exclusive focus. This broadening of scope allows methodologies developed to study quantum materials to advance the understanding of other leading-edge material systems, and in return, these allied projects enrich the study of quantum materials with valuable expertise and techniques representing different perspectives.

# By the numbers

**20** **SBQMI Faculty**

- **2** from Electrical Engineering
- **2** from Chemistry
- **16** from Physics
  - **6** Theorists
  - **10** Experimentalists

**2** **Affiliate Members**

**4** **Canada Research Chairs**

**7** **CIFAR Fellows**

**42** **Postdoctoral Fellows**

**113** **Graduate Students**

**41** **QuEST Scholars**

**32** **Research and Technical Staff**

**15** **Administrative Support Staff**

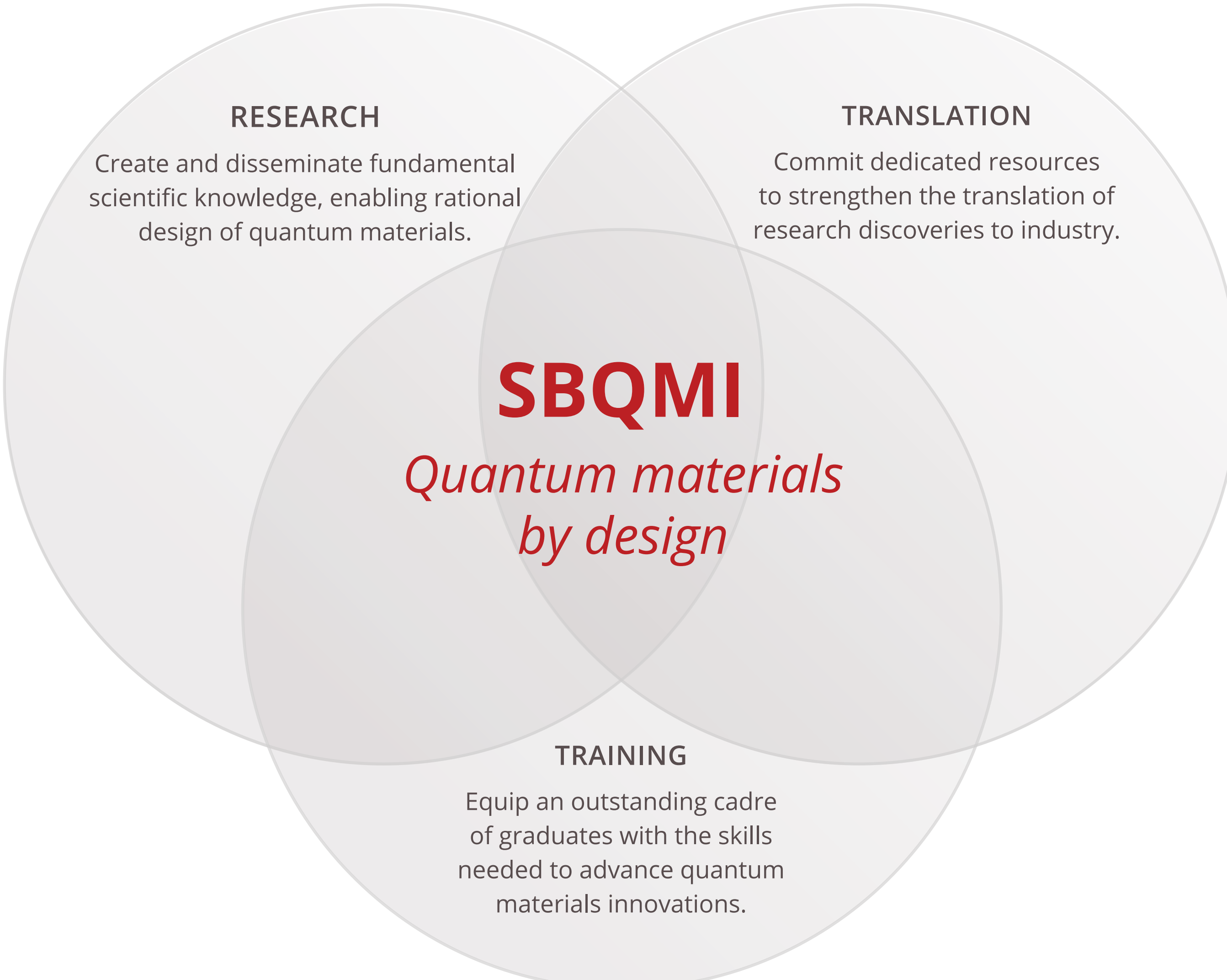
## Mission

SBQMI fosters the discovery, understanding, and control of quantum materials and related novel materials and devices; trains the professionals who will translate this intellectual capital into economic benefits for Canada; and transfers the discoveries to industry to create next-generation technologies.

## Vision

Within the next decade, SBQMI aims to emerge at the forefront of its international peers in the field of quantum materials and devices, and aspires to nucleate an ecosystem of companies developing future technologies.

# Pathways to the vision



# Overarching research theme

In most materials, electrons move around and scatter essentially independently of one another. In quantum materials, in contrast, electrons engage in highly correlated motions that resemble a complex dance. These correlations give rise to a wide range of astonishing electronic and magnetic properties that evoke the most profound scientific questions challenging the field of condensed matter physics.

Research at the Stewart Blusson Quantum Matter Institute (SBQMI) seeks to unravel and exploit the complex phenomena that emerge in novel engineered materials — not only as a result of these strong electronic correlations, but also from other sources of extraordinary behavior, such as topological states or physical structures created artificially at the atomic scale. Our research has advanced beyond merely exploring these materials so we can now begin to rationally design materials with the ideal properties to serve as building blocks for future ultra-high-performance technologies; synthesize these materials; characterize them, developing new experimental and theoretical techniques along the way as needed; and fabricate archetype devices from them to demonstrate their technological potential.

Just as silicon was the foundation for the microelectronics revolution and the rise of Silicon Valley as an economic superpower, the far richer set of properties emerging in quantum materials offers the potential to spark transformational innovation across many types of technologies. Key application examples include next-generation computing, communications, medicine, sustainable energy, and advanced manufacturing. It is too early to predict which of these areas will be transformed first.

SBQMI encourages a broad portfolio of projects across this overarching research theme, but will focus resources on whichever ones demonstrate the greatest promise for scientific or technological breakthroughs, and help translate them through industrial partners or through new start-ups. Mastering the design of quantum materials at the University of British Columbia (UBC) provides an opportunity to anchor the future of these industries around Greater Vancouver and drive enormous economic benefits for all of Canada.

# Scientific approach: SBQMI's foundational strengths

SBQMI's scientific plan is distinguished by five foundational strengths that span the Institute's research projects and serve as broad strategies to further promote research excellence:

**Synthesize the high-quality materials and fabricate the nanoscale devices** needed to advance experimental research objectives, so scientists can quickly iterate and evolve materials formulations and device designs. These systems include high-purity crystals, heterostructures deposited with atomic-level precision, quantum electronic devices, supramolecular structures, thin films, and photonic integrated circuits. SBQMI has historically relied on external collaborations to supplement its capabilities in this area; we seek to broaden and strengthen these internal capabilities over the next five years.

**Develop world-leading bespoke equipment and characterization techniques** that advance the state of the art in studying quantum and related novel materials, such as the two beamlines designed by SBQMI faculty members at the Canadian Light Source, TRIUMF, low-temperature high-magnetic field four point scanning probe techniques, ultrafast UV laser source for angle-resolved photoemission spectroscopy, electron microscopy (with high spatial, energy and momentum resolution), nanophotonic structure fabrication, and many others. Collaborative access to these tools is routinely shared among SBQMI research groups to an extent that is unprecedented for such highly specialized instrumentation, creating unique opportunities for scientific discovery.

**Integrate theoretical and computational approaches tightly within experimental projects** to help interpret experimental results, guide the selection and design of new materials and suggest new directions. Theorists and experimentalists at SBQMI have developed unusually close-knit and productive working relationships that greatly accelerate progress, and naturally align and mutually broaden research interests.

**Foster a unique culture of extreme proclivity to collaborate** — sharing materials, infrastructure, students, staff, and recognition — to best leverage resources and capitalize on the flexibility and vitality of independent investigators while avoiding their tendency to form silos. SBQMI collaborations effectively bring together not only theory and experiment, but also other complementary disciplines such as synthesis and characterization, materials and devices, and fundamental and applied research. At SBQMI this high degree of collaboration is deeply ingrained into the culture because it first arose naturally among the original group of faculty members that later founded the Institute.

**Apply these strengths to a broader set of materials systems** whose study benefits from the same scientific methods, collaborative approaches, and equipment. Quantum materials defined in the narrow sense of highly correlated electron systems remain a core competency of SBQMI but not an exclusive focus. The broadening of scope to encompass materials involving different types of correlations or artificially engineered structures at the atomic scale allows methodologies developed to study quantum materials to advance the understanding of other leading-edge material systems. In return, these allied projects enrich the study of quantum materials with valuable expertise and techniques representing different perspectives.

# Five research focus areas

**Faculty members of SBQMI are pursuing a wide range of research projects, most of which can be grouped into five major focus areas under the overarching research theme. SBQMI recognizes and articulates these areas through a deliberative process to highlight promising topics and reach consensus about where to prioritize resources. However, these areas do not limit the scope of research interests— any research topic that spans the five pillars that define SQBMI's scientific approach is appropriate to the Institute's mission.**

## I Atomic-Level Design of Quantum Materials

This research area explores materials in which strong local atomic interactions play a dominant role in determining the electronic behavior and physical properties, most often involving transition metals, such as copper and iron-based high temperature superconductors, ruthenates and iridates, as well as compounds based on rare earth elements such as cerium and samarium. Combining multi-scale theoretical predictions and calculations with specialized highly informative experimental characterization techniques enables rational design of new materials. Potential applications for these materials include new computing and information storage paradigms, exquisitely sensitive sensors, improved batteries, fuel cells, energy conversion catalysts and many others. This theme represents a central core competency of SBQMI.

## II Emergent Electronic Phenomena at Interfaces

Combining distinct quantum materials with different physical properties at atomically smooth interfaces forms heterostructures, which can exhibit emergent properties at the interface that do not exist in either of the bulk materials. This approach heralds the rational atomic-level design of complex structures with tunable properties, extending the potential of the first research area and creating a bridge from materials systems, to devices, and to the controlled functionality needed to realize applications. The wide range of properties achievable with distinct materials that are structurally compatible enables a wide range of devices and functionalities serving multiple applications.

## *III* Topologically Protected Quantum States

Materials with topologically protected conducting or superconducting surface states are predicted to exhibit many exotic phenomena and comprise an area of intense research around the world. SBQMI researchers have played a key role in this emerging field and are well positioned to play a leading role in the natural next step of elucidating topological materials with strong interactions. Robust topological protection of quantum states is widely recognized as offering the potential to create a revolutionary new class of quantum electronic devices that are not only fundamentally more advanced than conventional electronics, but could also leapfrog current efforts toward realizing quantum computing.

## *IV* Photonic Manipulation of Quantum States

Both quantum and classical light waves can be exploited to manipulate and read out quantum states of matter with high fidelity. SBQMI researchers are developing a variety of novel light sources and photonic techniques to control spin, valley, and charge degrees of freedom in 2D van der Waals materials, oxide superconductors, and silicon photonic circuits. While the first two efforts are still at an early stage and are focused on fundamental science, the latter will enable a unique approach to quantum computing: the silicon photonic circuits will interconnect individual spin-qubits formed by chalcogenide impurities embedded in silicon, and make them addressable to realize a scalable quantum computing platform.

## *V* Novel Materials for Sustainable Energy

SBQMI researchers are pursuing a variety of projects involving nanoscale solids and supramolecular materials with a broad range of applications including solar power, thermoelectric energy conversion, low-cost energy storage, and more efficient light-emitting devices (LEDs). These disparate projects are united by a common design paradigm that starts from properties and correlations at the atomic scale, then extends to transport across macroscopic devices. They all leverage the characterization methods, theoretical tools, and computational infrastructure developed at SBQMI, and rely on the same core pillars in their approach to success.

Research area I

# Atomic-level design of novel quantum materials

SBQMI researchers are engaged in research on a wide variety of materials that exhibit novel quantum behaviours and that can be approached and designed through the lens of theory governing nanoscale and atomic level structure. Here we highlight two recent research projects across this wide range, illustrating our expansion beyond our core strength in transition metal oxides.

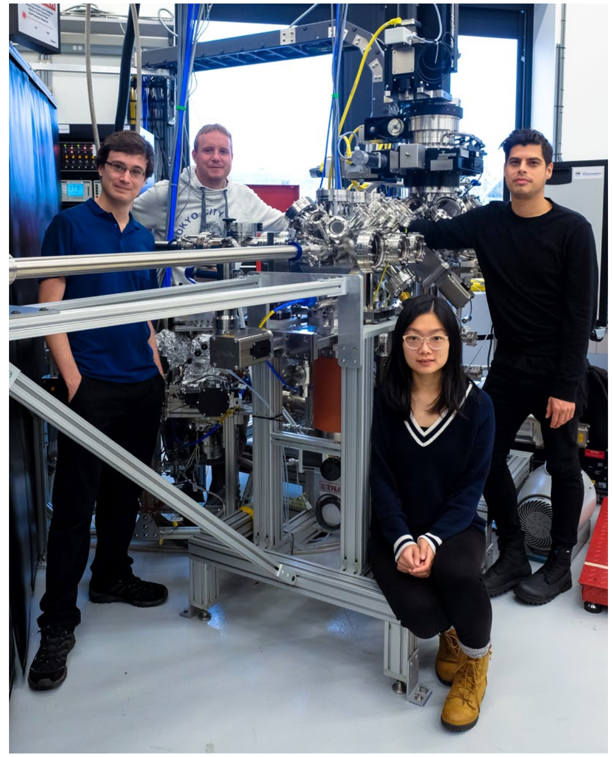
## Success stories

### Visualizing signatures of graphene quantum Hall physics without a magnetic field

*Principal Investigators: Andrea Damascelli and Marcel Franz*
*HQP: Christopher Gutiérrez, Étienne Lantagne-Hurtubise, Pascal Nigge, and Amy Qu*

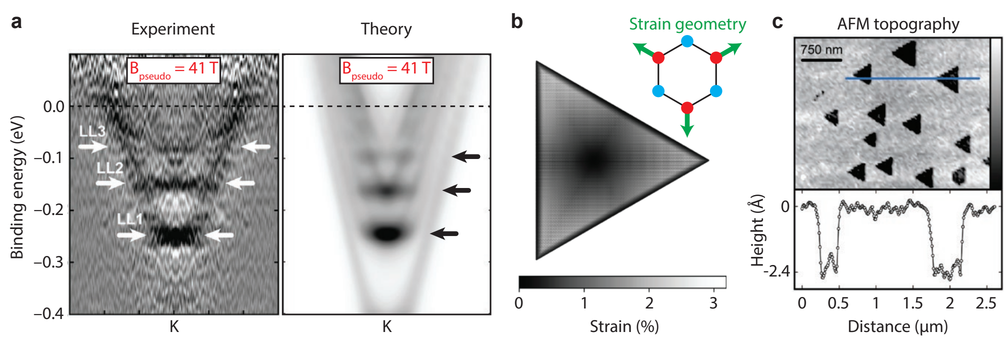
**Graphene, a single two-dimensional sheet of carbon atoms, has attracted attention for its interesting electronic properties that derive from its charge carriers behaving as massless Dirac fermions. In the presence of strong magnetic fields, these charges tend to move in circular trajectories called cyclotron orbits with kinetic energies quantized into discrete Landau levels. These ingredients form the foundation of the quantum Hall effect (QHE). In the past, the use of electronic transport and other methods revealed graphene QHE physics, but not the momentum-resolved electronic band. While angle-resolved photoemission spectroscopy (ARPES) is the tool of choice for these measurements, it is incompatible with the presence of magnetic fields that would destroy the momentum information carried by the photo-emitted electrons. However, Dirac fermions in graphene provide a way to circumvent this problem: straining graphene in a particular geometry causes its charge carriers to move in quantized cyclotron orbits and thus behave as if they were in a strong (pseudo) magnetic field.**

Using high-quality samples of graphene on silicon carbide (Gr-SiC) provided by our collaborators at the Max Planck Institute for Solid State Research in Stuttgart, we used ARPES to measure signatures of graphene's massless charge carriers in the quantum Hall regime for the first time. Figure a (left panel) shows an ARPES energy dispersion map measured at the graphene K point. Apart from the expected linear dispersion — a sign that the electrons move as if without mass — the data additionally showed several flat bands within the Dirac cone. These bands are associated with electrons performing cyclotron motion at specific Landau levels. Importantly, the energies of these flat bands were found to increase according to $\sqrt{n}$, where n is the Landau level index, allowing us to unambiguously distinguish the features as graphene Landau levels. From these measurements, we extracted an effective pseudo-magnetic field of 41 Tesla — comparable to the highest magnetic fields generated at only a few specialized laboratories around the globe.



To provide insight into the origin of these observations, we performed calculations of graphene under strain (Figure b). We simulated a triangular graphene flake with a triangular strain pattern that would yield a pseudo-magnetic field of B = 41 Tesla. We found that the maximal strain needed to achieve such a field was a realistic value of 3%. Using this strain pattern, we calculated the momentum-resolved spectral function (Figure a, right panel), which reproduced the salient features of the experimental ARPES map.

What exactly is causing the strain? Atomic force microscopy (AFM) imaging on Gr-SiC unexpectedly revealed the presence of triangular depressions, or "nano-prisms," covering the surface (Figure c). Found to have the same depth, these nano-prisms are all oriented in the same direction even several micrometers apart. The triangular geometry of the nano-prisms and their uniform orientation with respect to the graphene lattice coincides with theory simulations, and we hypothesize that they are responsible for the measured pseudo-magnetic field. These new results open the door to using ARPES to study quantum Hall physics in a host of strained 2D materials and heterostructures.



## Success stories

### Oxygen holes and hybridization in the bismuthates

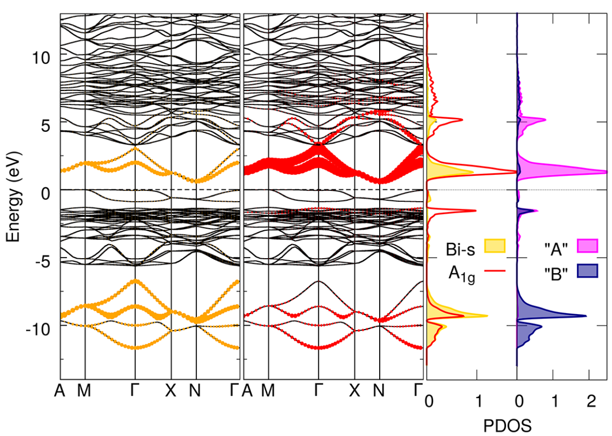
***Principal Investigator: George Sawatzky***
***HQP: Ilya Elfimov and Kateryna Foyevtsova***

**Hole-doped bismuth perovskites have recently attracted a lot of attention as one of the few examples of transition-metal-free high-transition-temperature oxide superconductors. The parent compounds are no less interesting, demonstrating a variety of temperature-driven electronic and structural phase transitions. At low temperature, perovskites $BaBiO_3$ and $SrBiO_3$ are insulators with distortions from an ideal cubic perovskite crystal structure. Namely, oxygen octahedra around the bismuth ions exhibit alternating breathing-in and breathing-out distortions along the three cubic crystallographic directions, resulting in disproportionated bismuth (Bi) oxygen (O) bond lengths.**

We used density functional theory (DFT) calculations to study the hybridization strengths between the constituent elements of bismuth perovskites demonstrating the extreme effects of interatomic hybridization involving the Bi- 6s and O- 2p orbitals. Having determined the most relevant atomic orbitals and interactions, we then studied the properties of our derived tight-binding (TB) model as a function of structural distortions in two and three dimensions. Finally, we explored possible simplifications of the TB model with a focus on describing low-energy electronic excitations.

Our aim was to better understand the relevance of various interactions in determining the electronic structure of bismuth perovskites and derive its minimal TB model. Such a minimal model describing the low energy scale states is especially useful in constructing model Hamiltonians that include the electron-phonon interactions in order to study aspects such as bipolaron formation and superconductivity in hole or electron doped systems.

The result is that low energy states straddling the Fermi energy are composed of these special molecular orbital states forming bands similar to those of molecular solids. In the bismuthates, these molecular orbitals are of A1g symmetry relative to the central Bi ion. In previous work we demonstrated a similar behaviour in the $RENiO_3$ perovskite structures but now the linear combination of O- 2p atomic orbitals form Eg symmetry states because of the strong hybridization with the central nickel (Ni)- 3d states. The Zhang Rice singlet-like states in the cuprate family of oxides can also be considered as forming a molecular solid. This seems to be a general trend in many high oxidation state oxides and provides a new way of looking at these materials' properties — properties that are not well understood.




