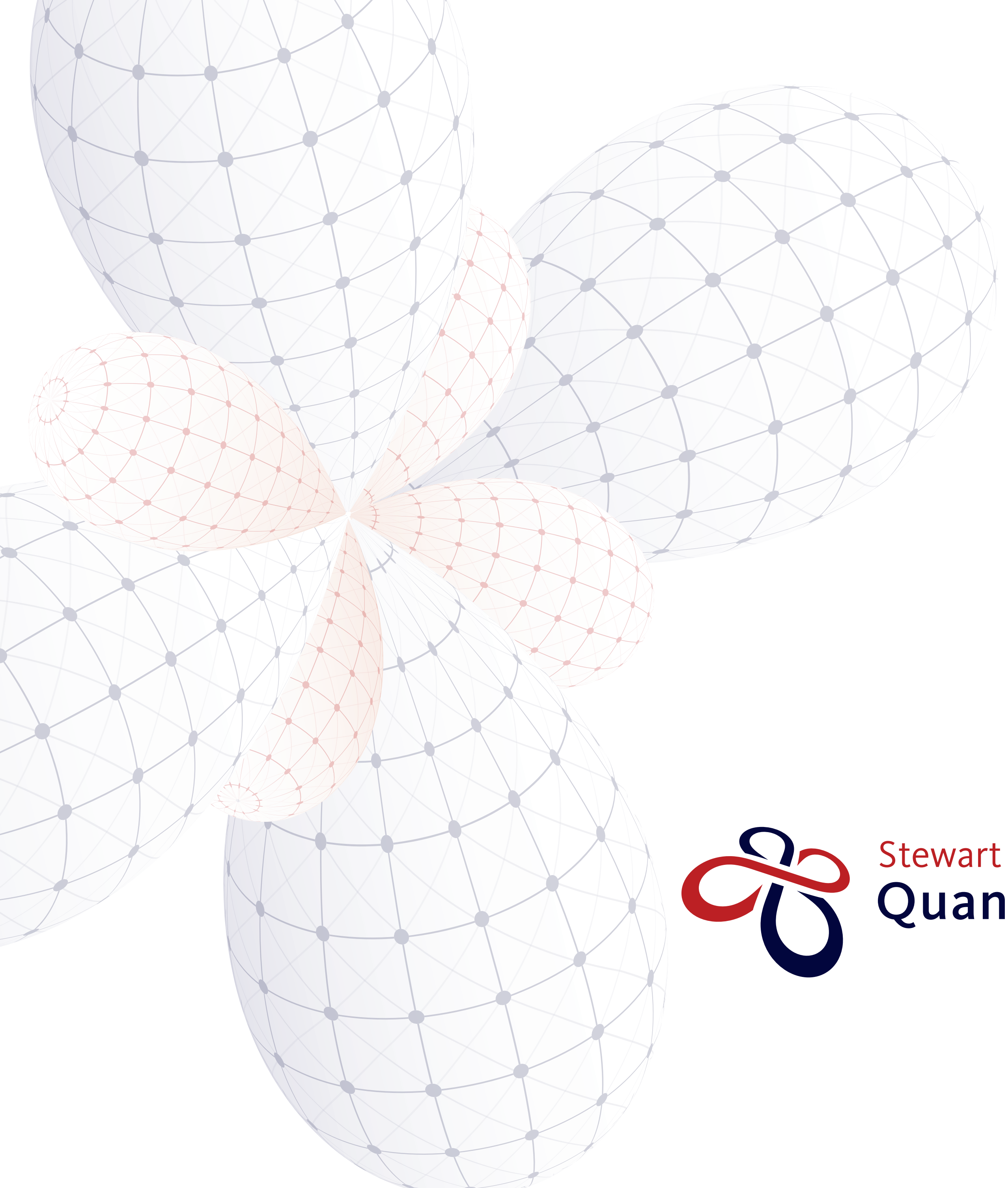


Stewart Blusson
Quantum Matter Institute
THE UNIVERSITY OF BRITISH COLUMBIA

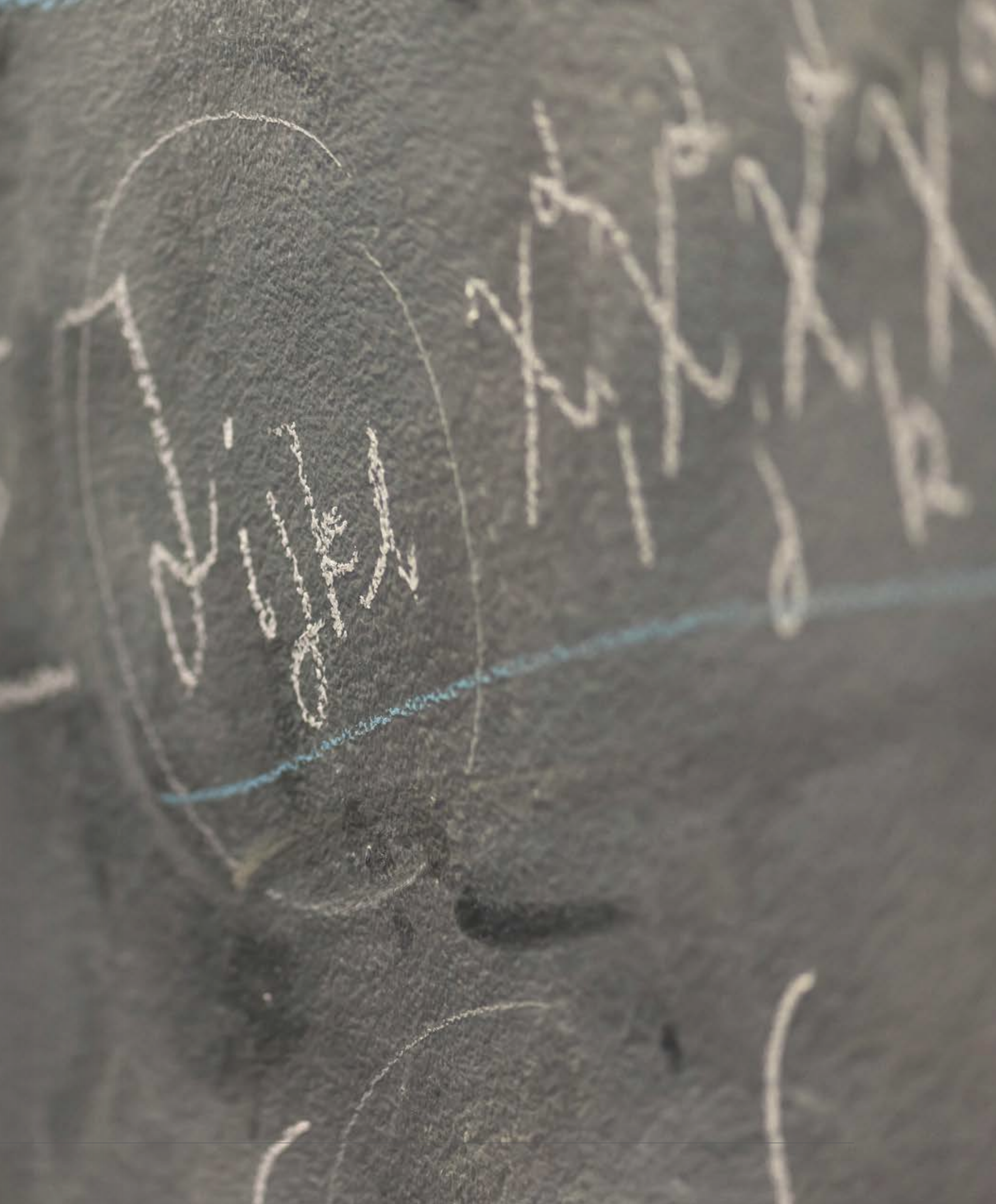
ANNUAL REPORT 2020

MISSION

The Stewart Blusson Quantum Matter Institute (Blusson QMI) fosters the discovery, understanding, and control of quantum materials and related novel materials and devices. We train the professionals who will translate this intellectual capital into economic benefits for Canada, and transfer the discoveries to industry to create next-generation technologies.

VISION

Blusson QMI 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.



OUR FUNDERS

Blusson QMI is deeply indebted to the generous support of our funders, partners, and sponsors. Our research is made possible thanks in particular to the following individuals and organizations:

Stewart and Marilyn Blusson
The University of British Columbia (UBC)
Canada First Research Excellence Fund (CFREF)
Canada Foundation for Innovation (CFI)
British Columbia Knowledge Development Fund (BCKDF)
Natural Sciences and Engineering Research Council of Canada (NSERC)
Canada Research Chairs Program (CRC)
Canadian Institute for Advanced Research (CIFAR)
The Gordon and Betty Moore Foundation
Western Economic Diversification Canada

We wish to express our sincere gratitude and appreciation for their support as their contributions have enabled Blusson QMI to accelerate research productivity and technology translation.

LAND ACKNOWLEDGMENT

We acknowledge that the land on which we work, study and gather is the traditional, ancestral, and unceded territory of the xwmə0–kwəy’əm (Musqueam) people.

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MESSAGE FROM THE SCIENTIFIC DIRECTOR

We finished laying the strong foundation for *Building to Last* in 2019, and little did we know that 2020 would take such an unexpected turn: it was a year that was both challenging and rewarding in unimaginable ways. Like the rest of the world, we watched as the World Health Organization declared the pandemic in March, and Blusson QMI quickly responded to establish new ways to keep our community connected and engaged, and our research moving forward. What stands out is the extraordinary *resilience* of our team: 2020 taught us that when we work together—even remotely—with dedication, ingenuity, and in support of each other, we can adapt and thrive.

We began the year strong, joining UBC in celebration of Stewart and Marilyn Blusson's generosity, including the incredible $50 million gift to UBC twenty years ago. As one of the beneficiaries of the Blusson's donation, we are forever grateful, and their support continues to resonate and impact the work we do.

By late winter, it was clear that we would need to start thinking about our programming for the year ahead in a different way; we delayed major conferences such as ICN+T and M^{2}S, and looked to online models for some of the events we had been planning. When the UBC shifted to remote work and virtual classrooms, our teams moved quickly to meet the challenge. Our online events, such as our tutorial on *Solid State Computational Physics,* brainstorming sessions including *Time-resolved Spectroscopy on Quantum Materials*, *Charge Order,* and *Crowding, Damping, and Localization at High Temperature,* and our informal presentation series *Blusson QMI Family & Friends,* were received with enthusiasm and brought the community closer together. I am impressed at how our faculty responded to having to shift to online course delivery on short notice, and how they—along with students and staff, including our 2020 cohort of Quantum Pathways participants—worked to reimagine and develop physics education in a virtual space.

The culture of Blusson QMI is critical to our success as an organization, and we saw our teams pull together to preserve that sense of community, welcoming new staff, students, and postdoctoral fellows—some of whom have yet to set foot in our building. We continued to hire, expanding our business operations and technical teams, and recruiting for a junior faculty position. In late 2020, we hired a new Managing Director, Kim Kiloh, as well as a Research Program Manager, Ken Wong, to lead the Project Management Office. Our work to ensure sustainability was affirmed as we continued to grow our team, develop our research, and adapt to new challenges.