*(Left) Bandstructure of $SrBiO_3$ with the Bi-s character in yellow, and oxygen A1g molecular orbital character in red. (Right) $SrBiO_3$ density of states projected onto the Bi-s atomic and oxygen A1g molecular orbitals, as well as the bonding and antibonding states they form.*

Research area II

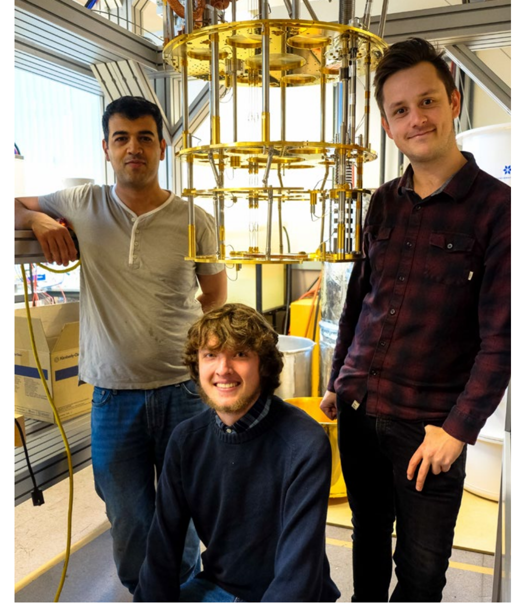
# Emergent electronic phenomena at interfaces

While the properties at interfaces between transition metal oxides have been a major target of SBQMI research, this field was broadened by recent breakthroughs in the techniques for stacking monolayers of 2-dimensional transition metal chalcogenides, which we highlight below.

## Success stories

### Superconductivity in tungsten ditelluride

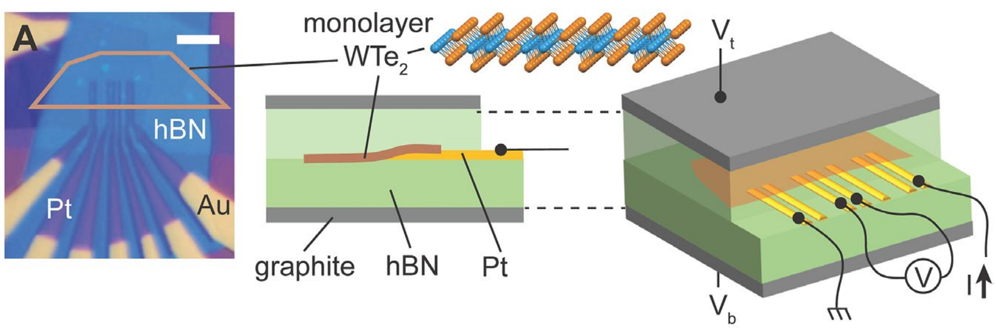
*Principal Investigator: Josh Folk*
*HQP: Phillip Bement, Christian Olsen, and Ebrahim Sajadi*



**Materials and devices that combine non-trivial topology with superconductivity are at the forefront of condensed matter research today, due to the tantalizing possibility of realizing unconventional superconductors whose excitations consist of emergent particles unlike any known to date. To this end, making hybrid devices that couple a conventional superconductor to a material with strong spin-orbit interaction is the focus of a global research effort. We showed that a single material, $WTe_2$ (tungsten ditelluride) in monolayer form, can easily be tuned using a gate voltage, shifting it between 2D topological insulator and superconducting states.**

$WTe_2$ in bulk form has an electronic structure that is topologically non-trivial (a Weyl semimetal) but it is not a topological insulator. Over the past two years, exciting studies demonstrated that $WTe_2$ becomes a topological insulator when thinned to a monolayer, confirming a theoretical prediction from 2014. Superconductivity has also been observed in bulk $WTe_2$, but only at extremely high pressures, and to our knowledge, it was not expected to emerge in the monolayer, much less at such low levels of electrostatic doping, corresponding to one extra electron for every ~200 W atoms. Superconductivity with so few charge carriers has only been observed in a few other systems, such as strontium titanate and bismuth. The fact that a topologically nontrivial electronic structure, and possibly nontrivial superconductivity, appears in a single material, and that the system can be tuned between the two states with just a few volts on a gate, opens up great possibilities for devices based on unconventional superconductivity, and possibly hosting Majorana zero modes.

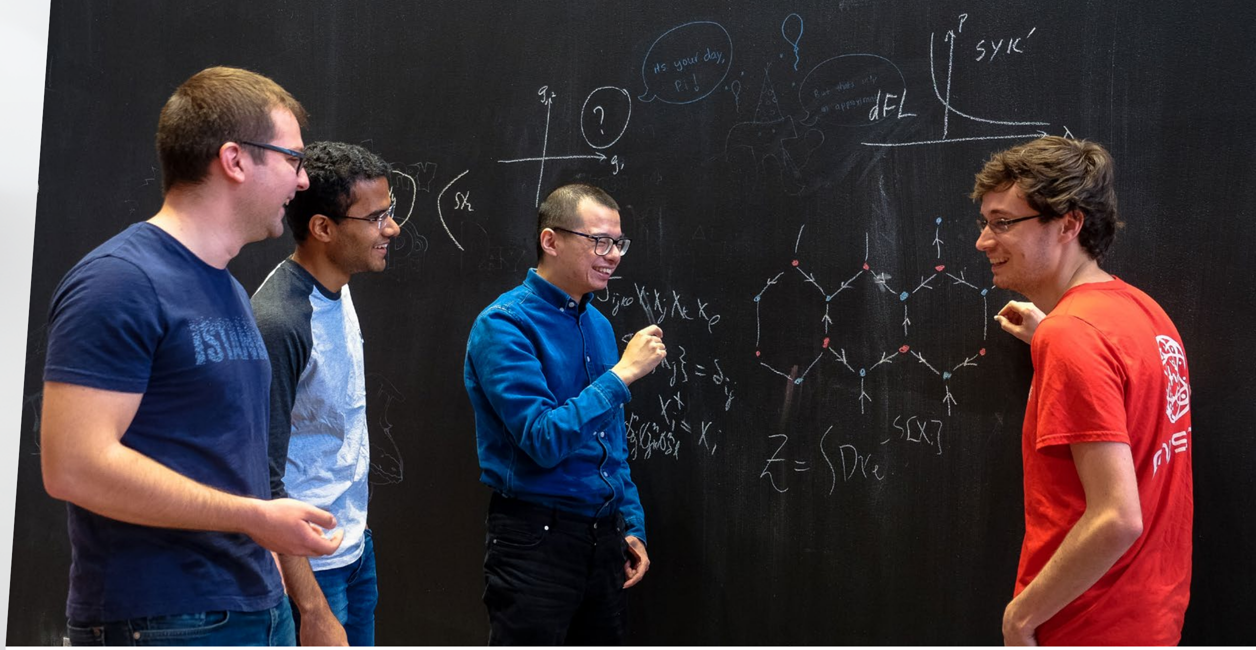
Led by two students from the QuEST program, Ebrahim Sajadi and Christian Olsen, the measurements at UBC took almost a year. Later, a talented FYSRE (First Year Summer Research Experience) student, Phillip Bement, joined the team and was an integral part of our careful characterization of the superconductivity in $WTe_2$. This work is part of an ongoing collaboration with the Cobden and Xu groups at the University of Washington. The devices were stacks built up from flakes prepared by scotch-tape exfoliation, with the monolayers of $WTe_2$ protected by thin boron nitride (hBN) flakes in a van der Waals heterostructure. Since $WTe_2$ is highly air sensitive, devices were prepared in a glove box by students at the University of Washington. Afterwards, the devices (with $WTe_2$ protected by hBN) arrived at UBC, where our team measured their transport properties down to milliKelvin temperatures.




## Research area III

# Topologically protected quantum states

SBQMI researchers have played a key role in the emergence of topological materials as a field and recent successes in the study of properties of that can arise from Majorana fermions, as well as progress in including many-body effects via the electron-phonon interaction.




## Success stories

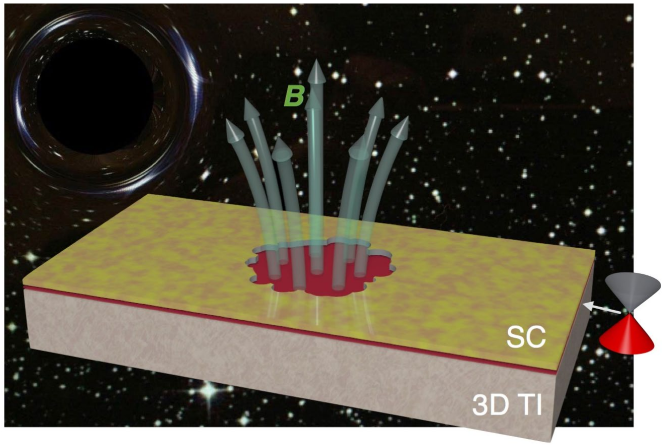
### Interacting Majorana matter: from solids with topology to supersymmetry and black holes

*Principal Investigator: Marcel Franz*
*HQP: Oguzhan Can, Étienne Lantagne-Hurtubise, Chengshu Li, and Tarun Tummuru*

**In 2015, we laid the foundation for studies of systems with strongly interacting Majorana fermions. These are unusual particles, conjectured to exist more than 70 years ago by Ettore Majorana but, until recently, unobserved. In fact, Majorana particles are distinguished by being indistinguishable from their antiparticles. We showed that Majorana fermions could be made to strongly interact with one another in a platform called a Fu-Kane superconductor, which occurs at an interface between a three-dimensional topological insulator and an ordinary superconductor like lead or aluminum.**

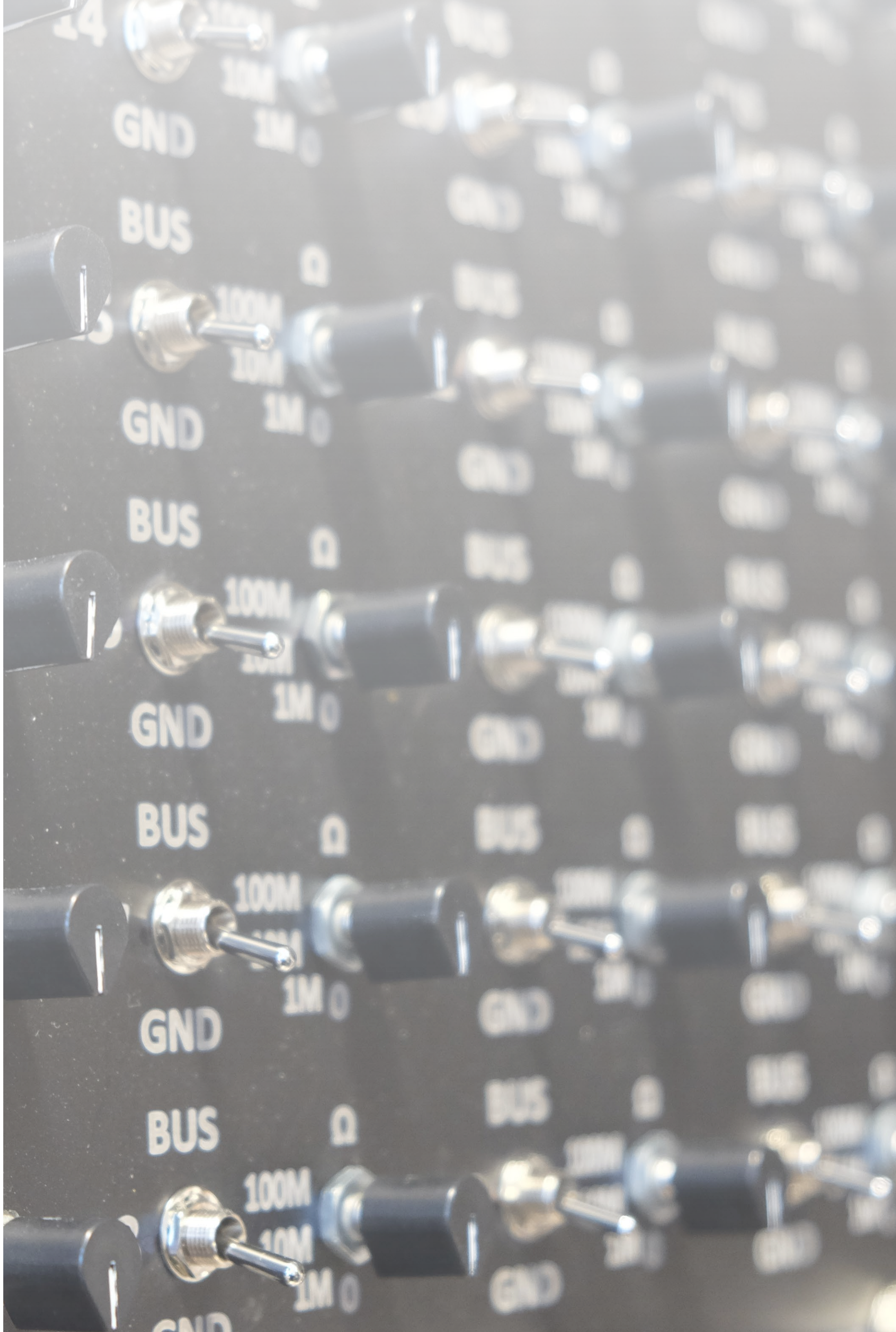
We know that interesting new phases of matter appear in systems of strongly interacting particles and this proved true for interacting Majorana fermions. Our subsequent investigations and those of scientists around the world, uncovered a bonanza of exciting physics in this platform. We studied one-dimensional chains of interacting Majorana fermions and discovered a variety of exotic quantum phases, including the first instance of emergent supersymmetry in a purely fermionic system. Extending the study to two dimensions, we found a range of interesting behaviours on the square lattice, and we continue to investigate, with exciting prospects, triangular and honeycomb lattices.

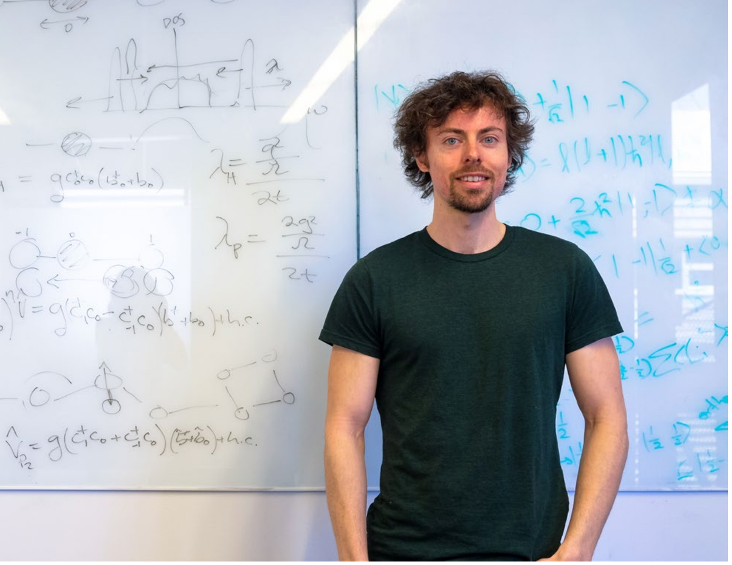
Another surprising development, based on the above platform, has to do with emergent black holes. It turns out that interacting Majorana fermions can realize certain key aspects of black hole physics, which in turn may be helpful in resolving some of the fundamental questions about our universe. The Sachdev-Ye-Kitaev (SYK) model, comprised of N Majorana fermions interacting with one another via random all-to-all interactions, provides the connection. In 2017, we proposed a way to realize physically the SYK model in a solid-state system, thus enabling tests of black hole physics in a tabletop experiment.




*The proposed setup for a solid-state realization of the SYK model. A three dimensional topological insulated (3D TI) surface is made superconducting by proximity to an ordinary superconductor (SC). A nanoscale hole fabricated in the SC is threaded by magnetic flux and contains N Majorana fermions. Under certain conditions, these can be made to interact strongly and realize the SYK model.*







## Success stories

### Type-II Dirac semimetal stabilized by electron-phonon coupling

*Principal Investigators: Mona Berciu, Marcel Franz, and George Sawatzky*
*HQP: Mirko Möller*

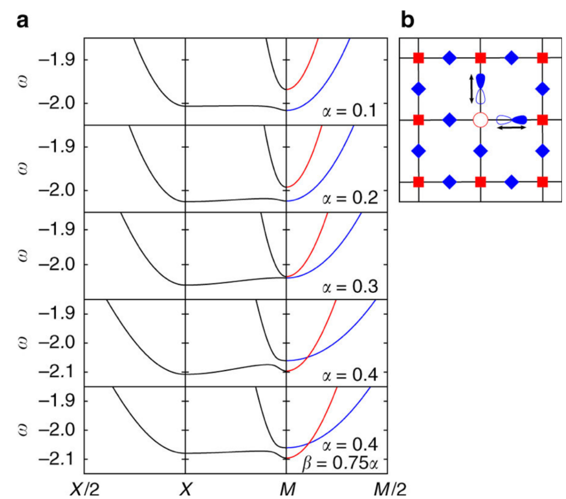
**Understanding the role of topology is a topic of major interest within the condensed matter physics community. To date, researchers have made remarkable progress in classifying topological properties of non-interacting electrons, and on understanding the interplay between topology and electron-electron interactions. We extended such studies to investigate the role of interactions with the lattice, and predicted non-trivial topological effects in infinitely long-lived polaron bands.**

First, we proved that a sharp crossing of two polaron bands is indeed possible in a realistic model of electron-phonon coupling. This band crossing is not due to a trivial renormalization of the bare bands because of coupling to the lattice. Instead, different bands are renormalized differently by the coupling to the lattice, and can move past each other. The avoided crossings one would generically expect are prevented along high-symmetry lines due to protection by certain crystal symmetries, opening the way for sharp level crossings. To our knowledge, such crossings have not been explicitly revealed for coherent polaron bands ever before. Moreover, we found that such crossings can lead to a new type of sharp transition in the ground-state properties of the polaron, where the ground-state momentum remains unchanged but a symmetry of its wave function changes discontinuously.

Second, we demonstrated that these crossings lead to the appearance of tilted Dirac points whose location, and even existence, can be controlled through the strength of the electron-phonon coupling. We find that the Dirac points can be stabilized for a wide range of parameters, even those for which the bare bands are far apart, if the electron-phonon coupling is sufficiently large. In practical terms, we envision the use of pump-probe experiments to resonantly excite the relevant phonons and renormalize the strength of their coupling to the carrier. In other words, it may be possible to create Dirac points and to shift their position in the Brillouin zone through optical pumping, opening a new pathway for the realization of topological semimetals.

We studied a 2D Lieb lattice in this work, but it is reasonable to expect that the phenomena described here are not restricted to it. Similar 3D models should stabilize 3D Weyl points, but this is yet to be verified. Ab-initio calculations will be needed to identify suitable candidates for experimental studies.

Recently featured in Nature Communications Editors' Highlights, this study is important because there are practically no previous studies of topological effects in the polaron bands, in particular no demonstration that polaron bands can acquire non-trivial topological features as the electron-phonon coupling is tuned.




*Polaron spectrum at various electron–phonon couplings (color online). **(a)** The infinitely long-lived polaron bands obtained from the spectral function $A^{\gamma,\gamma}(\mathbf{k}, \omega)$. For $M \longrightarrow M/2$ the symmetry of the bands is indicated in blue for p+ and red for p−. Parameters are $t_{sp} = -1$, $t_{pp} = -0.49$, $\epsilon_s = \epsilon_p = 0$, $\Omega = 1$ and $\alpha = 0.1 \ldots 0.4$. In the bottom panel $\beta = 0.75\alpha$, in all other panels $\beta = \alpha/2$. **(b)** The Lieb lattice. Arrows indicate the direction of oscillation of the phonons.*

Research area IV

# Photonic manipulation of quantum states

The collaboration between SBQMI and researchers at Simon Fraser University has moved us forward on the path to developing quantum information technology that integrates novel silicon-based qubits with monolithically-integrated silicon photonic circuits.

## Success stories

### Quantum information processing in Silicon

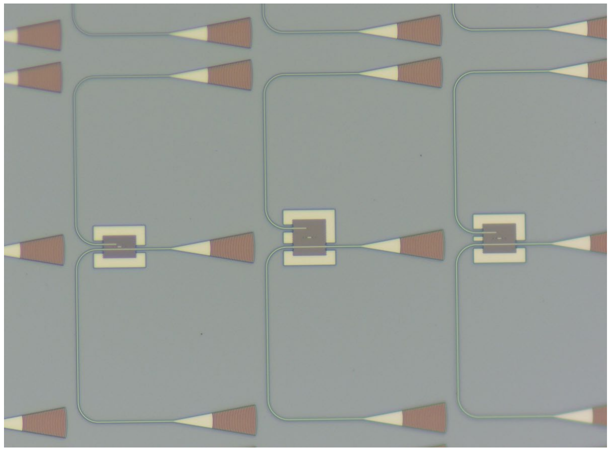
*Principal Investigators: Lukas Chrostowski, David Jones, Robert Raussendorf, and Jeff Young*

**Along with our colleagues at Simon Fraser University (SFU), we received a $19M Canadian Foundation for Innovation (CFI) and BC Knowledge Development Fund (BCKDF) equipment grant in support of a major new collaborative project, Silicon Quantum Leap, which aims to develop a silicon photonic circuit-based platform for scalable quantum information processing. Photons at wavelengths near 2.9 µm, resonant with a dipole allowed transition involving extraordinarily long-lived spin ground states of selenium (Se) impurity atoms in silicon, will be used to measure and couple spin-qubits that are directly addressed using microwave fields.**

Working at 2.9 µm requires us to develop our own tunable, narrow linewidth light sources, and to design and fabricate state-of-the-art silicon photonic circuit elements functioning at nearly double the wavelength at which most current silicon photonic circuitry operates. In 2017, we successfully designed and fabricated our first 2.9 µm chips in 500 nm thick silicon-on-insulator (SOI), that contain over 1,500 test circuits designed to assess differences in the intrinsic and extrinsic (fabrication-related) losses at these wavelengths (see example in Figure).

We built a prototype difference frequency source to measure high quality factor (Q) microcavity and optimized it for turnkey use with specialized pump laser sources. Our most significant success was the invention of a novel type of high Q, low mode volume microcavity that can have its resonant wavelength tuned electronically while maintaining a high Q factor at cryogenic temperatures. Using conventional SOI wafers at 1.5 µm, we fabricated and characterized test circuits. A patent is in progress, and we will present our work at the 2018 Conference on Lasers and Electro-Optics (CLEO).

This past year also saw significant progress in connecting our expertise in quantum computer architectures with the specific optical domain cavity quantum electrodynamic devices in development under this project.



*An optical image of three test circuits with grating couplers (triangles) connected to photonic crystal cavities via single mode waveguides in 500 nm thick SOI.*

Research area V

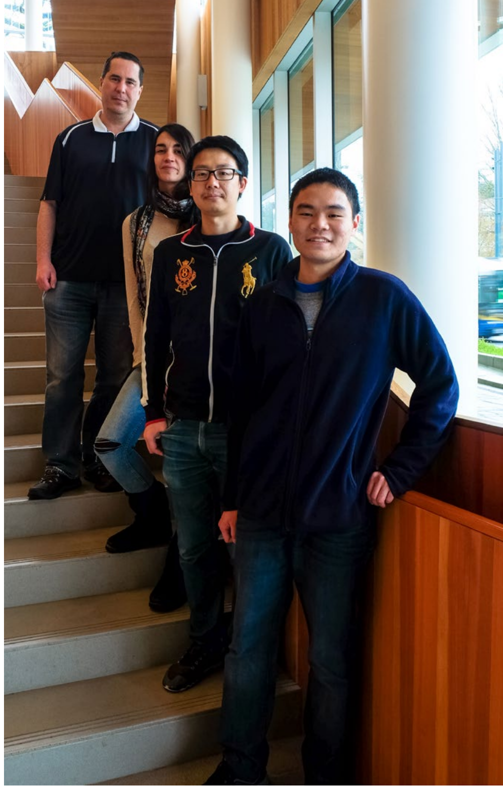
# Novel materials for sustainable energy

We pursue a wide range of materials and projects as part of SBQMI's efforts in sustainable energy.

## Success stories

### Electrochromic windows

*Principal Investigator: Curtis Berlinguette*
*HQP: Wei Cheng, Kevan Dettelbach, Noah Johnson, and Brian Tam*

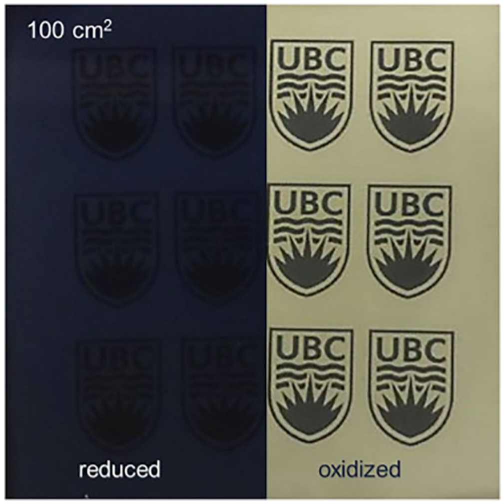


**Commercial buildings waste almost one third of the energy they consume through inefficient heating and cooling. Electrochromic windows are a promising technology for reducing this inefficiency by creating climate-adaptive building shells, which dynamically modulate heat and light in response to an applied voltage. Transition metal oxides such as tungsten oxide ($WO_3$), niobium oxide ($Nb_2O_5$), molybdenum oxide ($MoO_3$) and vanadium oxide ($V_2O_5$) are all materials known to display active "electrochromism", which is defined as the ability to reversibly change colour in response to a voltage stimulus. $WO_3$ is a particularly well suited material to meet commercial requirements because of its high colouration efficiency, fast switching speed, and the long lifetime it exhibits. Amorphous phases of $WO_3$ are especially appealing because the high atomic disorder and porosity can more readily facilitate charge diffusion and mobilization when switching between coloured and clear states.**

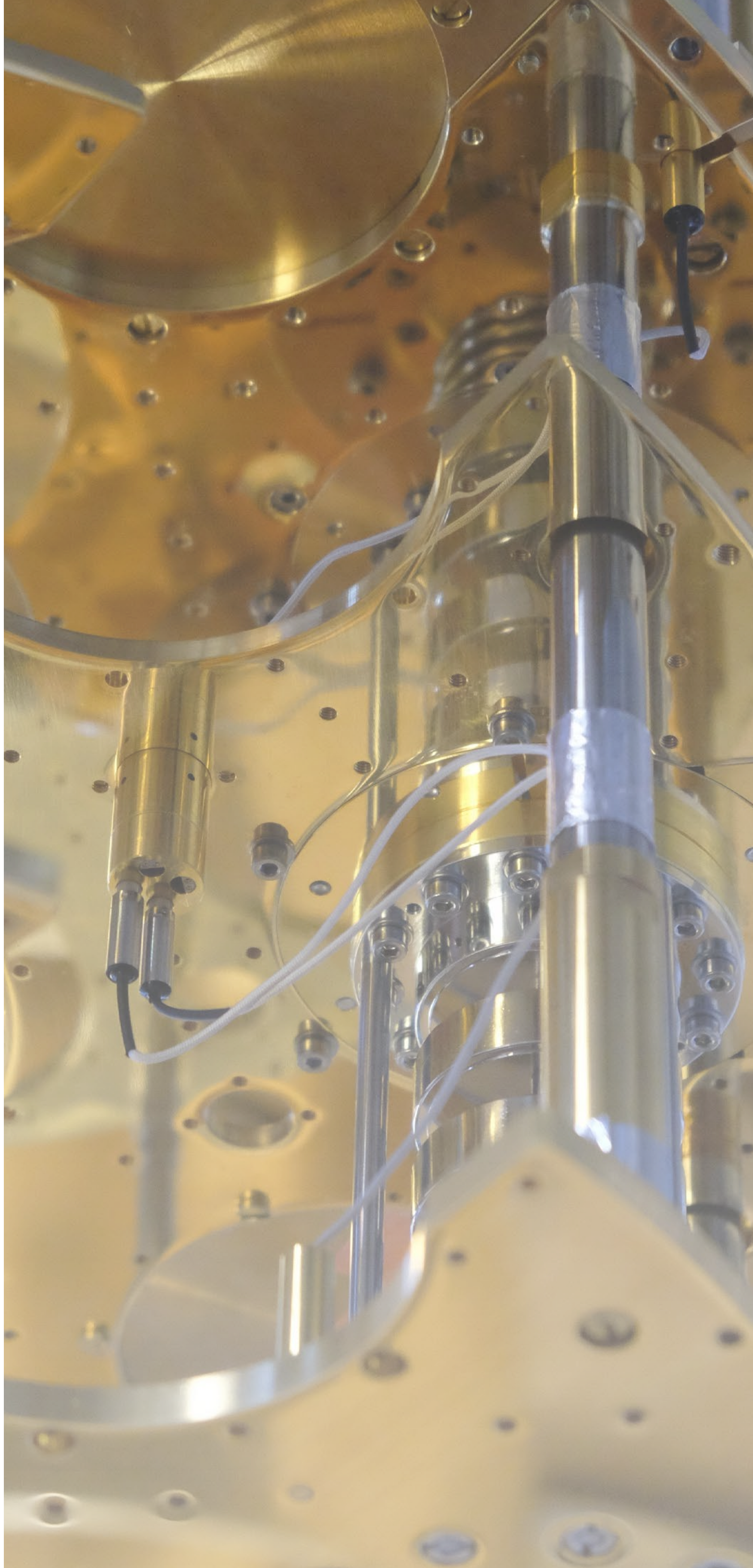
Industry produces amorphous $WO_3$ layers by a sputter coating method. This process is efficient and scalable, but requires specialized high-vacuum equipment and expensive metal targets. These methods can therefore render the cost of smart windows prohibitively high (~$500 to $1,000-per-square-metre), limiting their widespread appeal.

We have pioneered methods to make uniform layers of amorphous metal oxides using low-temperature techniques that do not require high vacuum or specialized equipment. This solution based "photodeposition" method leverages the ability of ultraviolet (UV) light to drive the decomposition of photoactive solution-deposited metal-organic precursors. We first applied this technique towards the production of low-cost water splitting electrocatalysts, and are now exploring the suitability of this method towards a range of clean technology applications.

We discovered that the application of UV-driven photodeposition to a solution of tungsten chloride ($WCl_6$) coated on transparent conductive glass yielded optical-quality films of amorphous $WO_3$ with excellent electrochromic performance. We were able to incorporate this material into a 10 cm x 10 cm window that showed high optical modulation (~70%) and switching times in the order of seconds (Figure). These metrics are commensurate with state-of-the-art windows used in industry, offering a potentially significant advancement for the affordable, large-scale deployment of electrochromic windows. The next steps are to create even larger windows, and to experiment with other precursors that allow access to other colour tints—a feat currently not possible in industry.



*A 10 cm x 10 cm electrochromic window comprising a solution-processed $WO_3$ active layer switching between dark (reduced) and clear (oxidized) state in response voltage stimulus.*



## Success stories

### AweSEM

*Principal Investigator: Alireza Nojeh*
*HQP: Mike Chang, Harrison Fan, Casimir Kuzyk, and Kevin Voon*

**Healthcare in the developing world continues to experience serious diagnostic limitations. Hospitals and clinics are often ill-equipped and most cannot afford new equipment. In fact, many operate using donated equipment that often ends up broken and discarded. Another serious issue is that patients usually have to walk, sometimes for days, to get rudimentary care. Studies have shown that implementing systems to bring care closer to patients (rather than patients going to a hospital or clinic for acute care) has an enormously beneficial impact. Focusing on preventive care and chronic disease management leads to healthier patients, resulting in less costly and more effective patient care.**

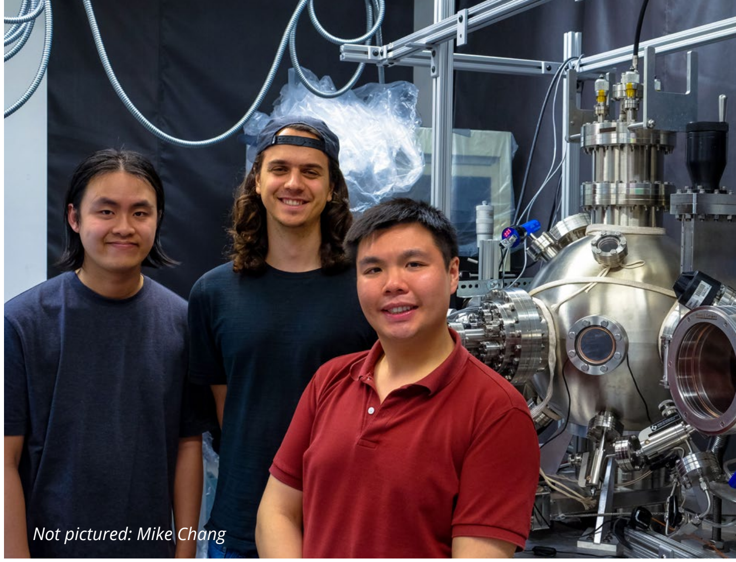
Currently, health professionals use expensive assays and imaging techniques to identify viruses like Ebola and polio, and remote areas have very limited access to these necessary diagnostic tools. With the goal of improving the access to and quality of affordable healthcare, we are developing AweSEM™, an inexpensive and portable scanning electron microscope (SEM).

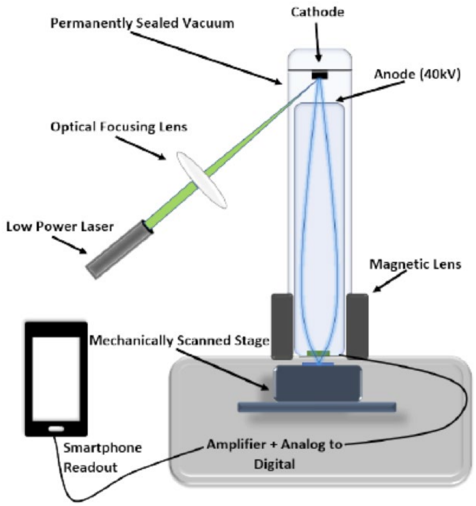
An SEM is a high-resolution imaging instrument that creates an image by bombarding a sample with an electron beam and analyzing the resulting backscattered and secondary electrons. This type of high-resolution imaging reveals important information about biological, inorganic, and manufactured materials.

Other electron microscopes in the market cost over $100,000 and are expensive to maintain. They are large, difficult to master, and require specialized specimen preparation. Projected to sell for less than 1/100th of an average tabletop SEM, our AweSEM™ has been designed to have 50nm resolution, and yet be portable (battery-powered).

We are currently developing and optimizing the cathode, which is an optically stimulated carbon nanotube forest. By focusing a low power laser on the forest, it experiences the “heat trap” effect, a localized heating to thermionic emission temperatures. This fundamentally new cathode technology has the potential to be an ideal SEM electron source.

With possible applications not just in life science (medical, pharmaceutical, forensics, biology), but also in material science (semiconductors, geology, metallurgy, nanotechnology, industrial manufacturing), we are developing AweSEM™ to be a robust instrument with the potential to revolutionize industries seeking an affordable and portable solution to high-resolution imaging.


*Not pictured: Mike Chang*



## Success stories

### Electrocatalytic conversion of Carbon Dioxide ($CO_2$)

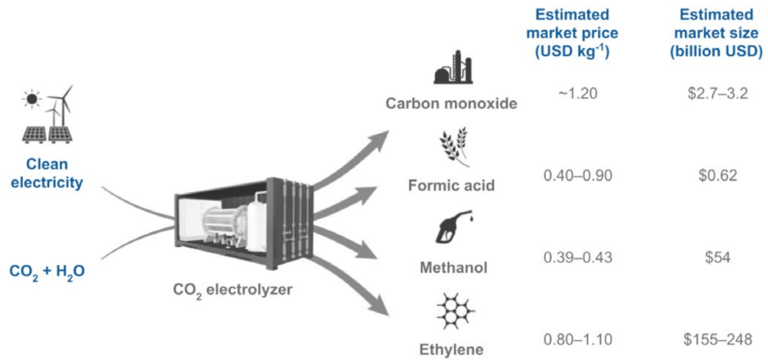
*Principal Investigator: Curtis Berlinguette*
*HQP: Kevan Dettelbach, Jeffrey He, Aoxue Huang, Angelica Reyes, Danielle Salvatore, David Weekes, and Danika Wheeler*

*Not pictured: Aoxue Huang*

**Reliable, cost-effective energy storage systems are required in order to support the growing global production of clean electricity. At present, there are no viable platforms able to accommodate the broad variance in seasonal and geographical energy demand that exists in many parts of the world. Electrolysis has the potential to meet this challenge by utilizing excess clean electricity to drive the formation of fuels and chemicals typically derived from fossil fuels. Water electrolyzers, for example, provide a means of storing energy as clean-burning dihydrogen ($H_2$) in "power-to-gas" schemes. However, the much lower cost of $H_2$ extraction from natural gas and a lack of infrastructure to support the deployment of $H_2$ as a transportation fuel challenges the economic case for this process. These observations provided us with the impetus to develop alternative strategies for converting electricity into chemicals, and a "$CO_2$ electrolyzer" is a particularly appealing candidate for producing high-demand fuels (e.g., syngas, alcohols, hydrocarbons) that can leverage our existing infrastructure.**

The tendency for a $CO_2$ electrolysis reaction to proceed efficiently and selectively is contingent on finding catalytic materials that can drive kinetically challenging electron transfer reactions in a controlled and robust manner. Amorphous multi-metal oxides are excellent candidates for electrocatalysts, but the relationships between structure, composition, and activity within $CO_2$ conversion systems are not well understood. In an effort to establish such relationships, we developed a series of mixed-metal materials that exhibit predictable activities towards the electrochemical conversion of $CO_2$ to CO. We leveraged our ability to make uniform binary/ternary electrocatalysts with exquisitely controlled stoichiometries to establish new activity trends, paving the way towards a high throughput synthesis platform. We are now expanding this platform to accelerate the discovery of new materials for $CO_2$ conversion to high-value multi-carbon products.

We are also addressing the systems-level engineering challenges in order to scale a $CO_2$ electrolyzer towards a commercially viable product. The majority of studies on $CO_2$ electrocatalysts are performed in batch-type "H-cells"; however, these systems are not necessarily relevant to the dynamic environment within an electrolyzer. We have developed a laboratory scale flow cell that incorporates components found in stacks that constitute large electrolyzer units (e.g., flow field, gas diffusion electrode, electrolyte membrane). This prototype is now capable of reaching the high reaction rates required by industry, and can operate continuously for several weeks. The system provides a platform to test and perfect each of the components, and is a critical stepping-stone for translating fundamental $CO_2$ catalyst discoveries into practice.




*Overview of the approximate market sizes (in USD) and prices (USD kg-1) for chemicals directly accessible via electrochemical $CO_2$ conversion.*

# Infrastructure

# New building

**In 2017, we moved into our long-awaited new building. Purpose-designed, vibration-insulated, and equipped with state-of-the-art facilities, the 20,000 feet of laboratory space will be the epicenter of quantum materials progress.**

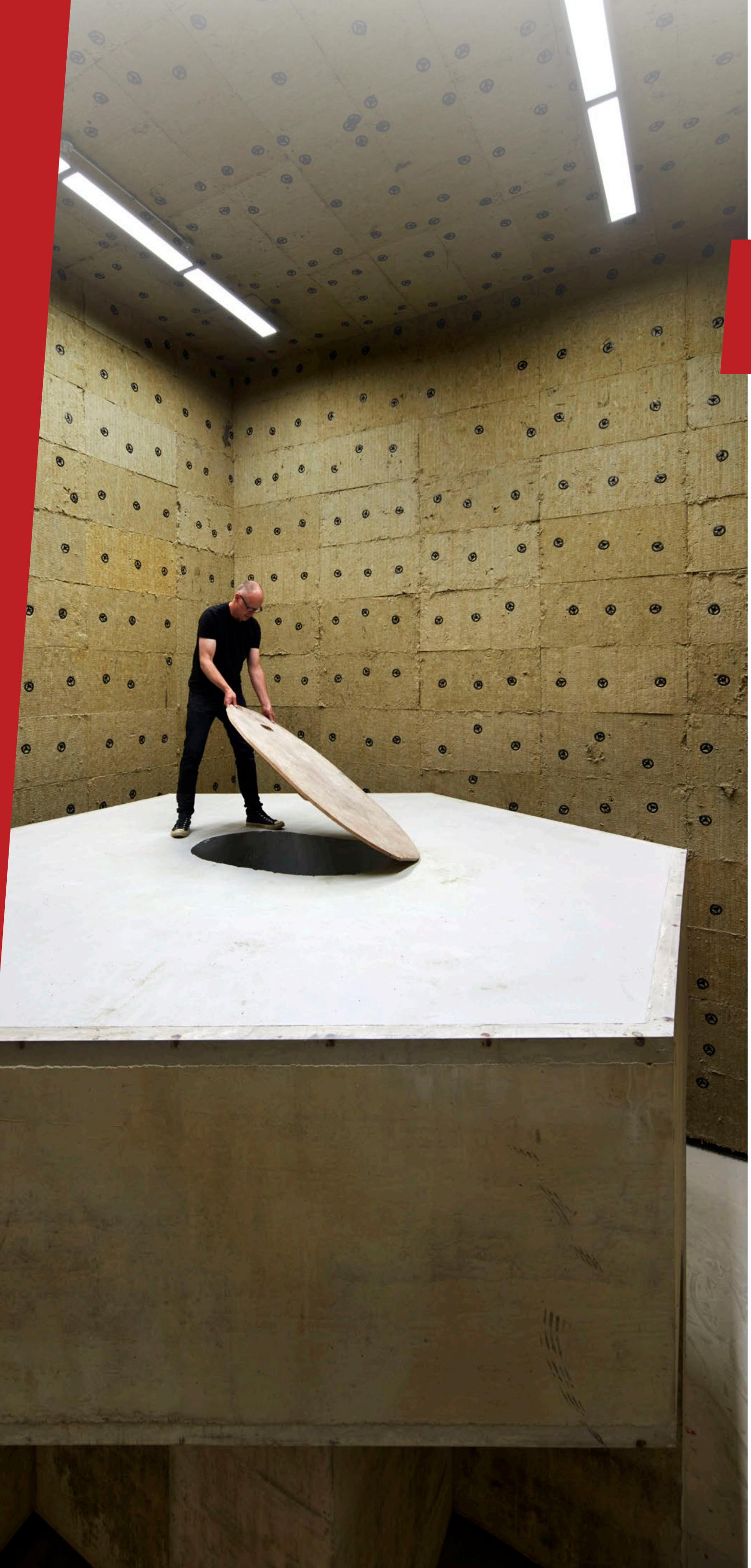
In 2017, we moved into our long-awaited building. Purpose-designed and vibration-insulated, this new space has become the new epicenter of our quantum materials explorations. Currently, we have 4,400 $m^2$ of lab space and are in the process of installing new capabilities to expand our total lab space to more than 6,000 $m^2$.