Our own Lukas Chrostowski working with Electrical & Computer Engineering colleague Karen Cheung and their teams received an exemption from the University in April, to build, test, and implement an efficient, ultra-low-cost screening tool enabling on-the-go diagnostic testing for coronavirus and future novel diseases. I want to thank the staff of our Cleanroom and Nanofabrication facilities who supported this important effort, carefully following new safety protocols and working around the clock due to mandatory reduced staffing levels. In September, Lukas and Karen were invited to a UBC roundtable to present this promising work to Prime Minister Justin Trudeau and Digital Government Minister Joyce Murray.

While work toward a Quantum Strategy for Canada stalled early in the year, the effort regained momentum by summer and we are now looking forward to those efforts coming to fruition in the coming months. Executive Director Karl Jessen has been integral to this process, and I am grateful for his continued leadership in this area.

This past year we further expanded our partnership with the Max Planck Society. The International PhD in Quantum Materials Program (Joint PhD) continued to grow with additional students enrolled, and we are working on creating faculty cross-appointments between the institutions. This will lead to even closer interaction and greater opportunities for our students. For instance, Bernhard Keimer (Director, Max Planck Institute for Solid State Research, Stuttgart) and Hao Tjeng (Director, Max Planck Institute for Chemical Physics of Solids, Dresden) have already been appointed Adjunct Professors at UBC, and will be teaching a graduate course next year.

Finally, I would like to thank our faculty, students, and staff for everything they have done to preserve our momentum and our community. Despite the resilience of our team, this was a challenging year for all of us. Parents juggled work, their children's remote learning and childcare facility closures; single people worked through months of isolation as gathering restrictions prevented social contact; those with partners found themselves vying for limited workspace in close quarters at home. It was hard. I am deeply moved by the empathy, compassion, and commitment our people have shown one another, and the strength of our team. I have seen first-hand how sturdy our foundation is. We truly are built to last. Our people are incredible, and they will lead us forward.

Andrea Damascelli
Scientific Director

BY THE NUMBERS

Our goal is to ensure that Blusson QMI is comprised of the professional personnel necessary to build a world-class institute while prioritizing the development of programs that support equity, diversity, and inclusion.

142
Graduate Students

46
QuEST Students

55
Postdoctoral Fellows

3
Affiliate Faculty

25
Faculty

4
Canada Research Chairs

26
Administrative Staff

35
Scientific & Technical Staff

4
CIFAR Scholars

PANDEMIC RESPONSE

Andrea Damascelli (left) and Pinder Dosanjh (right)

Steven Gou, Project Manager

Left to right: Yunhuan Xiao, Marcel Franz, Oguzhan Can, Ziliang Ye

The University of British Columbia suspended in-person classes and research operations and shifted to remote work and learning on March 16, 2020. This had enormous impacts on Blusson QMI, both on research and on our community of students, faculty and staff.

Our research and operations teams continued to work together on activities ranging from conference planning for 2021, grant applications and award nominations, online staff and student training, year-end financial reporting and business development. And while in-person research activities were suspended for applied teams until summer, when in-person research could resume at reduced capacity, some of our teams were able to continue on; for the theoretical teams, work was able to continue with minimal interruption, while other teams were able to adapt pre-pandemic efforts in support of the COVID-19 research prioritized by the University and the provincial and federal governments.

“Early on there was a bit of a psychological shift we had to make, which made things a bit challenging at first,” said Pinder Dosanjh, Blusson QMI Operations Manager. “But the sense of community that we have has remained, and in some ways may be stronger than ever.”

A number of staff members started new roles at Blusson QMI in the weeks immediately before and after UBC shifted to remote work, and our business operations team worked hard to ensure they were buoyed as they learned and were productive in their new roles. Steve Gou, a Project Manager who had only three days in the office before the shutdown, credits an active Slack network and Zoom for helping him get up to speed and immersed in his projects.

“There is considerable support, and what we can’t realize immediately we’re setting in motion for the future,” said Gou.

“I am pleased with how we have managed to work together through all of these changes,” said Scientific Director Andrea Damascelli. “Now more than ever it is apparent that Blusson QMI is a special place supported by incredible people.”

While the effects of the pandemic on research, training, and operations may unfold over years to come, we found ourselves able to adapt in ways that reinforced the value of our efforts to build agility into our systems.

New Pathways for Student Success

By March, planning for summer programs for Quantum Pathways students was already well underway, and the closure of laboratory spaces presented a huge challenge for supervisors, mentors and program participants themselves.

“Ordinarily, Quantum Pathways students would be working with Pinder Dosanjh and others at Blusson QMI to learn how to do experiments at low temperatures and how to operate cryogenic equipment,” said Doug Bonn. “They’d be learning about lab safety and how to conduct research experiments, but with the labs closed we had to adapt very quickly. We wanted to give our Quantum Pathways students meaningful work, and despite the fact that this is not what they expected to be doing, this was an incredible opportunity to have students offer their perspective on classes they had taken themselves relatively recently."

In order to bring first-year undergraduate physics classes into an online environment, Bonn and other faculty met with Quantum Pathways students twice per week throughout the summer in order to conceptualize and design the online program, which students including Luna Liu developed simulations for (see page 37).

"We really want students to develop a functional understanding of measurement uncertainty and a set of data handling skills," said Liu, a Quantum Pathways student entering her third year of undergraduate studies in the Department of Physics and Astronomy. "We build uncertainty into the measurements and that element of randomness forces them to estimate what the uncertainty is in order to understand and interpret the data."

"Originally we thought we could simply modify existing simulations, but we realized that to teach the students how to engage with the data, we needed to develop our own tools," said Liu.

The result is a series of custom simulations developed by students with first-hand experience in first-year physics labs that mimic real-world experiments.

"Students enrolled in these labs run through a sequence of experiments where they learn critical data handling skills; they learn about stats, graphing techniques used in the sciences, and fitting models, which is all at the heart of handling data, comparing data and models; that's the low-level goal of the course," said Bonn. "The higher-level goal is to deliver experimental experiences that challenge them—they have to build self-reliance, they have to understand how to go back and fix things, so there's an iterative cycle built in. If we can replicate that experience online, then we will be successful. And we know we can deliver that online."

"Many people are trying to figure out how to do a meaningful online lab, but the leadership on this is really at Blusson QMI; because what we're doing in our labs is so different, there are many opportunities to be creative and plenty of expertise among our colleagues we can draw from," said Bonn. "There are a lot of Blusson QMI feet on the ground, and I'm proud of how we've turned a challenging situation into something that's going to be valuable for a lot of people."

Summer Experimental Skills Workshops

While Quantum Pathways is for undergraduate students, our Summer Experimental Skills workshops are for everyone; though in the past these have involved opportunities to learn new lab techniques in-person, our experts were forced to get creative, designing informative sessions and teaching research skills over Zoom.

Workshops ranged from *Making Scientific Figures with Illustrator* and *Making Scientific Art with Blender,* both shared on YouTube by Christopher Gutierrez, former Damascelli lab postdoctoral fellow who is now an Assistant Professor at UCLA, to *Lithography and Patterning* with Matthias Kroug and *Computer-aided Design of Mask Layouts* with Kostis Michelakis.

Cornerstone Models for Quantum Computing

Blusson QMI joined partners including TRIUMF, the University of British Columbia, the University of Victoria and the Helmholtz Institute Mainz (Germany) in the Cornerstone Models for Quantum Computing series. The series, which comprised eight lectures and tutorials over four weeks in summer, attracted international participation and engaged audiences from across North America, Europe and Asia.

The series featured speakers, tutors, and industry representatives from across Canada, including Robert Raussendorf, who presented two sessions on measurement-based quantum computing. Lectures and tutorials were hosted remotely, and focused on emerging trends in the field, including gate-model quantum computing, quantum annealing, measurement-based quantum computing, and continuous-variable quantum computing. Attendees also benefitted from unprecedented hands-on access to cutting-edge hardware from two of Canada's leading quantum computing companies, D-Wave and Xanadu.

Drawing by Alex (Anas) Anees

Blusson QMI Family & Friends Seminars

Our outreach is often external: we speak to current and prospective students, to potential collaborators and colleagues, and even to the community at large; there are audiences who are eager to learn about quantum materials and devices, and we are eager to reach them. But sometimes an enthusiastic audience has been there all along, just waiting to be discovered: with more than 280 members in Blusson QMI's community of faculty, students, and staff, there was an opportunity to make the work we do more accessible to the people who work alongside the research. And thus, the Blusson QMI Family & Friends seminar series was born.

Developed by Alex Anees, Research Operations Facilitator, the program was originally intended to be an in-person event; the first in the series launched online in April, featuring Research Associate James Day and his daughter, Zoey, as they explained the physics of how materials behave at low temperatures.

"It was an opportunity to make what can often seem like esoteric concepts familiar and interesting to our whole community," said Anees. "These weren't lectures; they were meant to be more like social events."

The talks featured researchers, students and scientific staff presenting big ideas in condensed matter physics and quantum computing in accessible, lay-friendly terms. From their living room couches or dining room tables, speakers fielded questions from staff, students, researchers from other areas of study and, occasionally, from curious school-aged children.

"A lot of what we do requires a base level of knowledge. What is ARPES, for example? How do we image electrons? These are fascinating topics, but people who haven't done a PhD in physics may not have been exposed to these ideas," said Anees. "And for those who aren't experts in these areas, this is an opportunity to connect with the research we're supporting through our work."

> "It was an opportunity to make what can often seem like esoteric concepts familiar and interesting to our whole community."
>
> *Alex Anees*

Lukas Chrostowski

> We could not have adapted so quickly if not for the facilities at Blusson QMI and the expertise of our incredible team.
>
> *Lukas Chrostowski*

> Our system will give the reduction in cost and size that will make it possible to give the rapid, real-time information that will feed into EcoScreen's digital risk assurance data platform.
>
> *Karen Cheung*

From Quantum Materials to Silicon Photonics

On September 2, Lukas Chrostowski and colleagues presented their work to develop a powerful and low-cost sensor platform technology based on silicon chips that could one day be deployed for on-the-go diagnostic testing for coronavirus—and future novel diseases—to an audience that included UBC President and Vice-Chancellor, Santa Ono, as well as Prime Minister Justin Trudeau and Digital Government Minister Joyce Murray. The presentation was part of a UBC roundtable with the Government of Canada on developments in diagnostic tools and personal protective equipment.

Chrostowski partnered with long-time research collaborator Karen Cheung, Professor in the School of Biomedical Engineering and ECE, as well as industry partner EcoScreen, to develop the sensor. Much of the work took place at Blusson QMI, especially in the nanofabrication space inside the new cleanroom. The sensor is currently still in development as the team validates the chemistry for the biosensor and continues work on the chip.

"The short version of the story is that the pandemic hit, we invented something, and we got our teams back to work," said Chrostowski. "We could not have adapted so quickly if not for the facilities at Blusson QMI and the expertise of our incredible team."

When the labs at Blusson QMI were shut down in mid-March, a team of highly skilled researchers, technicians, and trainees were sent home, with many of their projects put on hold. As new information about the novel coronavirus became available, and as the shutdown lasted longer than anyone originally anticipated, necessity begat invention.

Soon, with an exemption from the University, Chrostowski and colleagues were able to return to the lab and get to work to build, test, and implement an efficient, ultra-low-cost screening tool that, when it is ready, would enable on-the-go diagnostic testing for coronavirus and future novel diseases based on silicon photonics and microfluidics technology the team was already adept at working with.