The new building is located at UBC's Vancouver Campus and is comprised of five storeys of research and support space including 20,000 square feet of laboratory space, a new nanofabrication facility and clean room, and state-of-the-art equipment. Below-grade basement level laboratories are insulated against vibration and fully protected against high magnetic fields. Future space is available to allow for a below-grade low vibration EM suite, which would connect to the main building at basement level.

Labs are configured to be as flexible as possible to support efficient utilization of space and long-term evolution of research direction.

To further encourage collaboration, the facility seamlessly connects with UBC's Applied Materials and Process Engineering Labs (AMPEL) to foster sharing of labs, equipment, and support functions. SBQMI has also significantly increased its computing capacity with the addition of a HPC graded cluster equipped with ~1500 cores, ~5GB/core RAM, nfiniBand interconnects (56Gb/s), 4 GPU nodes each equipped with 4 Nvidia K80 cards (16 in total), and ~120 TB of storage.

The Stewart Blusson Quantum Matter Institute is registered with the Canada Green Building Council, and is pursuing gold-level certification by following best practices regarding materials and resources and avoiding materials from the Living Building Challenge's 'red list'. It was recently awarded the Innovation Award from the Architectural Institute of British Columbia.

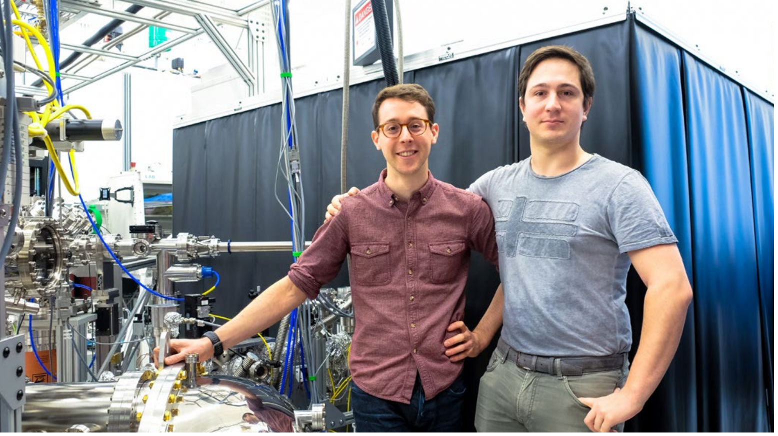


# Laboratories and equipment

**While we have invested heavily in state-of-the-art equipment to tackle some of the most important questions in condensed matter physics, our future plans require nanofabrication facilities that can operate at the nanoscale with high accuracy and reliability. This is vitally important for the development of quantum devices, which require tools that can repeatedly pattern materials with nanometer precision. With this in mind, we are renovating our existing cleanroom and increasing the active floor area to host a variety of new equipment. We anticipate that the new cleanroom will be operational in early 2019.**

We have just completed the installation of our new JEOL Electron Beam Lithography (EBL) system in our low vibration cleanroom, specifically designed for highly sensitive, precision lithography equipment. Importantly, only three of these machines are currently deployed in North America, which we hope will lead to new collaborations with both academic and industry users.

The Quantum Materials and Devices Foundry, under the direction of new faculty hire Dr. Ke Zou, will be dedicated to growing complex oxide materials and multilayer oxide thin films, from which new quantum devices will be fabricated. To complement this work, we are also in the midst of designing SBQMI's new Quantum Materials Electron Microscopy Centre, which will be comprised of three distinct and complementary microscopy systems. The first is a cutting-edge scanning transmission electron microscope (STEM) with electron energy-loss spectroscopy (EELS). The second instrument will be a very specialized and custom-built STEM/EELS instrument optimized for momentum and energy resolution. And the third will be a dual beam scanning electron microscope with a focused ion beam (FIB) for preparing samples for the first two systems. The combination of these three instruments targeting quantum materials will also form the basis for establishing an electron microscopy facility as a general user facility within UBC.



## Success stories

### New developments in spin-, time-, and angle- resolved photoemission spectroscopy

*Principal Investigators: Andrea Damascelli and David Jones*
*HQP: Ryan Day and Fabio Boschini*

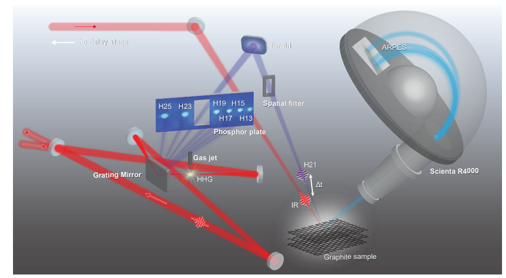
**Angle-resolved photoemission spectroscopy (ARPES) is one of the pre-eminent experimental techniques in the study of condensed matter, offering direct access to the momentum-dependent character, dispersion, and interactions of electronic carriers. SBQMI researchers have sought to push beyond the modern limits of electron spectroscopy, developing new tools for spin (S-) and time-resolved (TR-) ARPES for a more comprehensive picture of the electronic structure of quantum materials.**

In the solid state, relativistic effects of spin-orbit coupling (SOC) can imbue a complex momentum-dependent relationship between electronic spin and orbital degrees of freedom. Giving rise to a variety of different phenomena, the influence of SOC in unconventional superconductors is particularly challenging to ascertain. This has motivated the development of a technique capable of addressing both spin and orbital information independently.

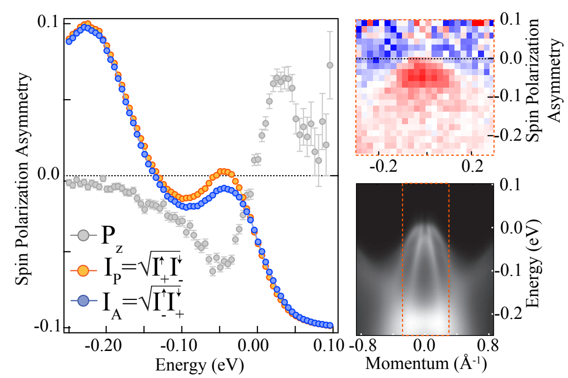
Circularly polarized spin-ARPES (CPS-ARPES) combines the orbital selective photoemission afforded by use of circularly polarized light with a spin-filtering ARPES detector to achieve this goal. Beginning with the ruthenates, we have advanced CPS-ARPES to a fully angle-resolved technique, most recently applied to iron-based superconductors. This work has confirmed the entanglement of spin and orbital degrees of freedom in those electronic states associated with the largest superconducting gaps, raising important questions regarding the superconducting pairing mechanism in these materials. More recently, advances in pulsed laser sources have made the exploration of the out-of-equilibrium electronic distribution viable. In TR-ARPES, the temporal delay between a low energy infrared pulse and a subsequent ultraviolet photoemission pulse is varied, facilitating study of the evolution of the transient electronic distribution.

These tools are essential to developing optically controlled quantum devices as well as expanding our understanding of the fundamental excitation and relaxation of quantum materials such as superconducting cuprates. By driving the system out of the superconducting phase and observing its subsequent relaxation, we found the onset and later suppression of phase fluctuations within the superconducting condensate to be the dominant mechanism suppressing, and then restoring superconductivity.

To date, the challenges to achieving meaningful scientific results with TR-ARPES have been the low photon energies of the probe light, high fluence of the sources, and low energy resolution. To overcome these challenges, we have developed new sources for TR-ARPES, exemplified by a new system offering an unprecedented range of photon energy from 8-40 Ev, allowing for full exploration of momentum space at high repetition rates, and energy and temporal resolution capable of supporting detailed studies of the low-energy dynamics essential to quantum phases of matter.




*Left: Schematic of TR-ARPES apparatus. Middle: Evidence of gap-filling in Bi2212 high-Tc superconductor. The filling of intensity within the superconducting energy gap reflects the prominent role of phase fluctuations in destroying the superconducting condensate. Right: Schematic diagram of the transient evolution of the condensate in the experiment.*



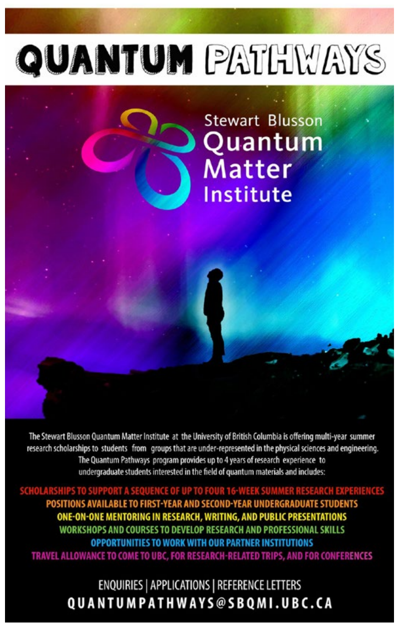

*CPS-ARPES on Fe-based superconductor FeSe. Left: CPS-ARPES intensity near normal emission with spin and orbital vectors aligned (blue) and counter-parallel (orange). Calculated polarization asymmetry from these curves shown in grey. Top Right: Polarization asymmetry over a range of momentum near the Brillouin zone-centre (blue positive, red negative). Bottom right: high-resolution ARPES on FeSe over a wider range of momentum, illustrating the hole bands interacting via spin-orbit coupling.*

# Training

**In addition to pursuing scientific breakthroughs, it is our aspiration to increase the number of Highly Qualified Personnel entering tomorrow's workforce. At the core of our strategic plan is a commitment to equip an outstanding cadre of graduates with the skills needed to advance quantum materials innovations.**

## QuEST (Quantum Electronic Science and Technology) program

The centerpiece of SBQMI's student training program is QuEST, an integrated study program combining access to world-class researchers and facilities with development of professional skills and opportunities to experience different research environments — internationally and in the broader UBC community. This enriched graduate program is aimed at increasing the quantity and quality of graduate students at SBQMI, engaging these students in our international research network, and connecting them to our industrial partners. As of 2017, the QuEST program has grown to 43 students in our cohort of 113 graduate students.




## Programming and outreach

An essential element of engaging students once they are at SBQMI is our comprehensive program of training, designed to prepare them for academic success, and for success in building a future career.

To support our students in their academic endeavours, we launched a summer experimental skills workshop in 2017. With 10 intensive, hands on sessions, this program trains our students to safely, effectively, and confidently use our facilities and equipment, setting them up for success in the experimental component of their graduate studies. Plans are underway to enhance this program and connect it to industrial partners upon the completion of our nanofabrication facility.

SBQMI also offers numerous professional development opportunities to augment each student's academic work. Among these are a series of student-led talks where students share their research progress and challenges, practice their presentation skills, and receive constructive feedback in a supportive environment. Monthly panel discussions are also held, giving students an opportunity to learn about careers from leaders in industry, academia, and entrepreneurship, and a mentorship program connects them with successful individuals in a variety of career paths.

This year, we have also launched 2 undergraduate internship programs, where selected students work with a faculty member on a research project for 16 weeks over the summer. This not only allows them to explore, and consider future studies, in quantum materials, it provides SBQMI with the opportunity to attract top-tier future graduate students to our Institute. One of these programs – Quantum Pathways – is particularly designed to attract students from under-represented groups in quantum physics and provides support for a sequence of up to four summer research experiences.

## Signature events

In addition to the outreach activities, another component of SBQMI's commitment to our trainees and community is centred on knowledge exchange at conferences, workshops, and brainstorming sessions. In 2017, SBQMI held two signature events to facilitate the sharing of research results and ideas. To deliver these events, we collaborated with researchers from five universities and organizations in Canada and around the world.

### Electronic Properties of Strongly Correlated Materials and their Link to Physical Properties

December 4-7, 2017, University of British Columbia
*Organizers: Mona Berciu (University of British Columbia), Hao Tjeng (Max Planck Institute for Chemical Physics of Solids), Dirk van der Marel (University of Geneva)*

Symposium
Invited speakers: 26
Total participants: 90

Abstract: This three-day workshop will bring together some of the leading experts in the study of strongly correlated materials and their properties, both from the theoretical and from the experimental side, to survey the status of this field. Presentations discussing various new materials, various experimental techniques, and various theoretical and numerical approaches for studying them will be followed by extended, in-depth discussions. The goal of this workshop is to find commonalities between different behaviours that might give additional clues about their possible origin, and identify additional avenues of research, such as what new materials and/or measurements might reveal important clues to some of the difficult questions.

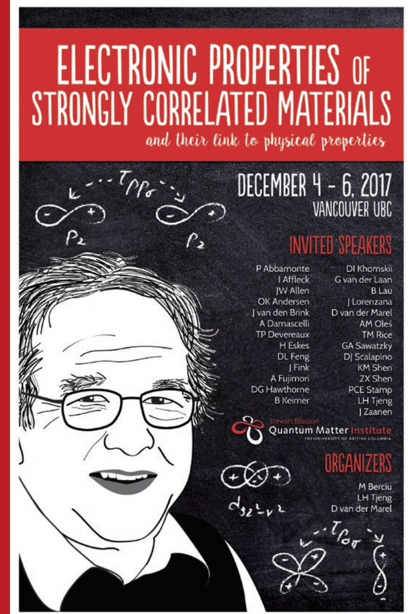
### Ultrafast Quantum Control of Matter: The Path to Solids

School: December 11-12, 2017, Brainstorming: December 13-15, 2017 — University of British Columbia
*Organizers: Paul Corkum (University of Ottawa), Andrea Damascelli (University of British Columbia), Claudio Giannetti (Università Cattolica del Sacro Cuore, Brescia), David Jones (University of British Columbia), François Légaré (L'Institut national de la recherche scientifique)*

School and Brainstorming
Invited speakers: 21
Total participants: 86

Abstract: The goal of this event is to promote real advances in the field of quantum control of matter. In particular, building on the advances in atomic and molecular physics, we will discuss possible new strategies to exploit the light-matter interaction at the quantum level to manipulate the properties of solids and create transient non-equilibrium states with no counterpart at equilibrium. This approach will complement the SBQMI mission, which focuses on the exploitation of equilibrium many-body quantum-mechanical properties. This workshop will constitute the first step to provide SBQMI with the knowledge necessary to develop new experiments to investigate and control the properties of quantum materials driven out of thermodynamic equilibrium by light pulses shorter than the thermalization time of the internal degrees of freedom of the material.

In order to boost the discussion and the interactions among participants, the talks and lectures will be followed by quite long roundtables and discussion/question times in which we will introduce some relevant questions and we will try to get the speakers and the audience involved in an open-minded and unbiased discussion.





# Partners

**Collaboration with our academic partners and institutions is at the core of our success. Novel discoveries are never the work of one isolated researcher. Rather, it is by working with dedicated, interdisciplinary, and highly cooperative teams of scientists, technical staff, and trainees that we discover new knowledge and solve complex problems.**

**By promoting strong collegiality, we have formed long-term alliances resulting in greater research outputs, a better educational experience for our students, and an increased global impact.**

### Max Plank-UBC-UTokyo Centre for Quantum Materials

In the spring of 2017, the University of Tokyo formally joined the UBC and the Max Planck Society of Germany in an international partnership designed to advance quantum materials research and innovation. This new three-way partnership led to the establishment of the Max Planck-UBC-UTokyo Centre for Quantum Materials (CQM), an expansion of the original Max Planck-UBC Centre for Quantum Materials.

The inaugural year of the expanded CQM included a first meeting in Stuttgart, Germany in December amongst the three co-directors to discuss the organization and scientific direction of the Centre. In 2017, we also developed a joint PhD degree program between UBC and the University of Stuttgart.

### TRIUMF

TRIUMF is Canada's national laboratory for nuclear and particle physics research, and one of the world-leading subatomic physics research laboratories.

In 2017, TRIUMF began work on two projects, which will significantly increase beamtimes for SBQMI investigators. In the near term, there will be a new high momentum muon beamline M9 (funded by the Canada Foundation for Innovation (CFI) and the BC Knowledge Development Fund (BCKDF)). This beamline will allow experiments under high pressure and at low temperatures, which will be extremely useful for SBQMI applications. Longer term, the new electron accelerator, named the Advanced Rare IsotopE Laboratory (ARIEL), is TRIUMF's new flagship facility. It will expand Canada's capabilities to produce and study isotopes for physics and medicine, and will result in a significant increase in beamtime for the 8Li+ beams used by SBQMI investigators.

### Canadian Light Source

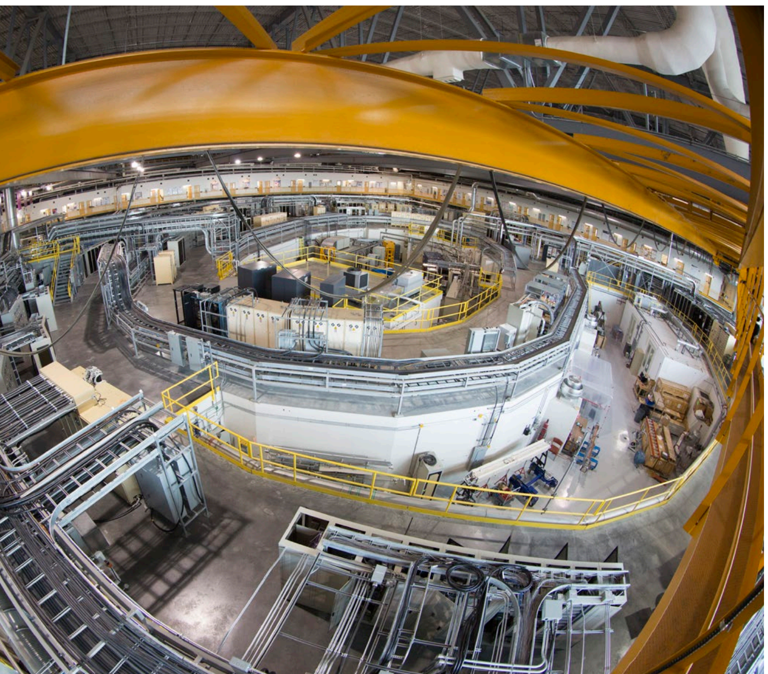
Officially opened in 2004, the Canadian Light Source (CLS) is Canada's national centre for synchrotron research. Our work at CLS plays a crucial role in many of our discoveries and research achievements. In fact, we have developed and currently operate two beamlines at CLS, and our faculty enjoys priority access to the facility.

Damascelli and Sawatzky have played pivotal roles in obtaining funding from CFI and BCKDF (approximately $25 M) to design and build two beamlines each with several end stations. The high-resolution spin polarized angle resolved photoelectron spectroscopy beamline with unique capabilities is now in the final stages of completion. Commissioned in 2012, the resonant elastic and inelastic X-ray scattering (REIXS) beamline is now one of most oversubscribed user facilities at the CLS.

**Working with our close international collaborators, we have made significant discoveries using the beamlines at CLS. Amongst them are:**

### Uncovering mechanisms for high mobility 2D electron liquids at oxide interfaces

In a collaboration with a group from the Technical University of Denmark, we studied oxide interfaces, which host exceptionally high electron mobilities. The materials have a tri-layer structure with a strontium titanate substrate, disordered film overlayer, and manganese-oxide based buffer layer sandwiched in between. Using a detailed, quantitative analysis of resonant X-ray reflectometry experiments carried out at the CLS, our team discovered that a combination of polarity induced electronic reconstruction and oxygen vacancies was responsible for the high mobilities. Recently published in Nano Letters (American Chemical Society), this result builds on an earlier study of the collaboration.