"It's essentially a side-project of a quantum devices effort; there are commonalities with quantum materials, and the technical expertise required for quantum devices engineering is the same," said Chrostowski.

"We prototype the chips at UBC, but ultimately these chips can be manufactured at low cost, in quantities of millions, by CMOS electronics foundries around the world," said Chrostowski.

Existing diagnostic technology is cumbersome and expensive, and requires a laboratory instrument to read screening chips, which can cost tens of thousands of dollars.

"Our system will give the reduction in cost and size that will make it possible to give the rapid, real-time information that will feed into EcoScreen's digital risk assurance data platform," said Cheung.

In April, the team filed a provisional patent that can put the entire instrument inside the chip with an end goal of developing disposable sensors that cost about $20, can diagnose many different diseases and several mutations, and connect to a smartphone.

"This is truly a made-in-Canada effort, and none of it would be possible without access to the brilliant minds and leading-edge technology available to us at UBC and Blusson QMI," said Chrostowski.

GRAND CHALLENGES

Our Grand Challenges (GCs) are three bold, ambitious ideas that will guide our research priorities and engage all of our research groups and investigators in collaboration over the next decade. GC leadership and teams began 2020 by working to develop a plan of activities for the year ahead. With the support of Pedro Lopes, a new Project Manager within Blusson QMI's Project Management Office dedicated to this effort, the GCs have developed considerably since 2019. In fact, the GCs were the focus of our International Scientific Advisory Board (ISAB) meeting in May 2020, and the feedback from ISAB helped the teams to further develop and solidify their research goals, hiring and infrastructure needs, and budgets.

PUSHING THE BOUNDARIES OF NISQ-ERA QUANTUM COMPUTING WITH FOCUS ON QUANTUM MATERIALS (QCGC)

The mission of the QCGC is to find and develop quantum matter-related problems that would benefit from, and help demonstrate advantage in, quantum information processing technologies. QCGC builds on three capacity pillars: **(1)** Machine learning, **(2)** Hardware Quantum Simulator (Hardware), and **(3)** Fundamental analysis of quantum computer programming approaches (Theory). These pillars support **(4)** the Applications layer. Building on the momentum gained in 2019, the QCGC team made important scientific progress in 2020:

1. **Machine learning:** Roman Krems and Joseph Salfi's groups have been working together to develop a machine-learning approach to building an optimal design for the analogue simulator of the Hubbard model. This approach combines first-principle quantum calculations and experimental measurements wrapped by machine-learning models to predict the design of electrodes and voltages needed for the realization of specific Hubbard model parameters. In parallel, Krems' group members have been exploring how to build regression models on the IBM quantum computer for applications in quantum dynamics and how to exploit machine learning for optimizing quantum machine learning, i.e. for building the best quantum analogues of classical classification machine learning models. The goal of this work is to identify possible advantages of quantum computers for applications targeting optimization of time-consuming experiments.

2. **Hardware:** Salfi's group has been working on building an experimental setup for control of qubits in a quantum simulator and fabrication of spin-based qubits and superconducting-based quantum devices that form a spin-based quantum computer and simulator. This setup was verified using prototype devices already demonstrating single-electron control at low (0.1 K) electron temperature. A device fabrication developed locally enables the extract spins from a mesoscopic reservoir underneath a nano-scale gate, the pre-requisite for single-hole spin qubits. The fabrication of two-qubit and three-qubit devices based on this capability is already underway. Kinetic inductance nanowire resonators with high internal quality factors have been demonstrated for high-fidelity spin readout. In 2021, the team will be putting these capabilities together with the goal of demonstrating a small-scale quantum simulator.

3. **Theory:** Krems, in collaboration with Fumika Suzuki (UBC), Mikhail Lemeschko (IST Austria), and Wojciech Zurek (Los Alamos National Lab), explored the role of internal structure of quantum particles on their localization in random media. This is a long-standing problem that dates back to the work of Philip W. Anderson in the late 1950s (for which Anderson received the Nobel prize), and has only recently become amenable to experimental tests. Anderson considered structure-less particles. This work,[1] under review in *Physics Review Letters,* shows how Anderson's results must be modified for particles with internal structure (such as molecules with ro-vibrational degrees of freedom or bi-excitons with multiple bound states coupled to the translation motion in disordered lattices). In particular, this work shows that the entanglement between the two degrees of freedom weakens localization due to the upper bound imposed on the inverse participation ratio by purity of a quantum state.

Another successful collaboration in 2020 involved QCGC members Robert Raussendorf (Blusson QMI) and Eran Sela (Tel Aviv University) in a project that was aided in part by Joint PhD student Rafael Haenel, and resulted in a high-impact journal publication[2] using data obtained through experiments on IBM's open-access quantum computer. The paper proposed and realized two protocols linking quantum information processing to the classification of symmetry-protected topological phases of matter.

Further, Raussendorf's group published a paper[3] that builds on work described in a *Physical Review A* publication,[4] questioning a long-standing idea that negativity in quasiprobability functions must necessarily show up in universal quantum computation. This work extends the ubiquitous stabilizer formalism, and casts a new light on the quantum-to-classical transition.

[1] F. Suzuki, M. Lemeshko, W.H. Zurek, R. Krems. *Localization of composite quantum particles in a random potential.* https://arxiv.org/abs/2011.06279.
[2] D. Azses, R. Haenel, Y. Naveh, R. Raussendorf, E. Sela, E.G. Dalla Torre. *Identification of Symmetry-Protected Topological States on Noisy Quantum Computers.* Phys. Rev. Lett. **125**, 12050 (2020).
[3] M. Zurel, C. Okay, R. Raussendorf. *A hidden variable model for universal quantum computation with magic states on qubits.* Phys. Rev. Lett. **125**, 260404 (2020).
[4] R. Raussendorf, J. Bermejo-vega, E. Tyhurst, C. Okay, M. Zurel. *Phase space simulation method for quantum computation with magic states on qubits.* Phys. Rev. A **101**, 012350 (2020).

4. **Applications:** Raussendorf and Jeff Young published a paper in the journal *Advanced Quantum Technologies*[5] that proposed a comprehensive quantum computing architecture and protocol based on silicon donor qubits coupled by photons. The paper describes a schematic layout for realizing fault-tolerant universal quantum computation that builds on emergent advanced silicon photonics circuit technology; while not yet validated on a single chip, the work utilizes functional components which already exist, potentially shortening the timeline to a functional combination of these components.

In addition, Young and Mona Berciu's teams have been working to better understand the effect of diagonal and off-diagonal coupling to optical and acoustic phonons, on the emission spectrum of a Se+ defect-based quantum emitter in Si. These defects, and others like them, are being considered as optically addressable spin-qubits for quantum information processing in silicon. The work is led by QCGC postdoctoral fellow Leon Ruocco. The first step, completed in 2020, was to understand whether the off-diagonal coupling, which is generically ignored in such problems in order to simplify them, is important. The answer, based on the study of simplified models, is yes. The second step involves a collaboration with Prineha Narang's group (Harvard), which will use their ab-initio codes to generate realistic values for these couplings and other material parameters, so that more quantitative predictions can be made and compared to experiments. This part will begin in 2021 and, if successful, the same framework will allow the QCGC team to consider various possible impurities doped into various semiconductors, to understand which ones would have optimal optical properties. This type of problem may be of interest for testing gaussian boson sampling processors like those made available by Xanadu.

ATOMISTIC APPROACH TO EMERGENT PROPERTIES OF DISORDERED MATERIALS (DISORDER GC)

The Disorder GC aims to discover new materials required for emerging technologies by identifying and understanding the local conditions under which structural, chemical, magnetic, and electronic disorder leads to novel material behaviour. The Disorder GC leverages Blusson QMI's strengths in materials by design by integrating theory and simulation, synthesis, characterization, and device engineering. The team has prioritized three immediate projects: **(1)** establishing structure-function relationships in high entropy oxides, with an eye towards possible applications as battery materials; **(2)** thermal transport of highly disordered materials at high temperature materials; and **(3)** amorphous coatings with exceptionally low mechanical loss for gravitational wave detectors.

One aspect of the Disorder GC is the effort to determine how thermal transport happens in materials at high temperatures, where phonons and disorder proliferate so much that usual methodologies breakdown. Such unconventional situations are of importance in the characterization of the origins of the 'heat trap' phenomenon, displayed by carbon nanotube (CNT) forests, which were discovered by one of our research teams. CNTs are cylinder-shaped materials comprised of one or more sheets of carbon atoms and find applications in composites, electronics, and energy storage materials.

In April, the team published new research in the journal *Physical Review B*,[6] that compare the length and temperature dependence of the thermal conductivity of CNTs in order to determine whether a fully diffusive heat transport regime and an intrinsic value of thermal conductivity exist for CNTs. The team employed three different atomic-level approaches to lattice heat transport and, by calculating acoustic normal mode coordinates on-the-fly, could resolve modes of unprecedented wavelength in tubes of varying diameters. The work demonstrates that such a regime can be established and traced back to three-phonon scattering rates of acoustic photons in the long wavelength limit, illustrating the decisive role of emerging long wavelength acoustic modes in governing the length dependence of thermal conductivity.

[5] X. Yan, W. Asavanant, H. Kamakari, J. Wu, J.F. Young, R. Raussendorf. *A Quantum Computer Architecture Based on Silicon Donor Qubits Coupled by Photons.* Adv. Quantum Technol. **3**, 2000011 (2020).

[6] D. Bruns, A. Nojeh, A.S. Phani, J. Rottler. *Heat transport in carbon nanotubes: Length dependence of phononic conductivity from the Boltzmann transport equation and molecular dynamics.* Phys. Rev. B **101**, 195408 (2020).

ENGINEERING EXOTIC PHASES IN TWO-DIMENSIONAL MATERIALS (2DGC)

When electrons are confined to two dimensions, they exhibit a range of emerging behaviors due to the enhanced interaction among them. As one of the frontiers in quantum materials research, two-dimensional (2D) materials offer an exciting platform to study these unusual behaviors and related exotic phases with potential applications for future technologies. The 2DGC explores some of these exotic phases, based on the ideas originated at Blusson QMI and in step with the institute's fundamental principle of *quantum materials by design.* With an emphasis on building interconnections, the GC brings together Blusson QMI's different material growth capabilities with the Institute's expanding range of experimental probes, and focus on three target areas: **(1)** Flat band physics by design, **(2)** building topological superconductors, and **(3)** electron-hole condensates in heterostructures.