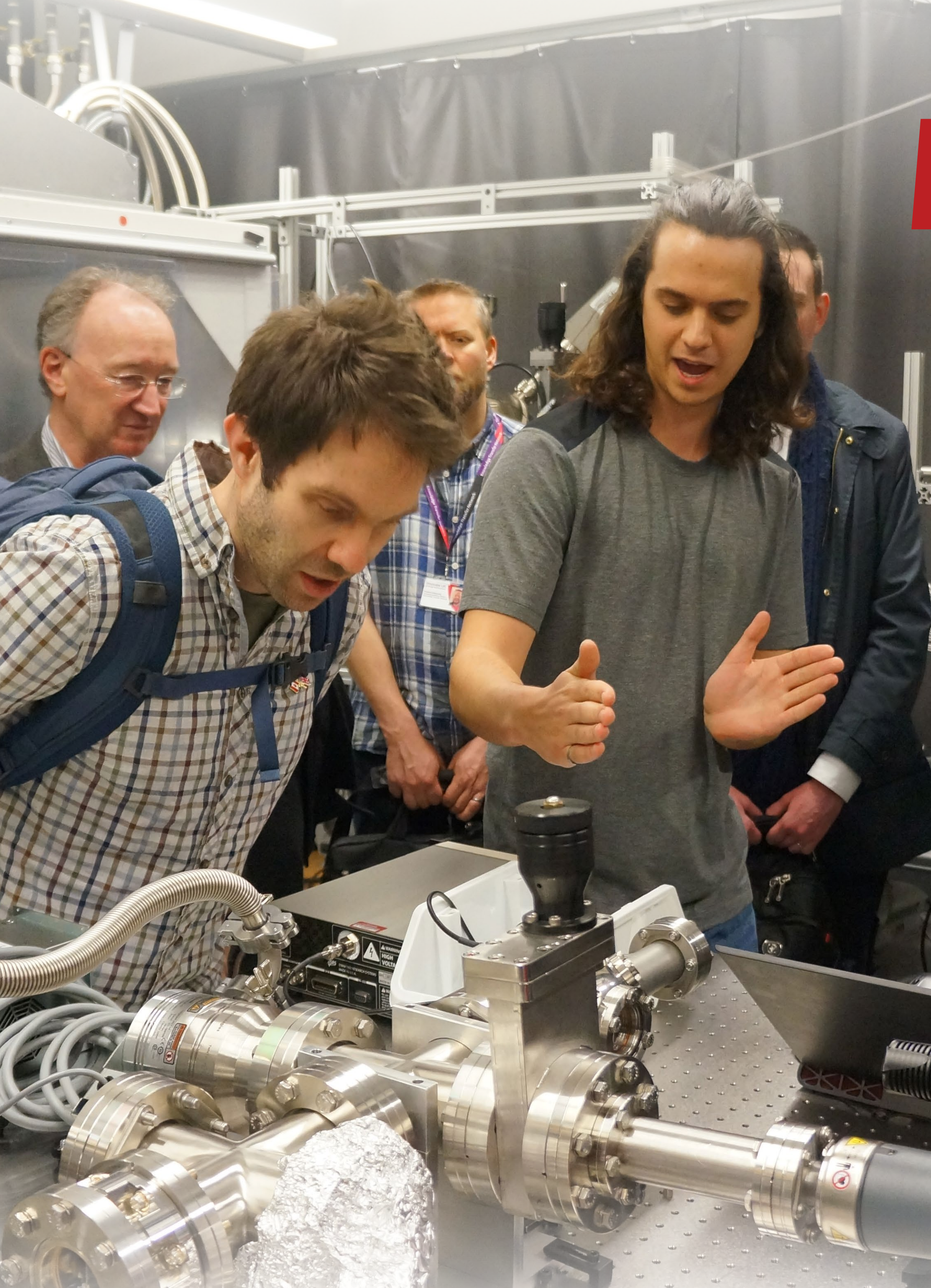


### Manipulating macroscopic properties in oxide heterostructures through oxygen octahedral connectivity at interfaces

Working with a team from the University of Twente, we studied high-quality oxide heterostructures where structural effects imposed at the atomically abrupt interfaces provide an effective control mechanism for macroscopic properties. Through the growth of lanthanum strontium manganite ($(La,Sr)MnO_3$) films on perovskite ($NdGAO_3$) substrates, the researchers found that octahedral rotations imposed by the substrates could be used to tune the magnetic anisotropy of the films. Further, they found that strontium titanate ($SrTiO_3$) buffer layers could cancel out the octahedral rotations, and thus the switching of the magnetic anisotropy. In a subsequent study, the collaboration found that similar octahedral-rotation-coupling effects could be used to manipulate the space group symmetry of epitaxial films, and thus tune metal-insulator and magnetic ordering transition temperatures. Finally, in the most recent study (submitted to Nature Materials), through precise control of octahedral tilts in nickelate-based superlattices, the collaboration reproduced the entire electronic and magnetic phase diagram of the nickelate family, and grew devices where the metal-insulator transition could be optically switched at room temperature.

### Depth resolved orbital symmetry and charge density of the 2D electron liquid at lanthanum aluminate ($LaAlO_3$)/strontium titanate ($SrTiO_3$) interfaces

We have developed a new way to study electron liquids in buried oxide interfaces. Through experiments at CLS, we have mapped out the reflectivity of X-rays, over a range of reflection angles, and for specific energies tuned to core level resonances. We applied this technique to the $LaAlO_3/SrTiO_3$ 2D electron liquid (2DEL), a highly studied yet highly controversial system, where the electron liquid emerges when the $LaAlO_3$ (LAO) film is thicker than three crystallographic unit cells. We studied a range of high quality samples grown by collaborators at the University of Twente in the Netherlands, and found a host of exciting results. For samples where the LAO film was too thin for the 2DEL to emerge, we were able to quantify the atomic-layer depth resolved symmetry breaking of the orbital energies for the titanium (Ti) atoms in the substrate layers nearest the interface. For samples with a thicker LAO layer and subsequent 2DEL, we were able to quantify the atomic-layer depth dependence of the 2DEL charge density and orbital symmetry. The results were consistent with the polar catastrophe model, a particular explanation for the presence of the 2DEL, which has been highly debated in recent years. Presented at several international conferences, these exciting results are being prepared for publication.



# Translation

**One of the pillars of SBQMI is to actively promote translation of fundamental research results into technology demonstrations and intellectual property — some with the potential to spark new industries and accelerate the adoption of applied research results by Canadian and global companies.**

In 2017, we made solid progress laying the foundation for our translation program by supporting 4 patent filings on technologies that are potentially viable for commercial application. Building a portfolio provides SBQMI with intellectual assets, protects inventions, and provides the basis for meaningful commercial interactions with industry. And, while some of the intellectual property will be licensed, some is expected to provide the basis for building new ventures.

Like our Max Planck collaboration, we see great value in collaborations and partnerships with industry. Currently, there isn't an overall 'quantum industry', but rather individual industries that could potentially benefit from quantum solutions to their unique challenges. Engagement with these companies is critical to identifying classically difficult problems for which a quantum-inspired approach might provide an elegant solution. One example is the AweSEM™ inexpensive electron microscope project, where the new approach to an electron emitter allows a 10x reduction in the size of the electron microscope by eliminating the bulky vacuum pumps, and reducing the high voltage power supplies needed. Because of the nature of the (patented) electron source, it is possible to modulate the output to improve resolution and compensate for imperfections, potentially eliminating the need to keep samples under vacuum.


**Quantum Research — SBQMI coming of age in BC**

In May 2017, Dr. Damascelli was invited to give the plenary talk at the BCIC Tech Summit — the preeminent annual business meeting in British Columbia. We created a professional video that preceded his very well received talk about "How Quantum will Change the World", SBQMI's first public introduction to the British Columbia business community.

**Future Horizons — working towards Quantum Canada**

Quantum research activities are spread across Canada — with Canada First Research Excellence Fund (CFREF) supporting activities at Sherbrooke University, the Institute for Quantum Computing (IQC) at Waterloo University, and SBQMI here at UBC. Working in collaboration with the National Research Council (NRC), we are striving to create a Quantum Canada strategy in the coming year that will articulate our national approach and provide a platform for engagement with the UK and European Union on the world stage.

## Watch

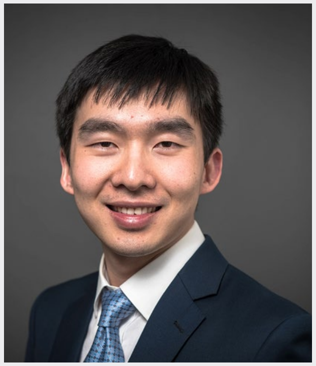
***How Quantum will Change the World***

https://www.youtube.com/watch?v=Dn5maSpO8Vg

## Quantum discovery in action

**In some cases, the translation is about the mobilization of quantum understanding and knowledge. Our engagement with ARM Ltd and Applied Materials, led to the award of a Defense Advanced Research Projects Agency (DARPA) grant. We are partnering to help develop a correlated electron switch (CES), which is a non-volatile logic switch capable of replicating the function of a neuron and synapse. Modeling the material characteristics based on theory, and subsequently improving and testing, will be critical to creating these devices. The goal is to deliver a technology enabling true neuromorphic computing, capable of ten thousand times better computing power and efficiency, and with revolutionary reductions in size, weight, and power requirements.**

# Principal investigators



# Ziliang **Ye**

## Mission

*To understand and control the emergent phenomenon in low-dimensional quantum materials with a wide range of optical techniques.*

### ***Background***

My research interest has been centered on the elucidation of electronic structure and their dynamics in low-dimensional materials using ultrafast optical techniques. In the past, I discovered for the first time the light-matter interaction in 2D transition metal dichalcogenides is originated from an anomalous excitonic effect by using two-photon photoluminescence spectroscopy. More recently, I was able to apply ultrafast optical pulses to manipulate the valley pseudospin, an emerging degree of freedom in transition metal dichalcogenide which can be a promising platform for quantum information processing. Besides ultrafast techniques, I am also experienced in applying scanning nearfield optical microscopy to study emergent phenomena beyond the diffraction limit.

### ***Future***

In the short term, I plan to build a research program to study the atomically thin van der Waals (vdW) materials and heterostructures, with emphasis on their light-matter interaction, spin-valley degrees of freedom, strongly correlated effects, topological phenomena, and optical induced phases. We will construct an ultrafast optical spectroscopy setup which can measure the material's transient properties with femtosecond time resolution at liquid helium temperature in a large magnetic field. In particular, the setup will allow multi-dimensional nonlinear optical spectroscopy in nanoscale materials for studying the hidden coherence within their electronic structure. Utilizing the same setup, we will combine ultrafast probe pulses with quasi-continuous pump pulses to explore the opportunity to artificially engineer the material's band structure with so-called optical Floquet states.

In parallel, we will build a new type of nearfield optical microscope to extend the optical imaging resolution beyond the diffraction limit. Compared with conventional nearfield techniques, this new method is expected to bring more quantitative information about the intrinsic optical property on the length scale that is critical to vdW heterostructures, where nonconventional superconductivity and long-lived interlayer exciton have been recently observed. In the long run, I am interested in integrating these vdW materials into nanophotonic platforms as active elements for achieving novel device applications.

### ***Selected Publications***

Z. Ye, T. Cao, K. O'brien, H. Zhu, X. Yin, Y. Wang, S.G. Louie, and X. Zhang. Probing excitonic dark states in single-layer tungsten disulfide. Nature, **513**, 214 (2014).

Z. Ye, D. Sun, and T.F. Heinz. Optical manipulation of valley pseudospin. Nature Physics, **13**, 26 (2017).

X. Yin, Z. Ye, D.A. Chenet, Y. Ye, K. O'Brien, J. C. Hone, and X. Zhang. Edge nonlinear optics on a MoS2 atomic monolayer. Science, **344**, 6183 (2014).

### ***Career Highlights***

*Ph.D.*
*University of California, Berkeley*
*2013*

*Postdoctoral Fellow*
*University of California, Berkeley*
*2014*

*Postdoctoral Fellow*
*Columbia University*
*2017 – 2017*

*Assistant Professor*
*University of British Columbia*
*2017 – present*

# Ke **Zou**

## Mission

*We aim to achieve scientific and technological breakthroughs in new materials and functional devices, utilizing the high tunability of the properties of two-dimensional crystals.*

### Background

My research interests are in the growth and studies of complex oxide and chalcogenide films, and electrical and magneto-transport studies of complex, nanoscale graphene devices by molecular beam epitaxy (MBE) growth. In addition, I have extensive experience in crystal characterization methods such as X-ray diffraction (XRD) and synchrotron XRD.

Research on new materials and functional devices has led to changes in our daily life for the past several decades. Our research will integrate molecular beam epitaxy synthesis with nanostructure fabrication and characterization techniques for physical and electronic structures, to explore and control the generated properties in new materials and in new forms of materials, such as in heterostructures and gated field effect transistors.

### Future

We aim to build a two-step research program to systematically design and study nanostructured materials with exceptional properties and functionalities. The first step is to utilize MBE and device fabrication to create thin films, heterostructures, and transistors of 2D crystals and optimize the physical crystal structures. The second step will be to characterize these crystals' properties and functionalities, and to examine the tunability of properties by methods such as gating the crystals, adding dopants, and applying strain. Together, we hope to advance fundamental understanding of the interactions between the 2D layers and the interface, with subsequent efforts focused on establishing a rapid feedback cycle so each new design is driven by specific improvements to its functionalities.

To achieve this, we will be acquiring a cluster system at SBQMI, which combines an oxide MBE, a metal chalcogenide MBE, and an angle-resolved photoemission spectroscopy (ARPES) system. Complex structures combining oxides and metal chalcogenides often lead to functions that are not present in simple devices. Experiments probing air-sensitive materials are demanding and challenging. These challenges provide the motivation for the development of the MBE and ARPES *in situ* instrumentation. This unprecedented combination of equipment will fuel an innovative materials research program at UBC.

### Selected Publications


K. Zou, X. Hong, D. Keefer, and J. Zhu. Deposition of high-quality HfO2 on graphene and the effect of remote oxide phonon scattering, Phys. Rev. Lett. **105**, 126601 (2010).

K. Zou, F. Zhang, C. Clapp, A.H. MacDonald, and J. Zhu. Transport studies of dual-gated ABA- and ABC- trilayer graphene: band gap opening and band structure tuning in very large perpendicular electric field. Nano Lett. **13**, 369 (2013).

K. Zou, S. Ismail-Beigi, K. Kisslinger, X. Shen, D. Su, F.J. Walker, and C.H. Ahn. LaTiO3/KTaO3 interfaces: a new 2D electron gas system. APL Mater. **3**, 036104 (2015).


### Career Highlights

*Ph.D.*
*Pennsylvannia State University*
*2012*

*Postdoctoral Fellow*
*Yale University*
*2012 – 2018*

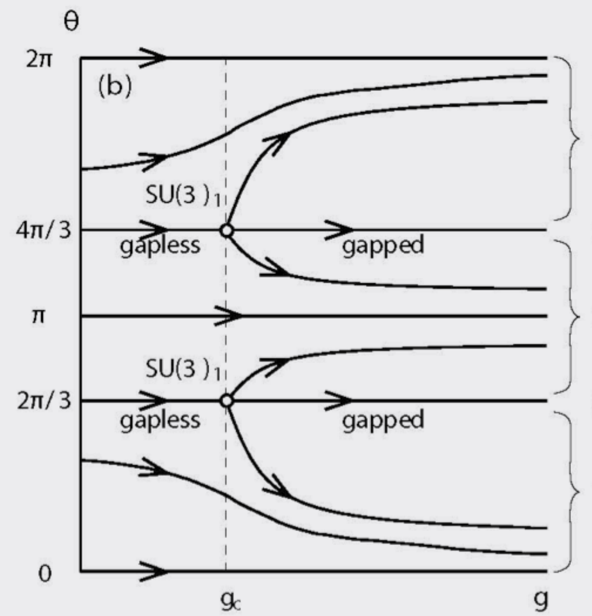
*Assistant Professor*
*University of British Columbia*
*2018 – present*

# Ian **Affleck**

## Mission

*We work on solving difficult problems in low dimensional, strongly-correlated condensed matter systems using a combination of analytical and numerical methods, frequently borrowing from high energy physics.*

One method which we have applied with great success is conformal field theory. While its original development was motivated by string theory, we have applied it to quantum spin chains, quantum wires, and various types of quantum impurity problems including the Kondo effect and junctions of quantum wires. We also use the renormalization group, which straddles high energy and condensed matter physics, and have frequently applied large scale numerical techniques to these problems, especially the Density Matrix Renormalization Group. Our collaborators include Steven White at UC Irvine and Frederic Mila at École Polytechnique Fédérale de Lausanne.




### Selected Publications

I. Affleck, T. Kennedy, E. Lieb, and H. Tasaki. Rigorous results on valence-bond ground-states in antiferromagnets. Phys. Rev. Lett. **59**, 799 (1987).

I. Affleck and J. Brad Marson. Large-N limit of the Heisenberg-Hubbard model — implications for high-Tc superconductors. Phys. Rev. B. **37**, 3774 (1988).

I. Affleck, T. Kennedy, E. Lieb, and H. Tasaki. Valence bond ground-states in isotropic quantum antiferromagnets. Comm. Math. Phys. **115**, 477 (1988).

### Current Projects

*Macroscopic numbers of interacting Majorana fermions*

*Majorana fermions at superconductor/Luttinger liquid interfaces*

*A possible non-Fermi liquid Kondo effect in graphene*

*Quantum spin systems for quantum computing*

*Generalization of the Haldane conjecture to the groups SU(n)*

### Career Highlights

*Ph.D.*
*Harvard University*
*1976 – 1979*

*Assistant Professor*
*Princeton University*
*1981 – 1987*

*Professor*
*University of British Columbia*
*1987 – present*

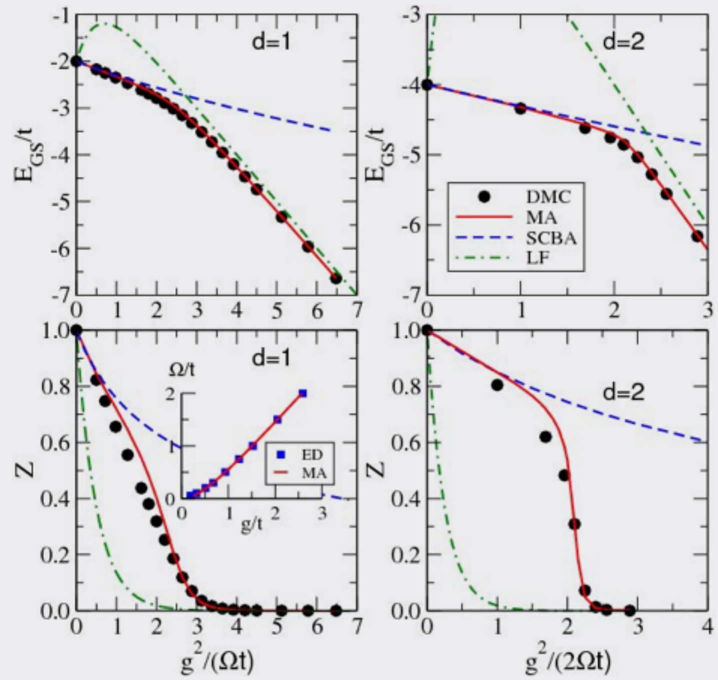
### Group Composition

**Graduate students**
*Samuel Gozel (EPFL)*
*Peter Gustainis*
*Zheng Shi*
*Tarun Tummuru*
*Kyle Wamer*

**Postdoctoral fellows**
*Emilian Nica*
*Dongsheng Wang*

# Mona **Berciu**

Our main interest is in the development of variational approximations that are quantitatively accurate yet computationally efficient, and can be used to explore the properties of some models of strongly-correlated systems in a wide region of the parameter space. Such studies supplement numerical exact studies, which are usually extremely time consuming and have limitations in terms of system size, temperature range, etc. Our main focus so far has been on few-particle properties in the extremely underdoped limit of insulators at zero temperature, but we are now attempting to expand our expertise to cover finite temperatures and finite particle densities.




## Mission

*We develop new variational approximations to study models of strongly-correlated systems, aiming to understand their unusual properties and relevance to real materials.*

### Selected Publications

H. Ebrahimnejad, G.A. Sawatzky, and M. Berciu. The dynamics of a doped hole in cuprates is not controlled by spin fluctuations. Nat. Phys. **10**, 951 (2014).

M. Berciu and R.N. Bhatt. Effects of disorder on ferromagnetism in diluted magnetic semiconductors. Phys. Rev. Lett. **87**, 107203 (2001).