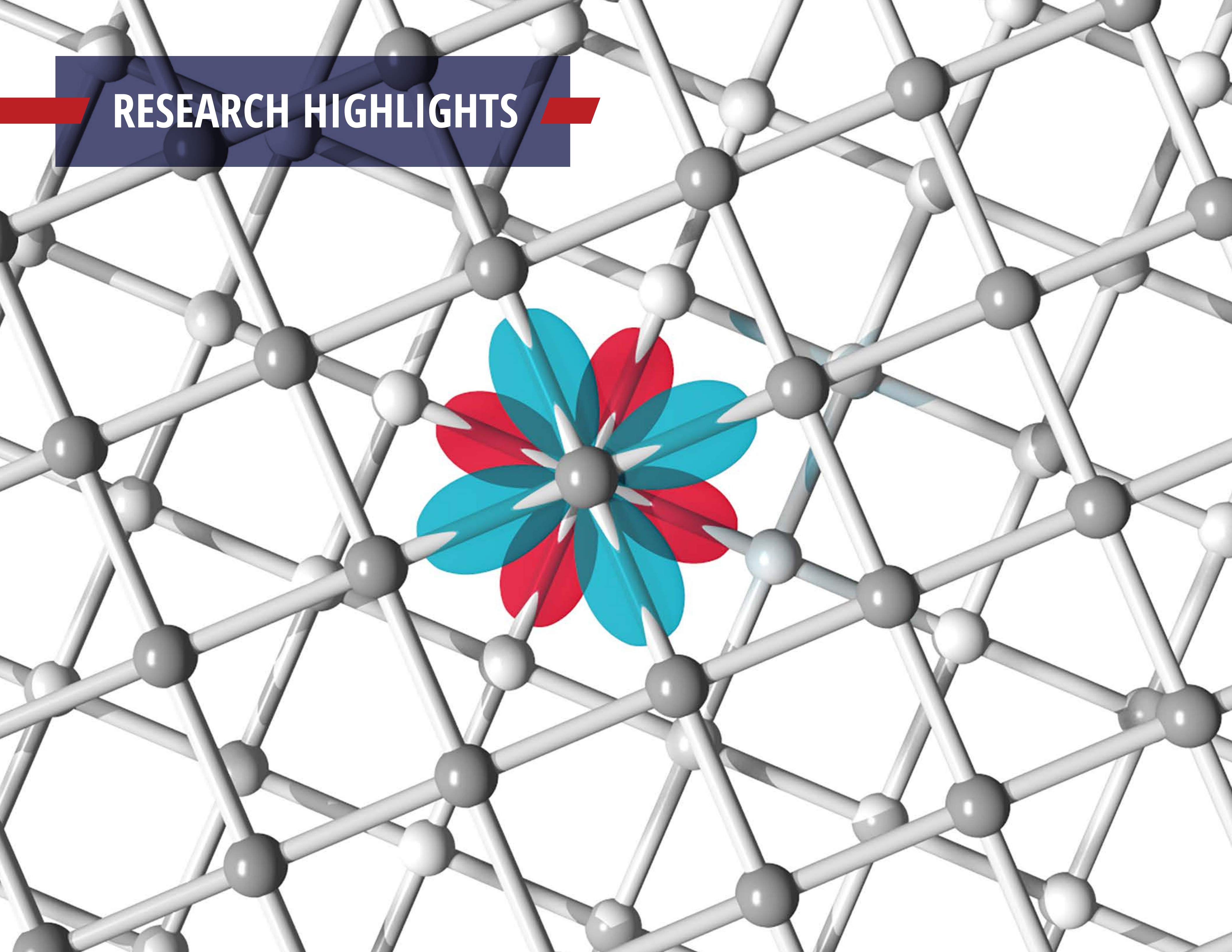
One important technique for 2D materials is Molecular Beam Epitaxy (MBE), which allows growth layer by layer. At Blusson QMI, Ke Zou has established a powerful MBE lab for the growing atomically precise heterostructures, combining two challenging families of materials: the transition metal oxides, and chalcogenides. Within that unique facility, samples can transfer between growth chambers always in the ultra-high vacuum condition. In the past year, a group of research associates from Sarah Burke, Andrea Damascelli, and Ke Zou's groups have further upgraded the capability by designing a sophisticated apparatus to shuttle samples between the growth chamber and various measurement apparatus without breaking the vacuum. This will allow study of a series of air-sensitive materials, which has not previously been possible.

In parallel, Ziliang Ye and Josh Folk's groups have established a range of facilities related to van der Waals (vdW) materials. Three transfer stations have been built to achieve high-yield and large-flake exfoliation of various vdW materials, including the air-sensitive types, as well as stacking them into heterosamples with controlled twisted angles. Various characterization and storage facilities have been established including an atomic force microscope, optical pump-probe microscope, and Raman microscope. To reveal the elusive physical properties arising from exotic phases, the team has also built a series of experimental techniques with state-of-the-art performance, such as a magneto optical Kerr interferometer with a sensitivity below 50 nanoradians and an optical parametric oscillator as fast as 50 femtoseconds. These capabilities will be crucial to develop a new generation of quantum devices based on quantum materials.

This year, the 2DGC delivered a key first milestone, featured on page 15, by providing a new theoretical framework for the realization of high-temperature topological superconductivity, which relies on the stacking and twisting of single layers of cuprate superconductors. Ye and colleagues are currently working toward the experimental realization of this concept.

Left to right: Ziliang Ye, Marcel Franz, Oguzhan Can

RESEARCH HIGHLIGHTS



GRAND CHALLENGE HIGHLIGHT

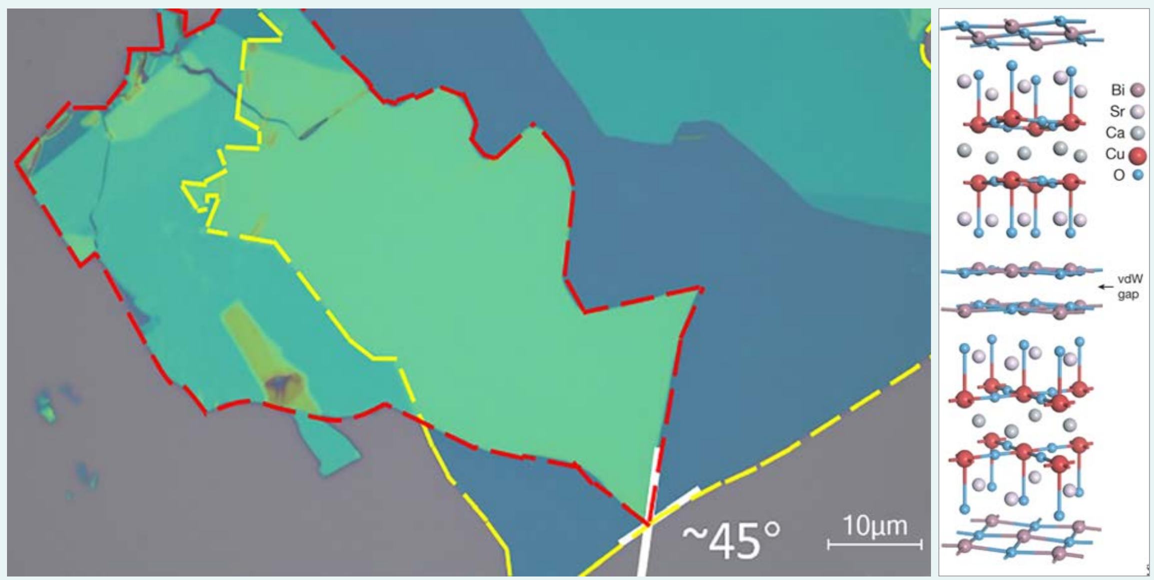
NEW TWIST ON CUPRATES COULD OFFER TOPOLOGICAL SUPERCONDUCTIVITY AT HIGH TEMPERATURES

Superconductivity is a quintessentially interesting quantum state of matter that is also used as a key ingredient in many existing and future technologies. *Topological superconductors* in particular are of great current interest both as a fundamental intellectual challenge and because they offer promise as platforms for fault-tolerant quantum computing. Unfortunately, their occurrence in nature is extremely rare and candidate materials require extremely low temperatures.

A team of physicists at Blusson QMI have proposed a path to creating the first *high-temperature* topological superconductor, offering an accessible method to expand the utility of this novel state of matter.

Marcel Franz and colleagues predict that combining two monolayer-thin sheets of copper-based high-temperature superconductor, such as $Bi_2Sr_2CaCu_2O_{8+\delta}$, in a twisted configuration (pictured on page 16) will lead to topological superconductivity at much higher temperatures than researchers have achieved so far.

“For the past few years, researchers have been interested in twisted structures in advanced materials, starting with graphene,” said Franz. “Some very interesting properties occur when you take two graphene monolayers and assemble them into bilayer structures with a slight—but precise—twist.”



Twisted Bi2Sr2CaCu2O8+δ, sample created by stacking method

Franz and colleagues predict that their copper-based material will offer more flexibility in its assembly than graphene because, among other things, the twist angle does not require the same extreme precision.

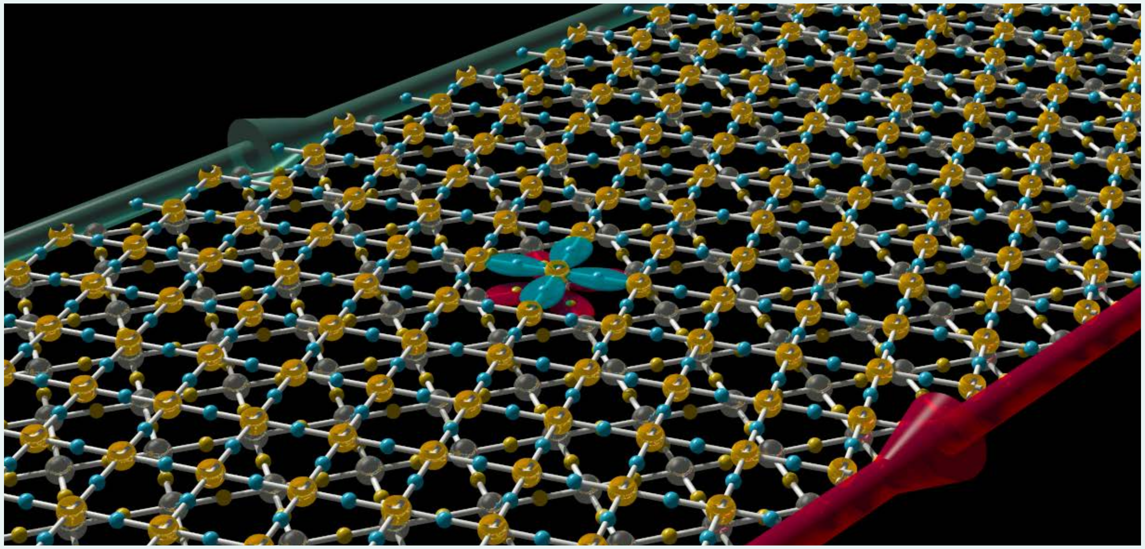
“Our modelling indicates that this material will become a topological superconductor when the layers are combined at an angle that is close to 45 degrees, meaning 45 degrees plus or minus ten degrees. You can do it by sight, almost. This material should be easier to assemble than graphene,” said Franz.

The proposed material is not merely hypothetical—all of the required ingredients already exist. In 2019 researchers in China reported success in isolating $Bi_2Sr_2CaCu_2O_{8+\delta}$ monolayers with critical temperature close to 90K, comparable to bulk crystals. More recently Ziliang Ye and his team managed to reproduce these results and also made first steps towards assembling twisted bilayers.

Superconductivity is a quantum state of matter that occurs at low temperatures. The state enables frictionless motion of electrons, meaning that electrical current does not lose energy in the form of heat and can persist indefinitely. Topological superconductors are a special class of superconductor with interesting and unusual properties, making them appealing candidates for use in applications such as quantum computers. While quantum computing shows promise for tackling problems that are challenging or impossible to solve using classical computers, current prototypes are highly sensitive to disturbances. Because of the way that electrons at the edge of a topological superconductor behave, they are particularly robust and not as sensitive to disturbances from heat, vibration, or noise, hence the promise of fault-tolerant quantum computation.