M. Berciu. Green's function of a dressed particle. Phys. Rev. Lett. **97**, 036402 (2006).

### Current Projects

*Effective magnon-mediated interactions between holes doped in a cuprate parent layer*

*Effective phonon-mediated interactions between particles in systems with Peierls-type electron-phonon coupling*

*Melting of a bipolaron crystal as a model for insulator-to-metal transition in $BaBiO_3$ and in rare-earth nickelates*

*Properties of polarons at finite temperatures*

*Exploring mapping between complex and simpler models*

### Career Highlights

*Ph.D.*
*University of Toronto*
*1995 – 1999*

*Postdoctoral Fellow*
*Princeton University*
*2000 – 2002*

*Research Associate*
*Princeton University*
*2001 – 2002*

*Assistant Professor*
*University of British Columbia*
*2002 – 2007*

*Associate Professor*
*University of British Columbia*
*2007 – 2012*

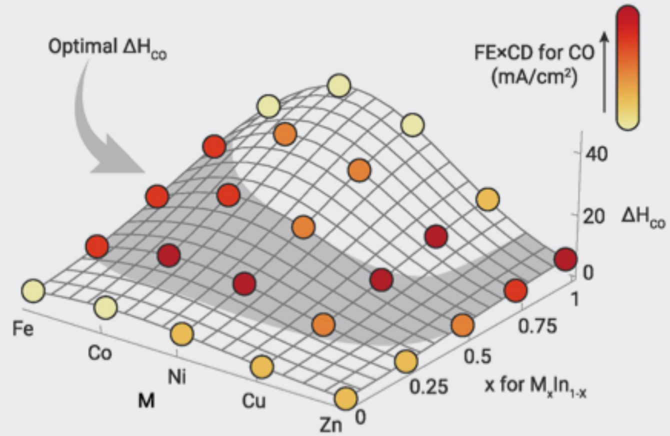
*Professor*
*University of British Columbia*
*2012 – present*

### Group Composition

**Graduate students**
*Nathan Cheng*
*Tao Fang*
*Stepan Fomichev*
*John Sous*
*Oliver Yam*

**Postdoctoral fellows**
*Mi Jiang*
*Mirko Möller*

Our research program specializes in the development and study of advanced materials for use in clean energy conversion and storage schemes, including $CO_2$ utilization technologies, dynamic windows and next-generation solar cells.




# Curtis **Berlinguette**

## Mission

*To accelerate the discovery of materials for clean energy applications.*

## Selected Publications

R.D.L. Smith, M.S. Prevot, R. Fagan, Z. Zhang, P.A. Sedach, M.K.J. Siu, and C.P. Berlinguette. Photochemical Route for Accessing Amorphous Metal-Oxide Materials for Heterogeneous Water Oxidation Catalysis. Science, **340**, 60 (2013).

D.M. Weekes, D.A. Salvatore, A. Reyes, A. Huang, and C.P. Berlinguette. Electrolytic $CO_2$ Reduction in a Flow Cell. Acc. Chem. Res., **51**, 910 (2018).

T. Li, T. Kasahara, J. He, K.E. Dettelbach, G.M. Sammis, and C.P. Berlinguette. Photoelectrochemical Oxidation of Organic Substrates in Organic Media. Nat. Comm. **8**, 390 (2017).

## Current Projects

*$CO_2$ electrolysis*

*High throughput clean energy materials discovery*

*Dynamic glass*

*Lattice engineering*

*Interfacial charge transfer*

## Career Highlights

*Ph.D.*
*Texas A&M University*
*2000 – 2004*

*Postdoctoral Fellow*
*Harvard University*
*2004 – 2006*

*Assistant Professor*
*University of Calgary*
*2006 – 2011*

*Associate Professor*
*University of Calgary*
*2011 – 2013*

*Associate Professor*
*University of British Columbia*
*2013 – 2017*

*Professor*
*University of British Columbia*
*2017 – present*

## Group Composition

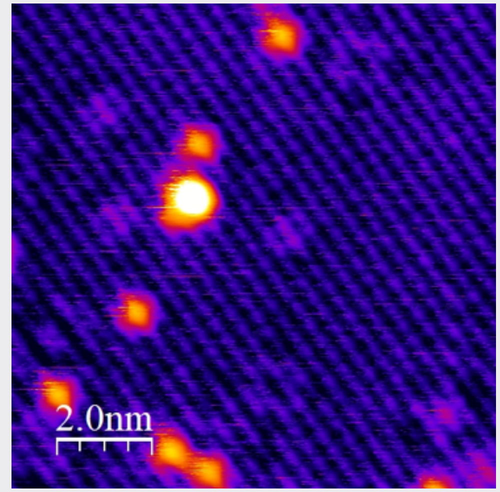
**Graduate students**
*Valerie Chiykowski*
*Roxanna Delima*
*Kevan Dettelbach*
*Rebecka Forward*
*Lucy Garland*
*Ken Hu*
*Aoxue Huang*
*Ryan Jansonius*
*Cameron Kellett*
*Caroline Krzyszkowski*
*Tengfei Li*
*Ben MacLeod*
*Thomas Morrissey*
*Fraser Parlane*
*Angelica Reyes*
*Danielle Salvatore*
*Rebecca Sherbo*
*Danika Wheeler*

**Postdoctoral fellows**
*Yang Cao*
*Pierre Chapuis*
*Wei Cheng*
*Jingfu He*
*Noah Johnson*
*Brian Lam*
*Marta Moreno*
*Lacey Reid*
*Carolyn Virca*
*David Weekes*

**Research associate**
*Phil Schauer*

# Doug **Bonn**

We synthesize ultraclean samples of quantum materials, particularly high temperature superconductors, by bulk single crystal and film growth. These samples are then used for microwave spectroscopy, which reveals the low frequency conductivity spectrum, and scanning tunnelling spectroscopy, which provides spectroscopic capabilities at low temperatures on a nanoscale. Crystal growth facilities include a wide range of furnaces in a solid state chemistry laboratory. Spectroscopic facilities involve custom microwave apparatus including a unique broadband spectrometer, and scanning tunnelling microscopes operating at room temperature, 4 Kelvin, and below 1 Kelvin.




## Mission

*We combine synthesis of quantum materials with the study of their electronic properties using low energy spectroscopic methods.*

### Selected Publications

W.N. Hardy, D.A. Bonn, D.C. Morgan, R. Liang, and K. Zhang. Precision Measurements of the Temperature Dependence of lambda in YBa2Cu3O6.95: Strong Evidence for Nodes in the Gap Function. Phys. Rev. Lett. **70**, 3999 (1993).

D.A. Bonn, K. Zhang, R. Liang, D.J. Baar, D.C. Morgan, P. Dosanjh, T.L. Duty, A. MacFarlane, G.D. Morris, J.H. Brewer, W.N. Hardy, C. Kallin, and A.J. Berlinsky. Microwave Measurements of the Quasiparticle Scattering Time in Y Ba2Cu3O6.95. Phys. Rev. B. **47**, 11314 (1993).

N. Doiron-Leyraud, C. Proust, D. LeBoeuf, J. Levallois, J.-B. Bonnemaison, R. Liang, D.A. Bonn, W.N. Hardy, and L. Taillefer. Quantum oscillations and the Fermi surface in an underdoped high temperature superconductor. Nature **447**, 565 (2007).

### Current Projects

*Quasiparticle interference in Fe-based superconductors*

*Microwave spectroscopy of long-lived quasiparticles in Fe-based superconductors*

*Quasiparticle interference in Weyl semimetal ZrSiTe*

*Development of ultra-low temperature STM with in situ MBE*

*Vapour-transport growth of chalcogenides*

### Career Highlights

*Ph.D.*
*McMaster University*
*1983 – 1989*

*Postdoctoral Fellow*
*University of British Columbia*
*1989 – 1991*

*Research Associate*
*University of British Columbia*
*1992 – 1994*

*Assistant Professor*
*University of British Columbia*
*1994 – 1997*

*Associate Professor*
*University of British Columbia*
*1997 – 2000*

*Professor*
*University of British Columbia*
*2000 – present*

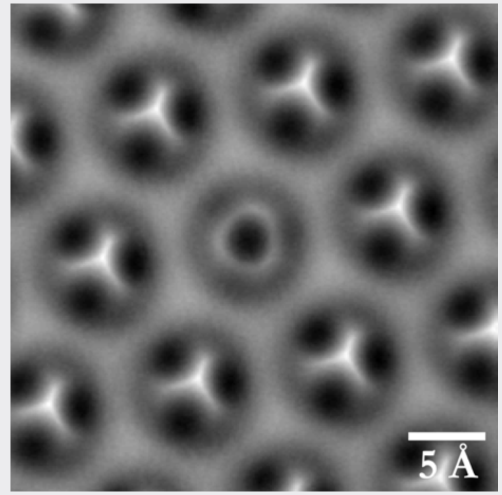
### Group Composition

**Graduate students**
*Jeff Bale*
*Graham Baker*
*Gelareh Farahi*
*Aaron Kraft*
*Andrew Macdonald*
*Brandon Stuart*

**Postdoctoral fellows**
*Shun Chi*
*Katherine Cochrane*

**Research associates**
*James Day*
*Jisun Kim*

My research interests broadly encompass the study of electronic processes where nanoscale structure influences or reveals the underlying physics. Using scanning probe microscopy (SPM) techniques, my group investigates materials for organic electronics and optoelectronics, graphene and other carbon-based nanomaterials, and other materials where a nanoscale view offers the potential for new understanding. We also work to expand the SPM toolbox, developing new methods in order to probe different aspects of materials, and to understand leading edge techniques.




# Sarah **Burke**

## Mission

*Building understanding from the atomic scale up of key electronic and optoelectronic processes in nanoscale materials and at interfaces, to pave the way for next generation materials and technologies.*

### Selected Publications

N. Levy, S.A. Burke, K.L. Meaker, M. Panlasigui, F. Guinea, A.H.C. Neto, A. Zettl, and M.F. Crommie. Strain-Induced Pseudo-Magnetic Fields Greater Than 300 Tesla in Graphene Nanobubbles. Science **329**, 544 (2010).

S. Chi, S. Grothe, R. Liang, P. Dosanjh, W.N. Hardy, S.A. Burke, D.A. Bonn, and Y. Pennec. Scanning Tunneling Spectroscopy of the Superconducting Gaps of LiFeAs. Phys. Rev. Lett. **109**, 087002 (2012).

S.A. Burke, J.M. Mativetsky, R. Hoffmann, and P. Grutter. Nucleation and submonolayer growth of C-60 on KBr. Phys. Rev. Lett. **94**: 096102 (2005).

### Current Projects

*Energetic landscapes of organic heterojunctions*

*Interaction between light and organic semiconductors on a single molecule level using SPM*

*Quasiparticle interference: understanding interactions with defects and mapping electronic properties of novel 2D materials*

*Dynamics of charge separation in organic solar cells using time- and angle-resolved photoemission spectroscopy*

*Molecular imaging of heterogeneous catalysis in action*

### Career Highlights

*Ph.D.*
*McGill University*
*2005 – 2009*

*Postdoctoral fellow*
*University of California, Berkeley*
*2009 – 2010*

*Assistant professor*
*University of British Columbia*
*2010 – 2017*

*Associate professor*
*University of British Columbia*
*2017 – present*

### Group Composition

**Graduate students**
*Graham Baker*
*Katherine Cochrane*
*Miriam DeJong*
*Andrew Macdonald*
*Brandon Stuart*
*Gary Tom*
*Yann-Sebastien Tremblay-Johnston*
*Alexandra Tully*

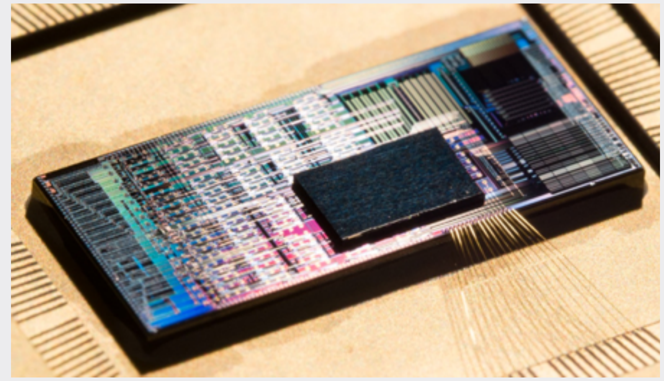
**Postdoctoral fellows**
*Erik Mårsell*
*Bingkai Yuan*

# Lukas **Chrostowski**

## Mission

*To be leaders in silicon photonics device, component and circuit design, design methodologies, fabrication, process design kit development, automated test, electronic-photonic integration and integrated systems, packaging, and silicon photonics education.*

Our main research interests are in the applications of silicon photonics, including optical communications, biosensors, and quantum information. Using the relatively mature silicon photonics technology, and very mature CMOS electronics technology, we are developing a quantum information platform. We are using a cavity quantum electrodynamics (cQED) approach with single atoms implanted in silicon as qubits, 4K cryogenic operation in vacuum, mid-IR wavelengths, single photon sources and detectors, and nano-electro-mechanical systems (NEMS). We have facilities to design, fabricate, and test silicon photonic devices and circuits. The fabrication capabilities include a state-of-the-art electron beam lithography system, the JEOL 8100FS, capable of fabricating samples as large as 200 mm wafers. Our test capabilities include several automated probe stations capable of measuring thousands of photonic devices per day, together with electronics control and high speed (10s of GHz) characterization.



### Selected Publications

L. Chrostowski and M. Hochberg. Silicon photonics design: from devices to systems. Cambridge University Press (2015).

X. Wang, W. Shi, H. Yun, S. Grist, N.A.F. Jaeger, and L. Chrostowski. Narrow-band waveguide Bragg gratings on SOI wafers with CMOS-compatible fabrication process. Opt. Express **20**, 15547 (2012).

Y. Wang, X. Wang, J. Flueckiger, H. Yun, W. Shi, R. Bojko, N.A.F. Jaeger, and L. Chrostowski. Focusing sub-wavelength grating couplers with low back reflections for rapid prototyping of silicon photonic circuits. Opt. Express **22**, 20652 (2012).

### Current Projects

*Tunable photonic crystal for cavity quantum electrodynamics (with Jeff Young)*

*Single photon sources (with Jeff Young)*

*Semiconductor laser stabilization using CMOS electronics*

*Silicon photonic biosensors*

*Monte Carlo simulations for silicon photonic manufacturing variability*

### Career Highlights

*Ph.D.*
*University of California, Berkeley*
*1998 – 2004*

*Postdoctoral Fellow*
*University of California, Berkeley*
*2004 – 2005*

*Assistant Professor*
*University of British Columbia*
*2005 – 2010*

*Associate Professor*
*University of British Columbia*
*2010 – 2015*

*Professor*
*University of British Columbia*
*2015 – present*

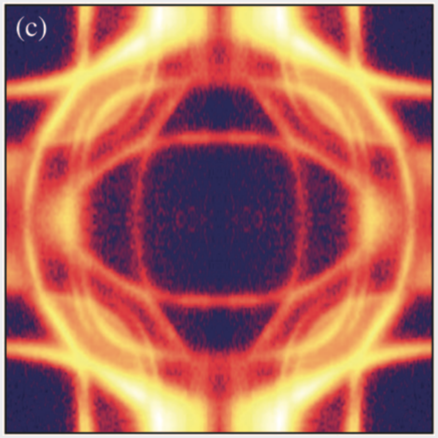
### Group Composition

**Graduate students**
*Abdelraman Afifi*
*Rui Cheng*
*Ya Han*
*Jaspreet Jhoja*
*Stephen Lin*
*Enxiao Luan*
*Minglei Ma*
*Anthony Park*
*Hossam Shoman*

**Postdoctoral fellow**
*Jingda Wu*

# Andrea **Damascelli**

Our group develops and utilizes angle-resolved photoemission spectroscopy (ARPES) and its time- and spin- resolved variants, as well as resonant x-ray scattering (RXS), to push the limits of these techniques and gain a deeper understanding of quantum materials and new phases of matter. Leveraging facilities we have established at SBQMI and the Quantum Materials Spectroscopy Centre at the Canadian Light Source, we pursue the engineering of the electronic structures of these materials through in situ adatom deposition, strain, and the optical coherent control of electronic states via pulsed laser excitations.




## Mission

*Through the development of new spectroscopic approaches, we explore exotic phases of quantum materials, and aim to understand, tailor, and control their electronic properties.*

### Selected Publications

B.M. Ludbrook, G. Levy, M. Zonno, M. Schneider, D.J. Dvorak, C.N. Veenstra, S. Zhdanovich, D. Wong, P. Dosanjih, S. Forti, U. Starke, and A. Damascelli. Evidence for superconductivity in Li-decorated monolayer graphene. Proc. Natl. Acad. Sci. **112**, 11795 (2015).

R. Comin, A. Frano, M.M. Yee, Y. Yoshida, H. Eisaki, E. Shierle, E. Weschke, R. Sutarto, F. He, A. Soumyanarayanan, Y. He, M. Le Tacon, I.S. Elfimov, J.E. Hoffman, B. Keimer, G.A. Sawatzky, and A. Damascelli. Charge ordering driven by Fermi-arc instability in underdoped cuprates. Science **343**, 6169 (2014).

A. Damascelli, Z. Hussain, and Z.-X. Shen. Angle-resolved photoemission studies of the cuprate superconductors. Rev. Mod. Phys. **75**, 473 (2003).

### Current Projects

*Non-equilibrium dynamics of quantum materials*

*Coherent control and spectroscopy of quantum materials*

*Spin-Orbit coupling and unconventional superconductivity*

*New avenues in charge and spin manipulation at surfaces*

*2D van der Waals materials and oxide heterostructures*

### Career Highlights

*Ph.D.*
*University of Groningen*
*1994 – 1999*

*Postdoctoral Fellow*
*Stanford University*
*1999 – 2002*

*Assistant Professor*
*University of British Columbia*
*2002 – 2007*

*Associate Professor*
*University of British Columbia*
*2007 – 2013*

*Professor*
*University of British Columbia*
*2013 – present*

### Group Composition

**Graduate students**
*Ryan Day*
*Marco Marchetto*
*Ketty Na*
*Pascal Nigge*
*Amy Qu*
*Alexander Sheyerman*
*Marta Zonno*
*Berend Zwartsenberg*

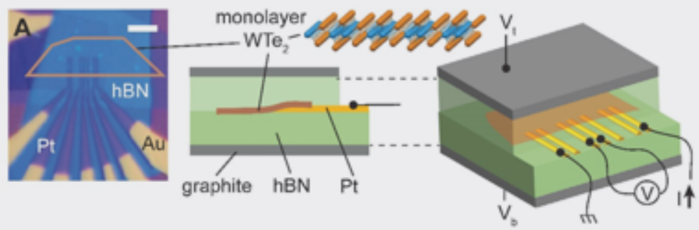
**Postdoctoral fellows**
*Fabio Boschini*
*Christopher Gutiérrez*
*Fuhao Ji*
*Sean Kung*
*Matteo Michiardi*
*Elia Razzoli*

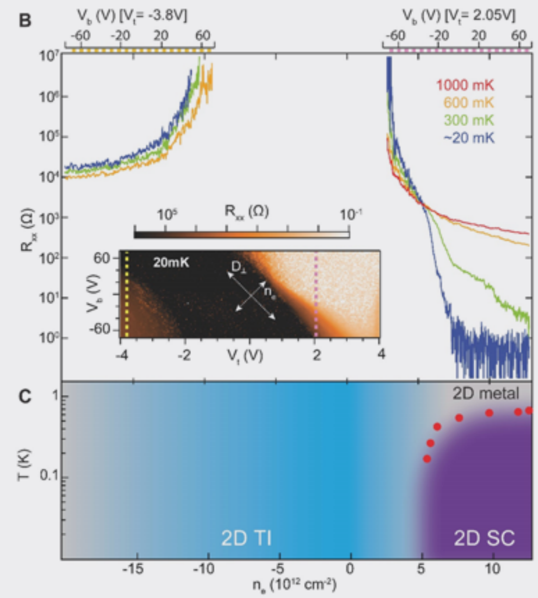
**Research Associates**
*Ilya Elfimov*
*Giorgio Levy*
*Arthur Mills*
*Sergey Zhdanovich*

*Michael Schneider* – Scientific Engineer
*Douglas Wong* – Engineering Technician
*Pinder Dosanjh* – Cryogenic Engineer

# Josh **Folk**

We perform ultra-low temperature electronic measurements, often at high magnetic fields, of devices defined by micro- and nano-lithography, and controlled by various electrostatic gates. Materials used for these devices range from conventional semiconductors, such as GaAs, to 2D materials such as graphene or dichalcogenides, to strongly correlated 2D materials such as strontium vanadate.




## Mission

*We build and measure electronic devices that embody quantum phenomena at the cutting edge of condensed matter physics. These effects typically emerge at ultra-low temperatures in nanoscale devices, and are often most clear in exotic materials.*

### ***Selected Publications***

M.B. Lundeberg, R. Yang, J. Renard, and J.A. Folk. Defect-Mediated Spin Relaxation and Dephasing in Graphene. Phys. Rev. Lett. **110**, 156601 (2013).

M. Kjaergaard, F. Nichele, H.J. Suominen, M.P. Nowak, M. Wimmer, A.R. Akhmerov, J.A. Folk, K. Flensberg, J. Shabani, C.J. Palmstrom, and C.M. Marcus. Quantized conductance doubling and hard gap in a two-dimensional semiconductor-superconductor heterostructure. Nat. Comm. **7**, 12841 (2016).

S. M. Frolov, S. Lüscher, W. Yu, Y. Ren, J. A. Folk, and W. Wegscheider. Ballistic spin resonance. Nature **458**, 868 (2009).

### ***Current Projects***

*Vanderwaals heterostructures*

*Non-abelian electronic states*

*Mesoscopic physics*

### ***Career Highlights***

*Ph.D.*
*Stanford University*
*1998 – 2003*

*Postdoctoral Fellow*
*Massachusetts Institute of Technology*
*2003 – 2004*

*Postdoctoral Researcher*
*Delft Technical University*
*2005*

*Assistant Professor*
*University of British Columbia*
*2005 – 2010*

*Associate Professor*
*University of British Columbia*
*2010 – present*

### ***Group Composition***

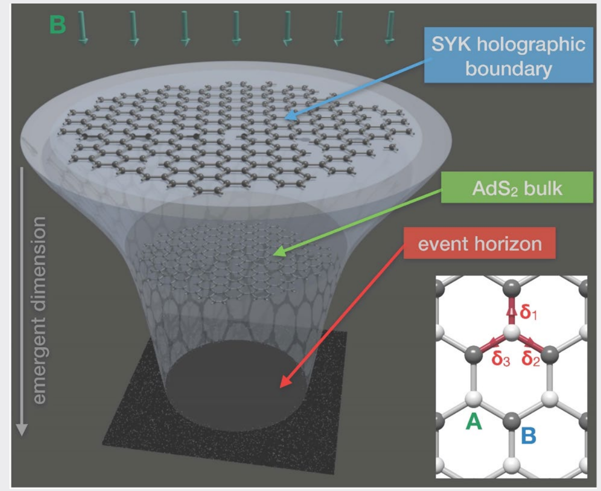
**Graduate students**
*Christian Olsen*
*Ebrahim Sajadi*
*Mohammad Samani*
*Hyungki Shin*
*Rui Yang*

**Postdoctoral fellow**
*Nik Hartman*

**Research associate**
*Silvia Lüscher*

# Marcel **Franz**

We formulate and study simple models of solids that are relevant to topological insulators, topological superconductors, Dirac and Weyl semimetals, and other topological or otherwise exotic states of quantum matter. The key criteria driving our research are: (i) cutting edge theoretical developments and (ii) relevance to real systems as studies by our experimental colleagues.




## Mission

*Using analytical and numerical techniques, we perform theoretical studies of topological states of matter relevant to experimental systems.*

### ***Selected Publications***

C. Weeks, J. Hu, J. Alicea, M. Franz, and R. Wu. Engineering a robust quantum spin Hall state in graphene via adatom deposition. Phys. Rev. X. **1**, 021001 (2011).

I. Garate and M. Franz. Inverse spin-galvanic effect in the interface between a topological insulator and a ferromagnet. Phys. Rev. Lett. **104**, 146802 (2010).

S.R. Elliott and M. Franz. Colloquium: Majorana fermions in nuclear, particle, and solid-state physics. Rev. Mod. Phys. **87**, 137 (2015).

### ***Current Projects***

*Quantum holography in a graphene flake with an irregular boundary*

*Antichiral edge states in a modified Haldane nanoribbon*

*Quantum oscillations and Dirac-Landau levels in Weyl superconductors*

*Optimal diabatic dynamics of Majorana-based quantum gates*

*Black Hole on a Chip: Proposal for a Physical Realization of the Sachdev-Ye-Kitaev model in a Solid-State System*

### ***Career Highlights***

*Ph.D.*
*University of Rochester*
*1992 – 1994*

*Postdoctoral Fellow*
*McMaster University*
*1994 – 1996*

*Postdoctoral Fellow*
*Johns Hopkins University*
*1996 – 2000*

*Assistant Professor*
*University of British Columbia*
*2000 – 2005*

*Associate Professor*
*University of British Columbia*
*2005 – 2010*

*Professor*
*University of British Columbia*
*2010 – present*

### ***Group Composition***

**Graduate students**

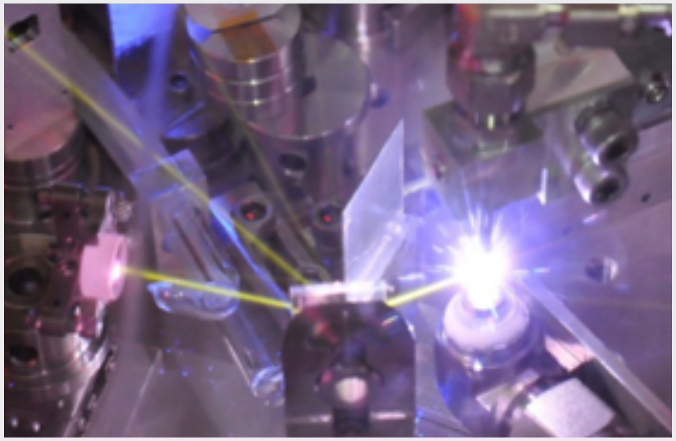
*Oguzhan Can*
*Anffany Chen*
*Rafael Haenel*
*Étienne Lantagne-Hurtubise*
*Chengshu Li*
*Tianyu Liu*

**Postdoctoral fellow**

*Emilian Nica*

# David **Jones**

We have developed (and are continuing to refine) a world-unique laser-based XUV source specifically optimized for high energy resolution time-resolved ARPES that is able to operate near the Brillouin Edge. This advance has enabled studies of previously unreachable non-equilibrium physics. We are also developing a flexible VUV laser to be integrated with time-of-flight electron spectroscopy. In parallel, we are working to extend multi-dimensional spectroscopy techniques (using these two sources) for probing quantum coherences in solids.



## Mission

*We develop next-generation laser sources, accompanied by spectroscopy techniques, to use in understanding (and controlling) quantum states in solids.*

### Selected Publications

D.J. Jones, S.A. Diddams, J.K. Ranka, A. Stentz, R.S. Windeler, J.L. Hall, and S.T. Cundiff. Carrier-envelope phase control of femtosecond mode-locked lasers and direct optical frequency synthesis. Science **288**, 635 (2000).

L.E. Nelson, D.J. Jones, K. Tamura, H.A. Haus, and E.P. Ippen. Ultrashort-pulse fiber ring lasers. App. Phys. B. **65**, 277 (1997).

A.K. Mills, T.J. Hammond, M.H.C. Lam, and D.J. Jones. XUV frequency combs via femtosecond enhancement cavities. J. Phys. B. **45**, 142001 (2012).

### Current Projects

*Femtosecond XUV sources for TR-ARPES over the full Brillioun zone*

*k-space optical tweezers*

*Flexible VUV femtosecond lasers sources for time-resolved photoemission*

*Spatio-temporal characterization of interfacial charge separation in organic photovoltaics*

*Multi-dimensional spectroscopy techniques for studying coherences in solids*

### Career Highlights

*Ph.D.*
*Massachusetts Institute of Technology*
*1994 – 1999*

*Research Associate*
*NIST Boulder Labs*
*1998 – 2000*

*Research Associate*
*University of Colorado at Boulder*
*2001 – 2003*

*Assistant Professor*
*University of British Columbia*
*2004 – 2010*

*Associate Professor*
*University of British Columbia*
*2010 – present*

### Group Composition

**Graduate students**
*Emily Altiere*
*Matthias Bohlen*
*Aghigh Jalehdoost*
*Ketty Na*
*Aurelien Pelissier*
*Alexander Sheyerman*

**Postdoctoral fellows**
*Fabio Boschini*
*Will Gunton*
*Erik Mårsell*

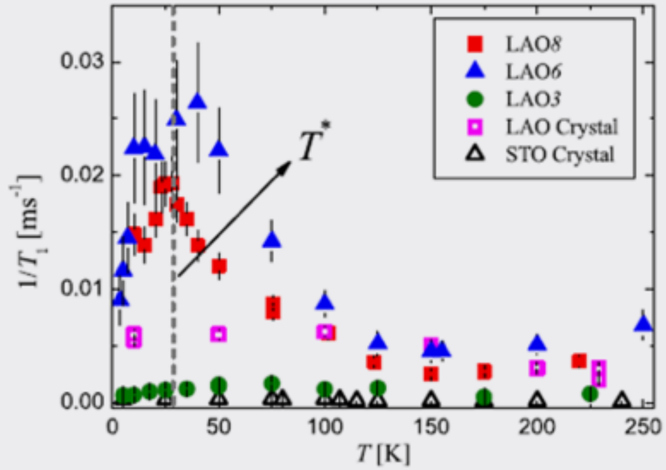
**Research associate**
*Arthur Mills*

**Visiting scientist**
*Edmund Kelleher*

**Scientific engineer**
*Evgeny Ostroumov*

# Rob **Kiefl**

We are using muon spin rotation and beta detected NMR to study magnetic and electronic properties of oxides and their interfaces. We also have a program to investigate magneto electrics and nanoparticles. We are exploring exotic states of a positive muon in magnetic materials in which the muon can behave as a magnetic monopole or form a bound state with a polaron.




## Mission

*Our mission is to explore and characterize the magnetic and electronic properties of novel materials and their interfaces.*

### Selected Publications

J.S. Gardner, S.R. Dunsiger, B.D. Gaulin, R.F. Kiefl, M.D. Lumsden, Z. Tun, N.P. Raju, I. Swanson, and J.E. Greedan. Co-operative Paramagnetism in the Geometrically-Frustrated Pyrochlore Tb2Ti2O7. Phys. Rev. Lett. **82**, 1012 (1999).

J.E. Sonier, J.H. Brewer, and R.F. Kiefl. μSR studies of the vortex state in type-II superconductors. Rev. Mod. Phys. **72**,769 (2000).

R.F. Kiefl, M. Celio, T.L. Estle, S.R. Kreitzman, G.M. Luke, T.M. Riseman, and E.J. Ansaldo. 29Si Hyperfine Structure of Anomalous Muonium in Silicon: Proof of the Bond-Centered Model. Phys. Rev. Lett. **60**, 224 (1988).

### Current Projects

*Magnetic properties of oxide interfaces and their near surface region*

*Novel magnetic and chemical properties of nanoparticles*

*Lithium diffusion studies in battery electrode materials*

*Local magnetoelectric effects studied with beta-NMR and muon spin rotation*

### Career Highlights

*Ph.D.*
*University of British Columbia*
*1978 – 1982*

*Research Associate*
*TRIUMF*
*1982*

*Postdoctoral Fellow*
*Physics Institute, University of Zurich*
*1982 – 1984*

*Research Scientist*
*TRIUMF*
*1984 – 1987*

*Research Fellow*
*University of British Columbia*
*1987 – 1990*

*Assistant Professor*
*University of British Columbia*
*1990 – 1992*

*Associate Professor*
*University of British Columbia*
*1992 – 1995*

*Professor*
*University of British Columbia*
*1995 – present*

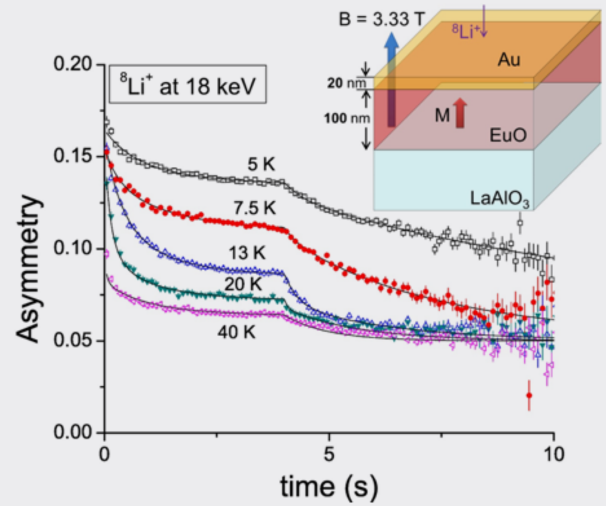
### Group Composition

**Graduate students**

*Aris Chatzichristos*
*Martin Dehn*
*Derek Fujimoto*
*Victoria Karner*
*Ryan McFadden*

# Andrew **MacFarlane**

Using radioactively beta-detected NMR, we study the electromagnetic properties in electronic materials in the form of single crystals, thin films and multilayers. Our main probe is the short-lived isotope 8Li. Using this probe we also study molecular dynamics and lithium ionic mobility in thin films and near interfaces. We develop the techniques and apply them to interesting materials problems which are difficult or impossible to address with more conventional techniques.




## Mission

*To boldly do NMR where no NMR has been done before (yes really!).*

## Selected Publications

J. Bobroff, W.A. MacFarlane, H. Alloul, P. Mendels, N. Blanchard, G. Collin, and J.-F. Marucco. Spinless Impurities in High-Tc Cuprates: Kondo-Like Behaviour. Phys. Rev. Lett. **83**, 4381 (1999).

C. Lupien, W.A. MacFarlane, C. Proust, L. Taillefer, Z.Q. Mao, and Y. Maeno. Ultrasound Attenuation in $Sr_2RuO_4$: An Angle Resolved Study of the Superconducting Gap Function. Phys. Rev. Lett. **86**, 5986 (2001).

W.A. MacFarlane. Implanted-ion βNMR: A new probe for nanoscience. Solid State Nucl. Magn. Reson. **68**, 1 (2015).

## Current Projects

*Metallic and magnetic properties of $LaNiO_3$ thin films*

*Spin relaxation in topological insulators*

*Indirect relaxation in magnetic heterostructures*

*Spin relaxation as a probe of Li+ ionic mobility in solids and near interfaces*

*31Mg, a new beta NMR probe*

## Career Highlights

*Ph.D.*
*University of British Columbia*
*1992 – 1997*

*Postdoctoral Fellow*
*Laboratoire de Physique des Solides, Université Paris-Sud*
*1997 – 1999*

*Postdoctoral Fellow*
*University of Toronto*
*1999 – 2001*

*Research Associate*
*TRIUMF, University of British Columbia*
*2001 – 2002*

*Assistant Professor*
*University of British Columbia*
*2002 – 2008*

*Associate Professor*
*University of British Columbia*
*2008 – present*

## Group Composition

**Graduate students**

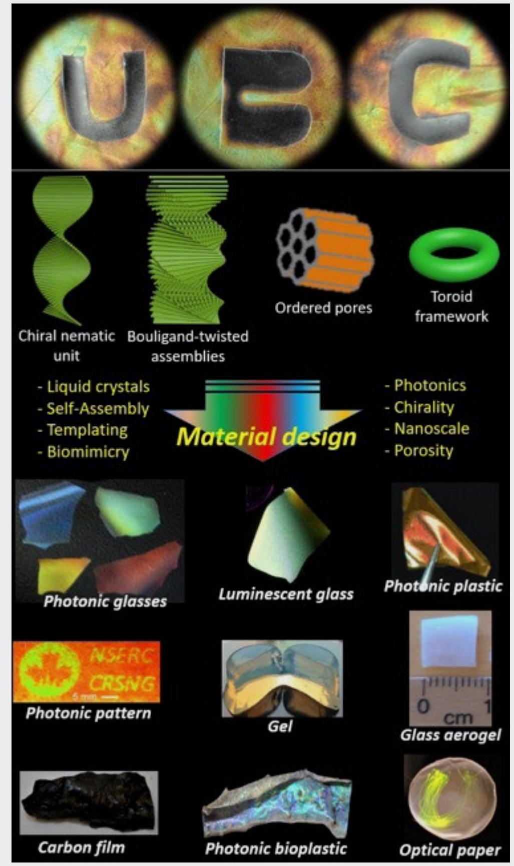
*Luca Egoriti*
*Derek Fujimoto*
*Victoria Karner*
*Ryan McFadden*
*John Ticknor*

# Mark **MacLachlan**

## Mission

*We strive to make innovative new materials and molecules that have function.*

Our group members synthesize new molecules (especially macrocycles) and study their self-assembly under different conditions. We also develop new photonic materials using liquid crystalline templates, especially derived from cellulose and chitin. Finally, we explore a variety of new nanostructured materials for different applications.




### ***Selected Publications***

K.E. Shopsowitz, H. Qi, W.Y. Hamad, M.J. MacLachlan. Free-Standing Mesoporous Silica Films with Tunable Chiral Nematic Structures. Nature **468**, 422 (2010).

T. Asefa, M.J. MacLachlan, N. Coombs, G.A. Ozin. Periodic Mesoporous Organosilicas with Organic Groups Inside the Channel Walls. Nature **402**, 867 (1999).

A.J. Gallant and M.J. MacLachlan. Ion-Induced Tubular Assembly of Conjugated Schiff-Base Macrocycles. Angew. Chem. Int. Ed. **42**, 5307 (2003).

### ***Current Projects***

*Flexible photonic materials from cellulose nanocrystals for stimuli-responsive applications (e.g., pressure sensors)*

*Stimuli-responsive gelation*

*Nanostructured catalysts for low temperature methane oxidation*

*Supramolecular compounds for stimuli-driven molecular delivery*

*Molecular cluster templating inside shape-persistent macrocycles*

### ***Career Highlights***

*Ph.D.*
*University of Toronto*
*1995 – 1999*

*Postdoctoral Fellow*
*Massachusetts Institute of Technology*
*1999 – 2001*

*Assistant Professor*
*University of British Columbia*
*2001 – 2007*

*Associate Professor*
*University of British Columbia*
*2007 – 2011*

*Professor*
*University of British Columbia*
*2011 – present*

### ***Group Composition***

**Graduate students**

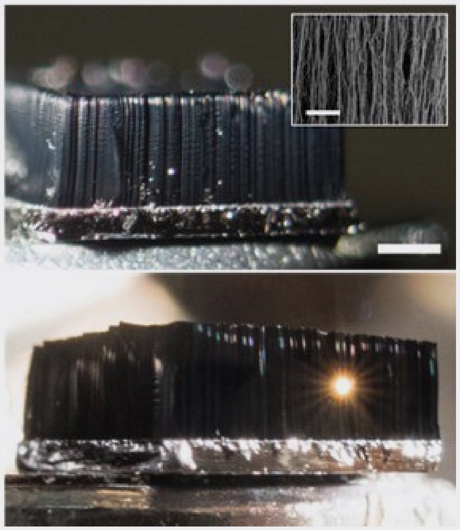
*Guillaume Beaulieu-Houle*
*Veronica Carta*
*Mohammad Chaudhry*
*Zhengyu Chen*
*Francesco D'Acierno*
*Yiling Dai*
*Debbie Le*
*Lev Lewis*
*Hessam Mehr*
*Andrea Terpstra*
*Andy Tran*
*Chris Walters*
*Peixi Wang*
*Rebecca Winnik*
*Yitao Xu*

**Postdoctoral fellows**

*Charlotte Boott*
*Yuanyuan Cao*
*Takayuki Hiratani*
*Ryutaro Ohashi*
*Miguel Angel Soto Muñoz*
*Pavan Kumar Vanama*

# Alireza **Nojeh**

Our research activities centre on device design, micro and nanofabrication in the cleanroom, nanostructure growth and deposition, electron and scanning-probe microscopy, building experimental apparatus such as high- or ultra-high-vacuum systems, electronic characterization and sensitive instrumentation, and working with lasers and optics. We complement our experimental efforts with modelling and simulation using methods ranging from continuum modelling (such as finite-element analysis) to classical molecular dynamics to first-principles, quantum-mechanical techniques such as the Hartree-Fock theory, configuration-interaction, perturbation theory and the density-functional theory.



## Mission

*We fabricate and explore nanostructures, with an emphasis on the interaction of electrons, photons, and phonons in them. We investigate the movement of electrons over and through energy barriers using excitation by heat, light, field, or other electrons.*

### Selected Publications

P. Yaghoobi, M. Vahdani Moghaddam, and A. Nojeh. "Heat trap": light-induced localized heating and thermionic electron emission from carbon nanotube arrays. Solid State Commun. **151**, 1105 (2011).

P. Yaghoobi, M. Vahdani Moghaddam, and A. Nojeh. Solar electron source and thermionic solar cell. AIP Adv. **2**, 042139 (2012).

A. Nojeh, W.-K. Wong, A.W. Baum, R.F.W. Pease, and H. Dai. Scanning electron microscopy of field-emitting individual single-walled carbon nanotubes. App. Phys. Lett. **85**, 112 (2004).

### Current Projects

*Heat localization in carbon nanotubes*

*Thermionic energy conversion*

*Compact, inexpensive electron microscope*

*Nanostructure-based heat engine*

*Controlled electron emission*

### Career Highlights

*Ph.D.*
*Stanford University*
*2006*

*Assistant Professor*
*University of British Columbia*
*2006 – 2011*

*Associate Professor*
*University of British Columbia*
*2011 – 2016*

*Professor*
*University of British Columbia*
*2016 – present*

### Group Composition

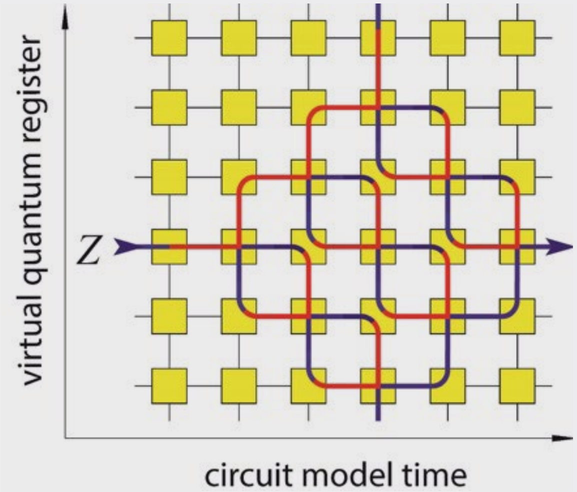
**Graduate students**
*Daniel Bruns*
*Mike Chang*
*Mokter Mahmud Chowdhury*
*Mohab Hassan*
*Mohammad Khalifa*
*Casimir Kuzyk*
*Shaghayegh Sadrekarimi*
*Kevin Voon*

**Postdoctoral fellows**
*Kais Dridi*
*Mike El-Kousseifi*
*Oleksandr Foyevtsov*
*Faezeh Mohammadbeigi*

**Research associate**
*Harrison Fan*

# Robert **Raussendorf**

The work in my group focuses on the theory of quantum computation, such as quantum computer architecture, the relation of quantum computation to foundations of quantum mechanics such as quantum contextuality, and the relation of quantum computation to condensed matter physics, e.g., symmetry-protected topological order.