In order to achieve topological superconductivity, the conventional candidate materials must be kept extremely cold, which requires expensive equipment inaccessible to all but the most highly specialized laboratories. By contrast, the model that Franz and colleagues proposed offers the benefits of topological superconductivity at much higher temperatures—possibly as high as 90 Kelvin—which means they can be cooled using equipment accessible in many laboratories.

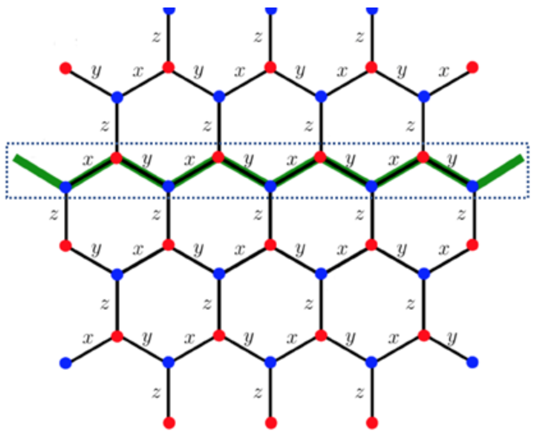
“Research at Blusson QMI seeks to unravel and exploit the complex phenomena that emerge in novel engineered materials, including topological states,” said Andrea Damascelli. “This new work represents an important milestone in Blusson QMI’s *Quantum Materials by Design* overarching mission, to rationally design, synthesize, and study quantum materials with the ideal properties to serve as building blocks for future ultra-high-performance technologies.”



Now, experimental work is underway in Ye’s lab to test Franz’s theory.

Ye and colleagues are using crystals grown in the Damascelli lab to construct a device employing Franz’s proposed structure, supporting this project in the next stage of its life cycle. While Franz’s publication represents a milestone for the 2D Grand Challenge, this project remains active, as Ye and colleagues work to test and validate theoretical predictions with the ultimate goal of producing the world’s first high-temperature topological superconductor.

SPINS SEEK ORDER IN KITAEV-TYPE SYSTEMS IN ONE DIMENSION



The biggest enemy of quantum computing technology is “noise,” perturbation at the atomic level that can disrupt the resilience of the materials that form the basis of quantum computing applications. New research from Ian Affleck’s team has found new clues as to the physics behind a class of materials that are robust enough to withstand such noise. The findings, published in the journal *Physical Review Letters,*[1] offer clarity on the ideal atomic structure for quantum computing materials.

The celebrated Kitaev model describes a peculiar way in which spin 1/2 electrons in a honeycomb lattice material may interact. Electrons are the negatively charged particles of an atom and the term “spin” refers to their intrinsic angular momentum, as they can be loosely viewed as microscopic spinning rigid bodies. In this model, proposed by physicist Alexei Kitaev, the spins interact with bond-directional dependent Ising interactions (a mathematical model regulating the ferromagnetic and/or antiferromagnetic relative alignment of the spins) with a strength K while all other parameters are zero. Kitaev was able to show that this model realizes a much sought-after phase of matter—a spin liquid—that can be very useful for quantum computing applications.

“The material we are looking at is a 2D material wherein a layer of atoms is organized into a honeycomb lattice structure; this material is interesting for us because it has the potential to realize the Kitaev model,” explained Research Associate Alberto Nocera, who worked with Postdoctoral Fellow Wang Yang and PhD student Tarun Tummuru, colleagues in the Affleck lab, as well as with Professor Hae-Young Kee at the University of Toronto.

The movement of electrons in any material at low temperature is perturbed by the presence of defects and atomic vibrations, and how electrons respond to these perturbations affects the stability of the material as a whole. The main question the team is asking now is, what if we add an interaction or perturbation that is common in nature? To answer this, they took a one-dimensional (1D) version of the Kitaev model (pictured) and added an off-diagonal “Gamma” interaction term to see how Kitaev physics reacted to this additional perturbation.

“The model is theoretical but realistic,” said Nocera, who believes the model is useful in that it may show researchers what they might be looking for in 2D.

What they found is that the system wants to be ordered antiferromagnetically, in a very specific way. Due to large quantum fluctuations, “true” order is never achieved, and the spins are in a highly correlated state. At long distances, the highly correlated motions of the spinning electrons generate a hierarchy of collective “dancing” patterns that can be classified by an infinite dimensional symmetry, which is an extension of the spatial rotational symmetry.

These “dancing” patterns in this 1D “cut” of the honeycomb lattice are interesting in that they reveal an organization principle based on infinite dimensional symmetry, but it may also be useful in giving clues to the correlated dynamics of electrons in 2D layers.

One material the researchers are interested in exploring in this context is made from ruthenium chloride (RuCl3). At Blusson QMI, Nocera and colleagues are using the Laboratory for Interdisciplinary Science Application (LISA) computational resources to determine the phase diagram of the model, isolating a row of atoms in order to imagine that the material only had a single dimension.

“These materials are made of several layers in 3D, but the layers are only weakly coupled between each other; this is the first approximation,” Nocera explains. “We are doing another approximation; we imagine that a single layer can be studied as a collection of 1D substructures which, coupled together, form a 2D honeycomb lattice. We focus our attention on only one of these 1D substructures.”

Further work, using LISA and a the newer and potentially more powerful LISA-2 cluster, will explore new quantum phases of matter stabilized within a more general model by the addition of a Heisenberg interaction term. These studies will provide theoretical predictions for future neutron and x-ray scattering experiments on Kitaev-1D model materials.

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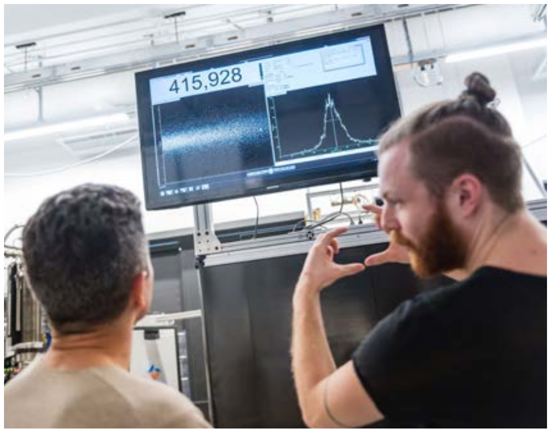
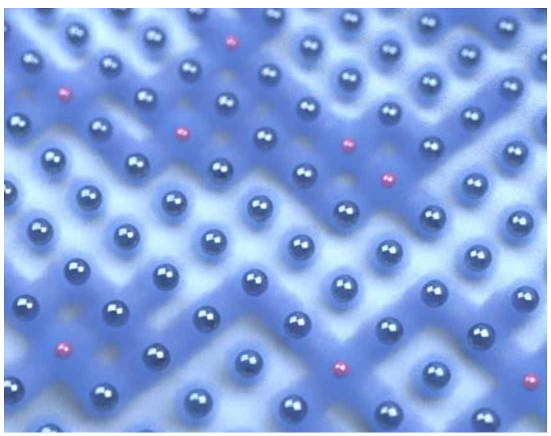
[1] W. Yang, A. Nocera, T. Tummuru, H.Y. Kee, I. Affleck. *Phase Diagram of the Spin-1/2 Kitaev-Gamma Chain and Emergent SU(2) Symmetry.* Phys. Rev. Lett. **124**, 147205 (2020).

NEW QUANTUM SWITCH TURNS METALS INTO INSULATORS



Andrea Damascelli (left) with Berend Zwartsenberg (right)



Artist's impression of the dissolving of the electronic "traffic jam." The red atoms are different in their quantum nature and allow transport of electrons in their surroundings. Credit: Berend Zwartsenberg

Most modern electronic devices rely on tiny, finely-tuned electrical currents to process and store information. These currents dictate how fast our computers run, how regularly our pacemakers tick and how securely our money is stored in the bank.

In a study published in *Nature Physics*,[1] Blusson QMI researchers have demonstrated an entirely new way to precisely control such electrical currents by leveraging the interaction between an electron's spin (which is the quantum magnetic field it inherently carries) and its orbital rotation around the nucleus.

"We have found a new way to switch the electrical conduction in materials from on to off," said lead author Berend Zwartsenberg, a PhD student in Andrea Damascelli's group. "Not only does this exciting result extend our understanding of how electrical conduction works, it will help us further explore known properties such as conductivity, magnetism, and superconductivity, and discover new ones that could be important for quantum computing, data storage, and energy applications."

Broadly, all materials can be categorized as metals or insulators, depending on the ability of electrons to move through the material and conduct electricity. However, not all insulators are created equally. In simple materials, the difference between metallic and insulating behavior stems from the number of electrons present: an odd number for metals, and an even number for insulators. In more complex materials, such as the so-called Mott insulators, the electrons interact with each other in different ways, with a delicate balance determining their electrical conduction.

In a Mott insulator, electrostatic repulsion prevents the electrons from getting too close to one another, which creates a traffic jam and limits the free flow of electrons. Until now, there were two known ways to free up the traffic jam: by reducing the strength of the repulsive interaction between electrons, or by changing the number of electrons. The team explored a third possibility: was there a way to alter the very quantum nature of the material to enable a metal-insulator transition to occur?

Using a technique called angle-resolved photoemission spectroscopy (ARPES), the team examined the Mott insulator Sr2IrO4, monitoring the number of electrons, their electrostatic repulsion, and finally the interaction between the electron spin and its orbital rotation, obtaining the first ever demonstration of a truly spin-orbit-controlled metal-insulator transition.

"We found that coupling the spin to the orbital angular momentum slows the electrons down to such an extent that they become sensitive to one another's presence, solidifying the traffic jam." said Zwartsenberg. "Reducing spin-orbit coupling in turn eases the traffic jam, and we were able to demonstrate a transition from an insulator to a metal for the first time using this strategy."

"This is a really exciting result at the fundamental physics level, and expands the potential of modern electronics," said co-author Andrea Damascelli. "If we can develop a microscopic understanding of these phases of quantum matter and their emergent electronic phenomena, we can exploit them by engineering quantum materials atom-by-atom for new electronic, magnetic, and sensing applications."

[1] B. Zwartsenberg, R. P. Day, E. Razzoli, M. Michiardi, N. Xu, M. Shi, J. D. Denlinger, G. Cao, S. Calder, K. Ueda, J. Bertinshaw, H. Takagi, B. J. Kim, I. S. Elfimov & A. Damascelli. *Spin-orbit-controlled metal–insulator transition in Sr2IrO4.* Nat. Phys. **16**, 290–294 (2020).

ADA: ACCELERATING MATERIALS RESEARCH WITH FLEXIBLE AUTOMATION AND ARTIFICIAL INTELLIGENCE (AI)

Image source: the Berlinguette group via www.projectada.ca

An artificially intelligent, self-contained, and self-driving laboratory named Ada can explore formulations for a type of thin-film material common to advanced solar cells and consumer electronics. Advanced solar cells are used to power sustainable energy production and enable more efficient energy storage, including longer-lasting batteries. As the need to find clean energy solutions becomes increasingly urgent, it will be imperative to leverage tools like Ada to work toward finding new materials to power industrial and consumer technologies.