## Mission

*We aim to develop a technology platform for quantum algorithm design.*

### Selected Publications

R. Raussendorf and H.J. Briegel. A one-way quantum computer. Phys. Rev.Lett. **86**, 5188 (2001).

H.J. Briegel and R. Raussendorf. Persistent entanglement in arrays of interacting particles. Phys. Rev. Lett. **86**, 910 (2001).

R. Raussendorf and J. Harrington. Fault-tolerant quantum computation with high threshold in two dimensions. Phys. Rev. Lett. **98**, 190504 (2007).

### Current Projects

*Quantum computational phases of matter (measurement-based quantum computation in SPT-ordered phases)*

*Quantum computer architecture with matter qubits coupled by photons*

*The role of contextuality for quantum computation*

### Career Highlights

*Ph.D.*
*University of Munich (LMU)*
*1999 – 2003*

*Postdoctoral Fellow*
*California Institute of Technology*
*2003 – 2006*

*Postdoctoral Fellow*
*Perimeter Institute for Theoretical Physics*
*2006 – 2007*

*Assistant professor*
*University of British Columbia*
*2008 – 2013*

*Associate Professor*
*University of British Columbia*
*2013 – present*

### Group Composition

**Graduate students**

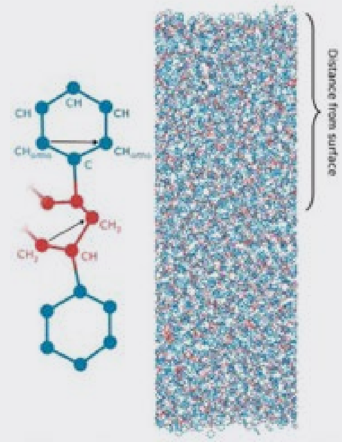
*Poya Hagnehgahdar*
*Oleg Kabernik*
*Hendrik Poulsen Nautrup (U Innsbruck)*
*David Stephen*
*Arman Zaribafiyan*

**Postdoctoral fellows**

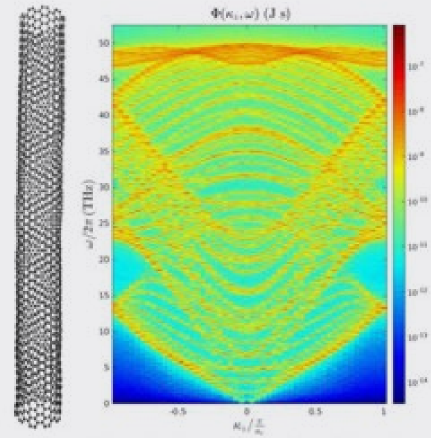
*Cihan Okay*
*Dongsheng Wang*

# Joerg **Rottler**

With state of the art computational techniques ranging from density functional theory (DFT) at the quantum level, molecular dynamics and Monte Carlo simulations on the atomic level, to field theoretic (phase field) methods on the mesoscale, we study a diverse set of materials that include polymers, disordered solids, and nanomaterials. Computer simulations facilitate the discovery of emergent phenomena, test theories and generic trends, and reveal quantities that are difficult or impossible to obtain in experiments, thus providing essential input into the design of new functional materials. Our group makes extensive use of SBQMI's high performance computing facility as well as Compute Canada resources.



Amorphous polystyrene film



Spectral energy density of carbon nanotube

## Mission

*We seek to explain the molecular level mechanisms that govern structure and dynamics of complex materials in and out of equilibrium.*

### *Selected Publications*

J. Rottler and M.O. Robbins. Shear yielding of amorphous glassy solids: Effect of temperature and strain rate. Phys. Rev. E. **68**, 011507 (2003).

M. Greenwood, N. Provatas, and J. Rottler. Free energy functionals for efficient phase field crystal modeling of structural phase transformations. Phys. Rev. Lett. **105**, 045702 (2010).

A. Nicolas, J.-L. Barrat and J. Rottler, Effect of inertia on the steady state shear rheology of amorphous solids, Phys. Rev. Lett. **116**, 058303 (2016).

### *Current Projects*

*Mechanisms of near-surface relaxation in amorphous polystyrene films via molecular simulations and beta-NMR measurements*

*Nanoscale phononics and the origin of the heat-trap effect*

*Statistical physics of driven disordered solids*

*Molecular simulations of smart polyelectrolytes and the piezo-ionic effect*

*Nonlinear response of nanostructured copolymer networks*

### *Career Highlights*

*Ph.D.*
*Johns Hopkins University*
*2003*

*Chercheur Associe*
*École Supérieure De Physique Et De Chimie Industrielles De La Ville De Paris*
*2003*

*Research Associate*
*Princeton University*
*2003 – 2005*

*Assistant Professor*
*University of British Columbia*
*2005 – 2010*

*Associate Professor*
*University of British Columbia*
*2010 – 2016*

*Professor*
*University of British Columbia*
*2016 – present*

### *Group Composition*

**Graduate students**

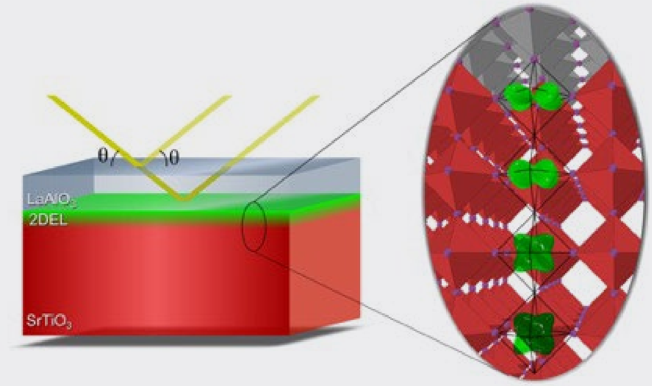
*Daniel Bruns*
*Derek Fujimoto*
*Amanda Parker*
*Vasiliy Triandafilidi*

**Postdoctoral fellow**

*Mona Habibi*

# George **Sawatzky**

We use a combination of advanced experimental and theoretical methods in studies of quantum materials exhibiting interesting and not well-understood physical properties. We also develop new experimental spectroscopic methods such as various forms of x-ray spectroscopies that can provide detailed information concerning the electronic, atomic, and magnetic structure of materials and material interfaces. The development of resonant x-ray reflectometry is one of the most recent highly successful developments. On the theory side, we use and develop further density function band theory methods as well as many body exact diagonalization methods to study the electronic structure of materials and material interfaces.




The results of a resonant x ray reflectometry determination of the depth dependent 2 dimensional electron density and d electron orbital symmetry of a buried interface between $LaAlO_3$ and $SrTiO_3$.

## Mission

*To determine the relationship between the chemical composition, atomic and electronic structure, and the morphology and physical properties of quantum materials.*

### Selected Publications

J. Zaanen, G.A. Sawatzky, J.W. Allen. Band gaps and electronic structure of transition-metal compounds. Phys. Rev. Lett. **55**, 418 (1985).

V.I. Anisimov, I.V. Solovyev, M.A. Korotin, M.T. Czyżyk, and G.A. Sawatzky. Density-functional theory and NiO photoemission spectra. Phys. Rev. B. **48**, 16929 (1993).

R.W. Lof, M.A. van Veenendaal, H.T. Jonkman, and G.A. Sawatzky. Band gap, excitons and Coulomb interactions of solid C60. Phys. Rev. Lett. **68**, 3924 (1992).

### Current Projects

*High oxidation state oxides and negative charge transfer gap materials like $BaBiO_3$*

*Bond disproportionation and dynamical charge fluctuations in the perovskite rare-earth nickelates*

*Electron-magnon-phonon coupling and their role in high Tc superconductors and topology*

*Resonant soft Xray reflectometry and the study of buried interfaces in heterostructures*

*Controlled physical properties by interface engineering*

### Career Highlights

*Ph.D.*
*University of Manitoba*
*1969*

*Postdoctoral Fellow*
*Groningen University*
*1969 – 1971*

*Associate Professor*
*Groningen University*
*1971 – 1979*

*Professor*
*Groningen University*
*1979 – 2001*

*Professor*
*University of British Columbia*
*2002 – present*

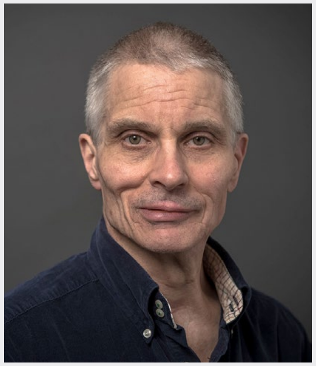
### Group Composition

**Graduate students**

*Shadi Balandeh*
*Arash Khazraie*
*Kevin Voon*
*Oliver Yam*

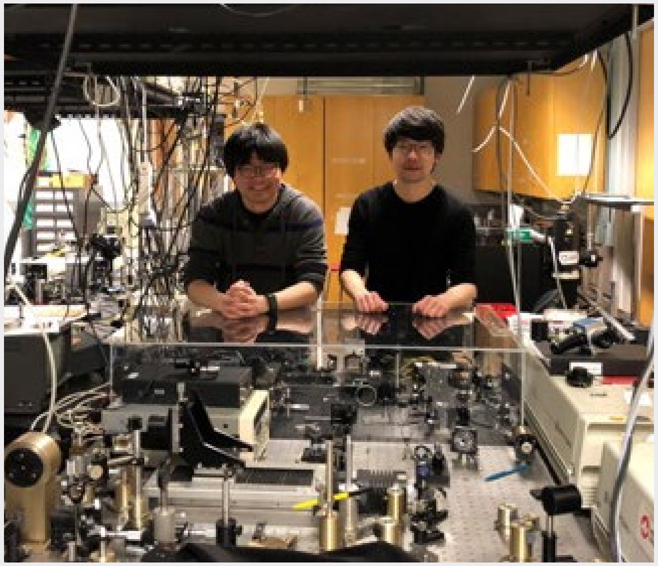
**Research associates**

*Ilya Elfimov*
*Harrison Fan*



# Jeff **Young**

Our group uses electrodynamic models and simulation tools to design compact nanophotonic components in silicon-on-insulator wafers to control the flow of light over a range of infrared wavelengths. Examples include single photon detectors, non-classical light sources, and high quality factor, low mode volume nanophotonic cavities for achieving strong-coupling with dipole transitions within quantum oscillators located in the nanocavities. We also carry out a combination of in-house and external nanofabrication and post-processing (electron beam and optical lithography, plasma etching, metal deposition etc.) tasks to realize our designs in silicon slab waveguides. We then carry out optical spectroscopic characterization of the fabricated circuits.



## Mission

*To develop the various design, nanofabrication, and characterization components necessary to realize quantum information processing in a silicon photonics platform.*

### *Selected Publications*

M.K. Akhlaghi, E. Schelew, and J.F. Young. Waveguide Integrated Superconducting Single-Photon Detectors Implemented as Near-Perfect Absorbers of Coherent Radiation. Nat. Comm. **6**, 8233 (2015).

P. Paddon, M. Jackson, J. Young, and S. Lam. Photonic Input/Output Port. US Patent 7,031,562, let April 2006.

S. Hughes, L. Ramunno, J.F. Young, and J.E. Sipe. Extrinsic Optical Scattering Loss in Photonic Crystal Waveguides: Role of Fabrication Disorder and Photon Group Velocity. Phys. Rev. Lett. **94**, 033903 (2005).

### *Current Projects*

*Developing a micro electro-mechanical based means of tuning photonic crystal microcavity resonance frequencies while maintaining high quality factors and low mode volumes*

*Developing practical single photon sources in the silicon photonic circuit platform*

*Designing quantum information processing strategies/architectures that are particularly suited to the photon-mediated coupling of chalcogenide impurities in silicon*

*Further developing our integrated single photon superconducting nanowire detectors to work over a broader range of frequencies*

*Developing novel coherent light sources for carrying out high resolution spectroscopy in the mid IR*

### *Career Highlights*

*Ph.D.*
*University of Toronto*
*1983*

*Associate Professor*
*University of British Columbia*
*1992 – 1996*

*Professor*
*University of British Columbia*
*1996 – present*

### *Group Composition*

**Graduate students**

*Ellen Schelew*
*Xiruo Yan*

**Postdoctoral fellow**

*Jingda Wu*

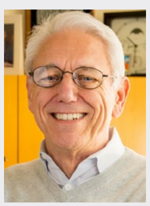
# International scientific advisory board

**We are fortunate to have the support and advice of a group of world-renowned scientists who meet with us annually to review our work, provide us with feedback, and advise us on future directions. The Scientific Advisory Board complements SBQMI's multi-disciplinary approach, with its balance of expertise in theoretical, experimental, and applied research, and representation of different scientific disciplines and strong links to academia and industry.**

**Dr. Lesley Cohen, Chair of the Scientific Advisory Board**
Consul for Faculty of Natural Sciences & Education Office
Imperial College London, Faculty of Natural Sciences, Department of Physics

Lesley Cohen is a Professor of Solid State Physics at Imperial College London. Her research focuses on quantum interference for organic thermoelectric, energy efficient solid-state caloric cooling, competing exchange antiferromagnets for spintronics and long-range triplet superconductivity. She is currently the Consul for the Faculty of Natural Sciences and Education at Imperial College and recently stepped down as head of Experimental Condensed Matter. She received the Imperial College Julia Higgins Award for her contribution to the promotion and support of women in science and remains committed to equality and diversity within STEM.

Dr. Cohen has served on numerous Boards including Superconductivity, Science and Technology; Imperial College Consultants ICON; the Education Board for the Institute of Physics; Kings College London Science Advisory Board; and the External Advisory Board of IFW Dresden and the EPSRC Materials Strategic Advisory Technical Panel.



**Dr. George Crabtree**
Argonne Distinguished Fellow
Director of the Joint Center for Energy Storage Research

George Crabtree is Professor of Physics at University of Illinois-Chicago, Distinguished Fellow of Argonne National Laboratory and Director of the Joint Center for Energy Storage Research (JCESR). His research interests include materials science, sustainable energy, nanoscale superconductors and magnets, vortex matter in superconductors, and highly correlated electrons in metals. He has led workshops for the Department of Energy (DOE) on next generation energy storage, hydrogen, solar energy, superconductivity, and materials under extreme environments, and co-chaired the Undersecretary of Energy's assessment of DOE's Applied Energy Programs. He has testified before U.S. Congress on the hydrogen economy, meeting sustainable energy challenges, and energy storage.

Dr. Crabtree has won numerous awards including the Kamerlingh Onnes Prize, U.S. DOE Award for Outstanding Scientific Accomplishment in Solid State Physics and an R&D 100 Award. He is a Fellow of the American Physical Society, a charter member of ISI's Highly Cited Researchers in Physics, and a Member of the U.S. National Academy of Sciences.

**Dr. J.C. Seamus Davis**
James Gilbert White Professor in Physical Sciences, Cornell University
Senior Physicist, Brookhaven National Laboratory;
Distinguished Professor of Physics, St. Andrews University

Seamus Davis is a Professor of Physics at Cornell University. He undertakes a wide range of experimental low-temperature research into the fundamental macroscopic quantum physics of superconductors, superfluids, supersolids, heavy-fermions, topological insulators and superconductors, magnetic spin and monopole quantum liquids, as well as developing new techniques for visualization and measurement of complex quantum matter.

Dr. Davis received the Outstanding Performance Award Berkeley National Lab. (2001); Science and Technology Award Brookhaven National Lab. (2013); Fritz London Memorial Prize (2005); Kamerlingh Onnes Prize (2009); Honorary Doctorate - National University of Ireland (2014). Science Foundation Ireland - Medal of Science (2016), Fellow of the Institute of Physics (UK), the American Physical Society (USA); Member of the US National Academy of Sciences.

**Dr. Benjamin Eggleton**
Professor of Physics, University of Sydney,
Director, The University of Sydney Nano Institute
Co-Director, NSW Smart Sensing Network (NSSN)

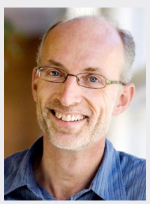
Benjamin Eggleton is a Professor of Physics at the University of Sydney and recently appointed Director of the University of Sydney Nano Institute. His research interests lie in nonlinear optics, all-optical signal processing and nanophotonics. He has focused his work on nonlinear optics of periodic media, slow-light in photonic crystals and ultrafast planar waveguide nonlinear optics. Applications of his work include photonic chip based ultrafast optical signal processing, ultrafast optical devices for telecommunications applications, record low-threshold supercontinuum generation sources and on-chip parametric sources and Brillouin photonic devices for microwave photonics applications.

Dr. Eggleton is a Fellow of the Australian Academy of Science (AA), the Australian Academy of Technology and Engineering (ATSE), the Optical Society of America and IEEE. He was previously an Australian Research Council (ARC) Laureate Fellow, and has twice been an ARC Federation Fellow.

**Dr. Antoine Georges**
CCQ Director, Flatiron Institute
Professor of Physics, Collège de France

Antoine Georges is a Professor at Collège de France, Paris (chair of Condensed Matter Physics) and the Director of the newly founded Center for Computational Quantum Physics at the Flatiron Institute, Simons Foundation in New York. He also has a joint appointment with University of Geneva, Switzerland. He obtained his Ph.D. from École Normale Supérieure in 1988. While his early research concerned the statistical mechanics of disordered systems, his main focus has been on the physics of quantum materials in which electron-electron interactions are strong.

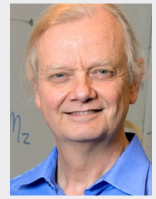
Dr. Georges is one of the co-inventors of dynamical mean field theory, for which he shared the 2006 Europhysics Condensed Matter Prize. This theory has deeply transformed our understanding of these materials and our ability to explain, calculate and predict their physical properties. He also received the 2007 Silver Medal of the CNRS, the 2014 Hamburg Prize for Theoretical Physics as well as a major Synergy Grant from the European Research Council. He is a member of the French Academy of Sciences.



**Dr. Stuart Parkin**
Director at the Max Planck Institute of Microstructure Physics,
IBM Fellow,
Consulting Professor Dept. of Applied Physics, Stanford University

Stuart Parkin is a Professor at the Institute of Physics of the Martin-Luther-University at Halle-Wittenberg where he develops and shapes the field of material sciences, and applied spintronics specifically. Considered a pioneer in the science and application of spintronic materials, he has made crucial discoveries in the behavior of thin-film magnetic structures leading to the increased data density and capacity of hard drives.

Dr. Parkin has received numerous honours including the Gutenberg Research Award, the Humboldt Research Award, the American Institute of Physics Prize for Industrial Applications of Physics, the European Physical Society's Europhysics Prize, and the American Physical Society's International New Materials Prize. Named the first "Innovator of the Year" by R&D Magazine in 2001, he received the "No Boundaries" Award for Innovation from The Economist in 2007. A corresponding Fellow of the Royal Society of Edinburgh, Scotland, Dr. Parkin received the Millennium Technology Prize for his work on spintronic materials.



**Dr. R. Stanley Williams**
Leads Rebooting Computing at Hewlett Packard Labs
Adjunct Professor, UCLA Chemistry and Biochemistry

R. Stanley Williams is a Hewlett Packard Enterprise Senior Fellow and Senior Vice President. His primary scientific research has been in the areas of solid-state chemistry and physics, and their application to technology. More recently, he has been focused on the dynamical properties of electrons, ions and photons in nanostructures and their applications for computation and cognition. In 2008, a team of researchers he led announced that they had built and demonstrated the first intentional memristor, the 4th fundamental electronic circuit element predicted by Prof. Leon Chua in 1971.

Dr. Williams has received widespread recognition for business, scientific and academic achievement, including: being named one of the top 10 visionaries in the field of electronics by EETimes; the 2014 IEEE Outstanding Engineering Manager Award; the 2009 EETimes Innovator of the Year ACE Award; the 2007 Glenn T. Seaborg Medal for contributions to Chemistry; the 50th Anniversary Laureate Lecturer on Electrical and Optical Materials for the TMS; the 2004 Herman Bloch Medal for Industrial Research; the inaugural Scientific American 50 Top Technology leaders in 2002; and the 2000 Julius Springer Award for Applied Physics. He was a co-organizer and co-editor of the workshop and book "Vision for Nanotechnology in the 21st Century", respectively, that led to the establishment of the US National Nanotechnology Initiative in 2000.

# 2017 Publications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