A team co-led by Blusson QMI investigator Curtis Berlinguette, Jason Hein (Associate Professor, Department of Chemistry), and Alán Aspuru-Guzik (Professor, Department of Chemistry and Department of Computer Science, University of Toronto) has demonstrated that it is possible for self driving laboratories to develop and test thin films in an automated fashion, with resulting data used to inform the design of subsequent experiments. Named for British mathematician and early computer scientist Ada Lovelace, and borne out of the Paris Climate Agreement and Mission Innovation, Ada conducts experiments autonomously and "learns" how to optimize thin-film materials in a continuous loop, refining its process through machine learning.

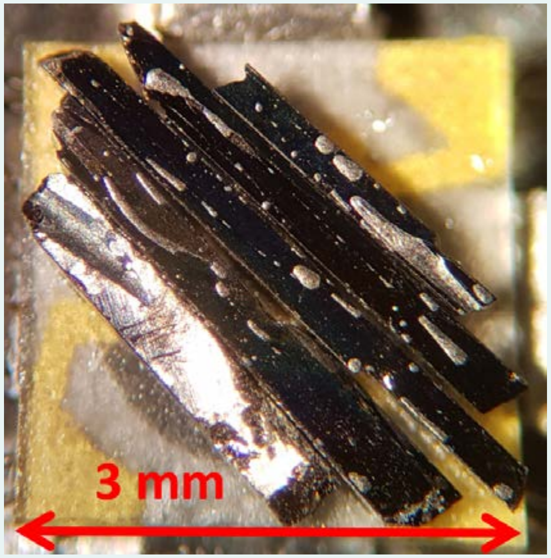
Project Ada was first funded by Natural Resources Canada in 2018. By 2019, the team had built the first fully functional Ada platform; they have since authored a milestone proof-of-concept paper showing that Ada can be effective in the search for new material formulations with desirable properties.

"Ada was able to determine that a particular annealing temperature produced a material that performed better than we had predicted; the result is a discovery that we would not likely have made using conventional methods," explained Berlinguette. The paper, published in the journal *Science Advances*,[1] offers findings that speak to the possibilities of using autonomous laboratories to refine and test organic and inorganic materials of relevance to materials science and clean energy technologies.

Thin films are chemical deposits applied to materials such as glass or silicon that improve the properties of those materials, and are useful in applications ranging from solar technology to nanomedicine. Thin films also offer the opportunity to explore materials with unique and unconventional properties, such as those that show promise for quantum applications.

Translating new functional materials from lab to market has typically followed a rigorous process that can take decades; Project Ada has shown for the first time that self-driving laboratories can be leveraged in an effort to accelerate this timeline for thin-film materials. In the future, the Ada team is aiming for an ambitious but plausible tenfold acceleration, bringing a theoretical material from experimental to commercially viable in just a few years.

[1] B.P. MacLeod, F.G.L. Parlane, T.D. Morrissey, F. Häse, L. Roch, K.E. Dettelbach, R. Moreira, L.P.E. Yunker, M.B. Rooney, J.R. Deeth, V. Lai, G.J. Ng, H. Situ, R.H. Zhang, M.S. Elliott, T.H. Haley, D.J. Dvorak, A. Aspuru-Guzik, J.E. Hein, C.P. Berlinguette. *Self-Driving Laboratory for Accelerated Discovery of Thin-Film Materials*. Sci. Adv. **6**, eaaz8867 (2020).



La2Ni2In crystal

New Family of Superconducting Materials Identified

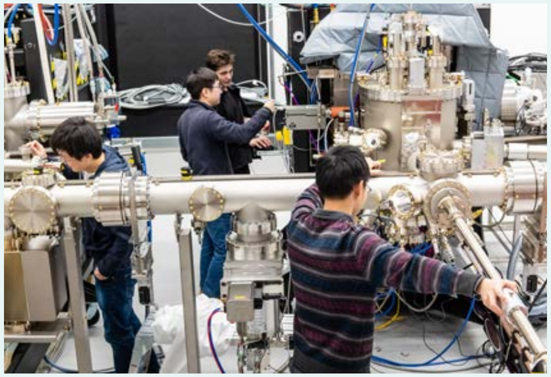
A team of researchers led by Meigan Aronson recently synthesized high-quality single crystals of La2Ni2In,[1] previously only available in polycrystalline form, and have observed superconductivity in the material at temperatures below 0.9 Kelvin (-272.25 degree Celsius). The material, a non-magnetic metal in the nickel (Ni) family, is comparable to other conventional (s-wave) superconductors. Superconductors can be either type-I or type-II; the team found through detailed analysis of the magnetic susceptibility, specific heat, and electrical resistivity measurements that La2Ni2In is likely a conventional type-II superconductor in the so-called dirty limit, although they suggest that subsequent measurements on even higher purity samples could reveal either type-I superconductivity, or even unconventional (non-s-wave) superconductivity. This new discovery is significant because it is the first report of superconductivity in this class of materials; identifying a new superconducting family of materials may provide critical insight that could enable researchers to uncover materials that offer superconductivity at higher temperatures in the future.

Theories Around Cuprate Glue Don't Quite Stick for Nickelates

For Mona Berciu and George Sawatzky, the goal of understanding the mechanisms underlying high-temperature superconductivity in cuprates is an important priority. For more than three decades, an intense effort in the field of condensed matter physics has failed to achieve consensus on what constitutes the "pairing glue" for superconducting cuprate materials. One way to explore this phase has been to find similar but non-cuprate-based families of superconductors, including nickelates (Ni), which might provide key insights into the emergence of superconducting properties in certain metals. Their new work, published this year in *Physical Review Letters*,[2] explores current theories around the role of nickel dioxide (NiO2) in superconducting infinte-layer nickelate NdNiO2, arguing that NiO2 layers should not be treated like simple Mott insulators or charge transfer insulators, and proposing that the leading theory for the superconducting "glue" in cuprates might not be relevant for infinite-layer nickelates.

[1] J. Maiwald, I.I. Mazin, A. Gurevich, M. Aronson. *Superconductivity in La2Ni2In.* Phys. Rev. B **102**, 165125 (2020).

[2] M. Jiang, M. Berciu, G.A. Sawatzky. *Critical Nature of the Ni Spin State in Doped NdNiO2.* Phys. Rev. Lett. **124**, 207004 (2020).



Members of Ke Zou's lab

Superconductivity Found in 3D Titanium Monoxide

Quantum materials are the basis for many emerging quantum technologies, but the extent to which they are understood depends on scientists' ability to produce these materials in the laboratory and study them. The 3D transition metal monoxides represent a well-studied family of quantum materials, and most are insulators; one exception is titanium monoxide (TiO) that had not been examined in its single-crystal state. A collaboration between George Sawatzky and Ke Zou's team at Blusson QMI and scientists at the Canadian Light Source (CLS) in Saskatchewan, with support from partners at Yale University, Brookhaven National Lab, and Chinese Academy of Science, has resulted in new clarity around the intrinsic properties of TiO. Published in the journal *Science Advances*,[3] these results resolve a lingering uncertainty around the behaviour of TiO, revealing that it behaves similarly to its metal counterpart, distinguishing it from other transition-metal monoxides.

"Prior to our work, it was not clear whether TiO is a metal or an insulator," explained Fengmiao Li, a Research Associate who works closely with Sawatzky and Zou and is first author on the paper. "We demonstrate with this new publication that TiO is both a metal and, below 0.5 degrees Kelvin, transitions to a superconducting state, similar to Ti in its metal state; it is the only superconductor in the family of 3D monoxide compounds that are otherwise insulators at low temperatures."

It has been difficult to develop a pure TiO crystalline sample for study; atomic titanium favors a bond with two oxygen atoms forming titanium dioxide (TiO2). Using a technique called molecular beam epitaxy (MBE), Li and colleagues were able to stabilize the compound and generate the cleanest TiO thin film to date.

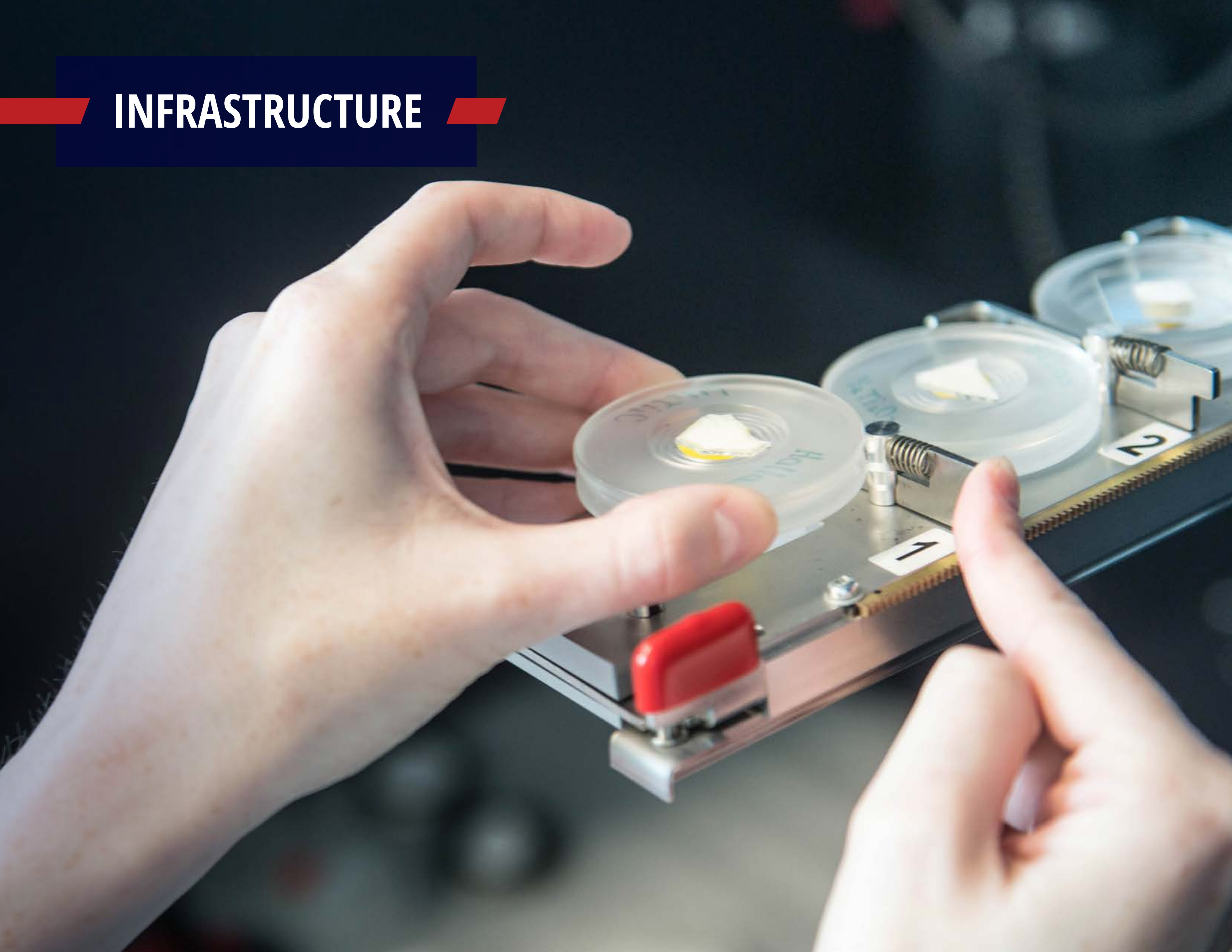
"This recipe for growth was established at CLS, where they have the capacity to do the kind of in situ spectroscopy necessary to examine the films, guiding crystal growth in order to produce clean samples for research," said Li.

Now that the team has a recipe for the thin film, they can grow pure crystals in the lab at Blusson QMI, and work to further understand the material and its potential applications. It is important to note, however, that the formula could not have been developed without collaboration and support from the Resonant Elastic and Inelastic X-ray Scattering (REIXS) staff at the CLS. The development of the REIXS beamline was championed by Sawatzky, who is also the beam team leader.

The REIXS beamline at CLS was funded by the Canada Foundation for Innovation and commissioned in 2010. It opened for general users in July 2011, and since then has been important asset for Blusson QMI researchers, and the collaborative connections Blusson QMI researchers have at CLS are essential for this study.

[3] F.M. Li, Y.T. Zou, M.-G. Han, K. Foyevtsova, H.K. Shin, S.J. Lee, C. Liu, K. Shin, S.D. Albright, R. Sutarto, F.Z. He, B.A. Davidson, F.J. Walker, C.H. Ahn, Y.M. Zhu, Z.G. Cheng, I. Elfimov, G.A. Sawatzky, K. Zou. *Single-crystalline epitaxial TiO film: A metal and superconductor, similar to Ti metal.* Sci. Adv. **7**, eabd4248 (2021).

INFRASTRUCTURE



Nanofabrication Facility

The newly renovated Nanofabrication Facility, operated by five dedicated engineers and managed by Director Kostis Michelakis, is enhancing Blusson QMI's ability to conduct world-class research. This state-of-the-art infrastructure and associated expertise are being made available to industry partners to provide advanced fabrication services. This facility is also the cornerstone of the SiEPICfab industry consortium recently established under Lukas Chrostowski's leadership.

The infrastructure development includes facility upgrades, and the purchase of specialized equipment as well as industry-standard tools such as 8-inch wafer-capable electron beam lithography (EBL) and focused ion beam (FIB) systems (both key nanomachining tools). This will provide researchers and industry partners an integrated advanced manufacturing solution, solidifying Blusson QMI as a hub for developing new quantum technologies.

Phase 1 of this initiative was recently completed in 2020, with cleanroom upgrades to higher ISO levels; these upgrades have increased the cleanliness levels by a factor of 10. The cleanroom is now available to academic and industry users.

Phase 2, expected to be complete in early 2021, completes this series of upgrades and acquisitions. By retrofitting the existing space and adding the FIB system to the current suite of nanofabrication tools, Blusson QMI will be able offer a more streamlined production process for researchers who are designing nanostructures on semi-conductive substrates (wafers) requiring a high degree of reliability and accuracy in the etching process.

Nanospectroscopy Laboratory for Polaritonic Materials Discovery

Steve Dierker was awarded $2.0M to develop the Nanospectroscopy Laboratory for Polaritonic Materials Discovery—a state-of-the-art research facility with a focus on exploring, understanding, and controlling polaritonic materials that have the ability to trap and manipulate light at the nanoscale. The project was funded through the Canada Foundation for Innovation John R. Evans Leaders Fund ($800K), with matching funding ($800K) from the British Columbia Knowledge Development Fund. Additional support ($400K) includes a combination of vendor in-kind contributions and UBC matching funds.

"Advances in our understanding of the physics of optical phenomena at the nanoscale will help to drive the development of a myriad of next generation optical devices, with applications in fields such as photovoltaics, sensing, nanophotonics, communications, and computing," said Dierker.

Quantum Materials Design Lab

Led by Alannah Hallas, the Quantum Materials Design Lab is a multi-faceted materials space that is building an impressive array of crystal growth techniques. Construction on the main crystal growth lab was completed in February 2020. This main working area—a lab space shared by Hallas, Meigan Aronson, and Doug Bonn—includes sample preparation workbenches, gloveboxes for handling air sensitive materials, six fumehoods, and 15 conventional furnaces. The newest addition to the lab is a Bruker D8 Advance Powder x-ray diffractometer, which was installed in 2020. This instrument, available to all of Blusson QMI, is used to study the structural properties of bulk materials, which are intimately tied to their quantum electronic behaviors. x-ray diffraction is a crucial technique that provides a unique "fingerprint" for each material, allows growers to identify their newly synthesized materials and assess sample quality. The instrument has been optimized towards high resolution, minimal background, and rapid phase identification in a high-throughput environment. Having these capabilities in house will accelerate the materials discovery process by allowing crystal growth recipes to be iteratively tested and modified.

In addition, the renovation for the new floating zone crystal growth laboratory is nearly complete with Hallas expected to take occupancy in early 2021. When completed, it will house two new furnaces: a halogen lamp floating zone and a laser diode floating zone. Floating zone furnaces, in which a freestanding rod of polycrystalline material is melted and re-crystallized, allow researchers to grow single crystals of unparalleled size (up to 15 cm) and purity. The halogen lamp floating zone—a four-mirror system—is ideally suited for materials with lower melting temperatures and insulators. The laser diode floating zone provides sharp pin-point heating allowing the growth of materials with lower viscosity or more volatile starting reagents.

"The ideal growth conditions for any material depend on a complex set of material parameters. Having these two image furnaces housed in one central facility will provide tremendous flexibility and versatility to Blusson QMI researchers," said Hallas. Planned expansions for this space include a third floating zone furnace optimized for high-pressure growth in gas pressures up to 300 times atmospheric pressure.

PARTNERSHIPS

Our partnerships allow us to collaborate and share our resources in order to address our research questions with a richer perspective. In 2020, our partnerships were a lifeline, connecting us with colleagues across North America and around the world. Together, we worked within the limitations of our local pandemic-related restrictions to accelerate research where we could, and nurture research questions to be pursued with vigour in less uncertain times.

CREATE Program in Quantum Computing

A new program aimed at developing leaders in quantum computing—solidifying British Columbia's (BC's) reputation as an international quantum technology hub—was awarded $1.65 million from the Natural Sciences and Engineering Research Council (NSERC).

Led by Lukas Chrostowski, the CREATE program—under the banner of Quantum BC—will unite faculty from the University of British Columbia (UBC), Simon Fraser University (SFU), and the University of Victoria (UVic). This collaborative network brings together an influential and interdisciplinary team of scientists and educators who will train the next generation of students to shape the emerging BC quantum computing industry.

"Quantum computing is a field that is growing exponentially in British Columbia, and this program will be the first in the world to produce graduates capable of both building elements of quantum computing hardware and programming, and developing quantum computing algorithms, systems and applications," said Chrostowski, lead of the UBC Quantum Computing Research Excellence Cluster. "The students we train through this CREATE will go on to be the researchers and innovators who realize Canada's quantum computing goals over the next ten to twenty years."

Students who complete the CREATE program will receive highly specialised training and work experience to become leaders in their field, enhance the local ecosystem, and create their own companies. This program, the first of its kind in Canada, will enable participants to work directly with industry through internships that give real-world context for

Credit: Barbara Tevarotto

the theoretical and experimental work they will do in labs at Blusson QMI and UBC, as well as at SFU and UVic. The program has partnered with Canadian companies including D-Wave, 1QBit, Xanadu, CMC, and Lumerical, as well as international companies such as Google, Microsoft, and IBM in order to create learning and career opportunities for this new generation of specialists.

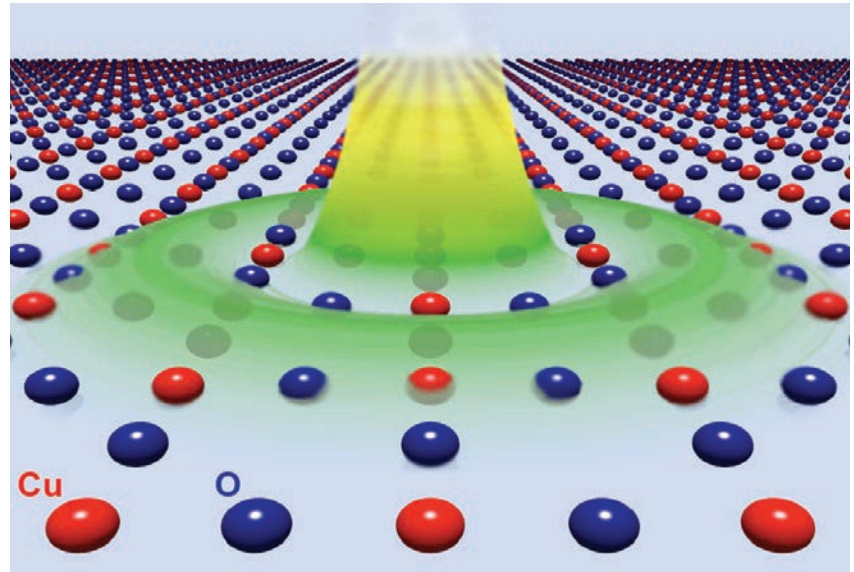
"We're in a really interesting time in this field," said Joseph Salfi, Assistant Professor of Electrical and Computer Engineering and partner in the CREATE program. "We're buoyed by a lot of big discoveries, at a moment when the possibility of advancing quantum computing in significant ways is within our reach. It's a great time to be a grad student in physics, computer science, or engineering—any area that can feed into quantum computing."

Max Planck-UBC-UTokyo Centre for Quantum Materials (CQM)

Numerous projects engaged researchers from the CQM partnership, resulting in multiple publications, beyond the one on spin-orbit-controlled metal-insulator transitions discussed on page 15. One, a direct testament of the far-reaching value of this partnership, emerged in early 2021 and linked former trainees from the Max Planck Institute for Solid State Materials and Blusson QMI—Fabio Boschini, Alex Frano, and Eduardo H. da Silva Neto—who now hold faculty positions at INRS, University of California-San Diego, and Yale University, respectively, and have gone on to become emerging leaders in quantum materials research: a true milestone in this partnership. This multi-institutional, international collaboration began at the Blusson QMI in 2014 and has culminated in a novel interpretation of how electrons interact and self-organize in superconducting cuprates. The study, published in *Nature Communications,*[1] found dynamic electron correlations with charge-order wavelength along all directions in the copper oxide plane, which has immediate consequences to our understanding of rotational and translational symmetry breaking in the cuprates, and in quantum materials more generally.

Another important connection is the collaboration between Mona Berciu and Dirk Manske at the Max Planck Institute for Solid State Research in Stuttgart, Germany. The collaboration, an effort to classify and characterize nonequilibrium Higgs modes in unconventional superconductors, offers researchers the ability to study concepts of spontaneous symmetry breaking, motivations shared by the high energy and condensed matter community, on a smaller energy scale. Rather than using expensive, location-specific tools such as a particle collider, researchers study these concepts in a more accessible laboratory setting, giving physicists looking to understand the origins of the universe—and the mass that gives it shape—the tools to explore new fundamental physics. The result, published in *Nature Communications,*[2] demonstrated a theory for a tailored nonequilibrium quantum quench to excite all possible oscillation symmetries of a superconducting condensate.

A partnership between Ziliang Ye and a team at the University of Tokyo led by Yoshihiro Iwasa and Toshiya Ideue emerged following the CQM meeting hosted at Blusson QMI in 2019. The collaboration has become productive in recent months, leading to a publication due to appear in *Science* in early 2021 around a new type of photovoltaic effect that occurs in specific configurations of certain Van der Waals, or two-dimensional (2D) materials; this research links our partners with our Grand Challenges, particularly in the realm of 2D materials.



A graphic representation of the interaction between electrons in a copper oxide grid

We were successful in securing Adjunct Faculty appointments in the Department of Physics and Astronomy at UBC for Bernhard Keimer and Hao Tjeng; they will begin teaching graduate courses at UBC in 2021. We are in the process of securing reciprocal appointments for Blusson QMI investigators as well.

In addition, we increased our efforts to recruit PhD students for our International PhD Program in Quantum Materials, with our second student, Rafael Haenel, travelling to Stuttgart in September to begin his second year in the program. A third student is expected to start at Blusson QMI in 2021.

[1] F. Boschini, M. Minola, R. Sutarto, E. Schierle, M. Bluschke, Y. Yang, M. Michiardi, Y.C. Shao, X. Feng, S. Ono, R.D. Zhong, J.A. Schneeloch, G.D. Gu, E. Weschke, Y.D. Chuang, B. Keimer, A. Damascelli, A. Frano, E.H. da Silva Neto. *Dynamic electron correlations with charge order wavelength along all directions in the copper oxide plane*. Nat. Commun. **12**, 597 (2021).

[2] L. Schwarz, B. Fauseweh, N. Tsuji, N. Cheng, N. Bittner, H. Krull, M. Berciu, G.S. Uhrig, A.P. Schnyder, S. Kaiser, D. Manske. *Classification and characterization of nonequilibrium Higgs modes in unconventional superconductors.* Nat. Commun. **11**, 287 (2020).

Institute for Complex Adaptive Matter (ICAM)

In 2020, we partnered with the Institut Quantique at Sherbrooke, McMaster University, and University of Toronto to join ICAM as a consortium under the name QMat Canada. ICAM is an international collective of scientists participating in a collaborative and responsive partnership that includes workshops, schools, fellowships, awards, and innovative science outreach projects in the areas of correlated electronic materials, soft condensed matter, biological matter, and emerging materials in energy. In a first step toward engaging with the ICAM community, QMat Canada participated in the ICAM event *Condensed Matter in all the Cities 2020—Deep Challenges of Quantum Materials*, at which Meigan Aronson delivered a presentation.

Joint Rice RCQM and UBC Blusson QMI Workshop

In December, Blusson QMI and Rice University's Center for Quantum Materials jointly hosted a second *New Frontiers in Quantum Materials* workshop. The goal was to bring researchers and trainees from each institution together to explore opportunities for new and synergistic research collaborations with a focus on: **(1)** Fe-based superconductivity; **(2)** 2D materials; **(3)** Topology and quantum criticality. This year, workshop sessions were held virtually, and discussions took place over Zoom.

IMPRS & MP-UBC-UTokyo Summer School

From September 28 to October 2, the Max Planck-UBC-UTokyo Centre for Quantum Materials organized the International Max Planck Research School for Condensed Matter Science (IMPRS-CMS) & MP-UBC-UTokyo Summer School. This five-day event, titled *Design and Synthesis of Quantum Materials* was hosted online by the Max Planck Institute for Solid State Research in Stuttgart, Germany, and structured so that participants across time zones could present live. The program was an opportunity to strengthen existing partnerships, and to encourage young researchers and graduate students to forge connections within the MP-UBC-UTokyo Centre for Quantum Materials.

TRANSLATION

Joshua Folk

Quantum Devices Group Joins International Collaboration to Study the Entropy of Exotic Quantum States

A team of researchers including Blusson QMI's Joshua Folk was awarded the equivalent of CAD $20 million to develop a new approach for investigating new phases of matter that emerge in quantum electronic devices. The project, *Entropy in engineered quantum systems—Mesoscopic thermodynamics of correlated quantum states*, will receive the funds through a European Research Council (ERC) Synergy Grant; ERC Synergy Grants recognize ambitious, collaborative projects.

The project is based on the measurement of entropy in isolated quantum states, an area in which Folk has unique expertise. Reflecting the intersection of these two concepts in physics, the project goes by the name "Quantropy." Folk will join Klaus Ensslin (ETH Zurich, Switzerland), Frédéric Pierre (CNRS, France), and Yigal Meir (Ben Gurion University of the Negev, Israel). The project emerged as a result of ongoing discussions with Ian Affleck (Blusson QMI) and visiting scholar Eran Sela. Sela remains a member of Blusson QMI's Grand Challenge in Pushing the Boundaries of Noisy Intermediate Scale Quantum (NISQ) Computing.

Entropy is a metric of thermodynamic heat capacity—essentially, how much heat must be added to an object to raise its temperature by a certain amount. This quantity is easily accessible in everyday materials but is exceedingly difficult to measure in engineered quantum states, such as those that might be the basis for future quantum computers.

Different materials have different heat capacities, reflecting differences at the microscopic level. In conventional materials, these microscopic details have been understood for over a century, but in quantum materials, the electrons interact so strongly with each other that new (and often poorly-understood) states can emerge. In many cases, these hold the potential to form the basis for a range of future technological applications, from new technologies for conventional electronics to new architectures for quantum information processing.

In order to understand the exotic electronic states found in quantum materials, this team of researchers will devise new ways to measure their thermodynamic properties by creating them in quantum electronic circuits, which are similar to the transistor in a computer chip but measured at temperatures close to absolute zero.

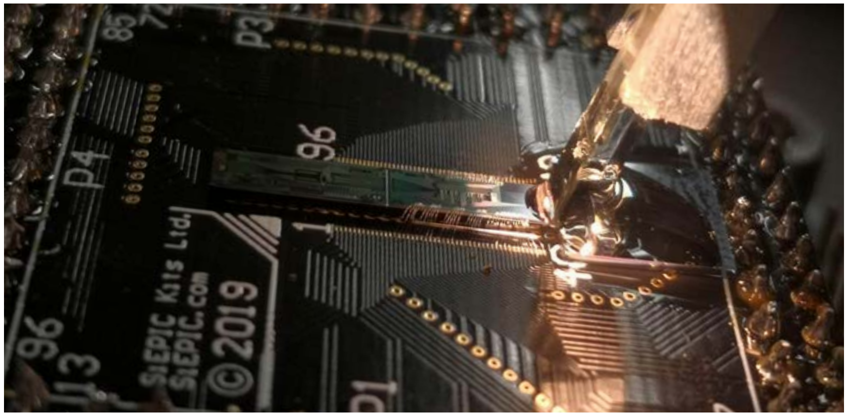
"We start from electronic circuits that, fundamentally, are not so different from those that live in your computer—they share many of the same components and functionality; they're built in the same way but much simpler," said Folk. "The degree of control that's possible in electronic circuits allows us to study in greater detail the physics seen in quantum materials."

"The heat capacity, or entropy, of single quantum states is normally too small to measure, but we have found a way around this roadblock," said Folk. "Our new approach gives us a very powerful tool to probe some of the most exotic states known to emerge in nature—and even some states that are not known to exist in nature but that we can create on an electronic chip."

Folk's team will build electronic circuits on chips using novel 2D materials, like graphene, as well as more conventional materials, like silicon. The researchers will then measure the entropy of these states in order to understand them at a deeper level.

Nearly a decade ago, the Quantum Devices group that Folk leads at UBC began an experiment to measure entropy at the level of single electrons, leading to a recent publication in the journal *Nature Physics*[1] and setting Folk and colleagues on the path to this new project.

[1] N. Hartman, C. Olsen, S. Lüscher, M. Samani, S. Fallahi, G.C. Gardner, M. Manfra, J. Folk. *Direct entropy measurement in a mesoscopic quantum system.* Nat. Phys. **14**, 1083 (2018).



A SiEPIC Kits chip in production

Karl Jessen, Executive Director

SiEPIC Kits

SiEPIC Kits was founded in 2018, when co-founders Mustafa Hammood and Jaspreet Jhoja met with Lukas Chrostowski about a project to develop software tools to assist with the design of silicon photonic circuits for a Singapore-based chip foundry that suddenly needed massive scale-up and commercial support. Hamood is a graduate student in the Department of Electrical and Computer Engineering at UBC, and Jhoja is a former UBC graduate student and current Photonic Engineer and Nanofabrication Technician at Blusson QMI.

While the company began as a software company, demand for their design services began to increase due, in part, to their affiliation with SiEPICfab, an industry consortium launched in 2018. In 2019, the company partnered with cryptocurrency mining company PoWx (Arrakis Photonics) to develop the world's first optical cryptocurrency miner prototype that uses photonic integrated circuits, a project that generated considerable attention for SiEPIC Kits, enabling the company to pivot to focusing on silicon photonics consulting and hardware design services.

With SiEPIC Kits, Hammood and Jhoja pooled their expertise in silicon photonics chip design and, with access to the Nanofabrication Facility at Blusson QMI, the company now works closely with Chrostowski-led SiEPICfab. In 2019, SiEPIC Kits joined SiEPICfab, and have been working with consortium members to design silicon circuits and chips using the newly installed photonic wire-bonding machine in the Blusson QMI Cleanroom.

National Quantum Strategy and Quantum Days

The Canadian effort to advocate for a quantum strategy was strong early in 2020, but, like so many things, was paused during the height of the global pandemic. While the effort picked up momentum again in late summer, much of the work of the Executive Working Group and the Research and Development Group, including Blusson QMI Scientific Director Andrea Damascelli and Executive Director Karl Jessen, will come to fruition in 2021.

The work of the National Quantum Strategy team will be important over the coming months, with investment in Canadian quantum research and innovation becoming increasingly urgent as other nations fuel their own burgeoning quantum industries. Canada is an emerging hub for quantum science and technology, and the industry is being nurtured by expertise developed (and trained) at government-funded institutions and private companies across the country. With strategic investment and support for research and training, quantum technology and innovation is expected to be a major Canadian industry within the next ten years.

To unite Canadian quantum players and advocate for cooperation among academic and industry leaders in quantum science and technology across Canada, the first Quantum Days conference was planned for early 2021. Hosted by NanoCanada, an Alberta-based driver of commercialization of advanced materials, as well as quantum and nano-technologies, this three-day event will bring together Canada's quantum community to enable networking and collaboration across the country. This is an important step in building awareness beyond our existing audiences and stakeholder groups.

EQUITY, DIVERSITY, AND INCLUSION

Equity, Diversity, and Inclusion (EDI) is critical to excellence, and Blusson QMI's excellence manifests in research and breakthroughs, as well as in the ability to attract and train world-class talent. Despite not being able to hold in-person outreach activities this year, our teams adapted quickly, turning previously in-person opportunities into online activities, in some cases making programming accessible to new audiences across British Columbia. In addition to outreach and other programming, we worked this year to strengthen our connections with artists in the community, completing a mural project in our building and establishing a partnership with the Morris and Helen Belkin Art Gallery we expect to nurture to maturity in 2021.

QUANTUM COMPUTING OUTREACH AND GEERING UP

In summer of 2020, Quantum Computing Outreach Manager Haris Amiri and his Geering Up team reached 324 youth through live streams and online summer camps. The team was able to offer their first ever online quantum computing summer camps for kids in grades 6 through 12.

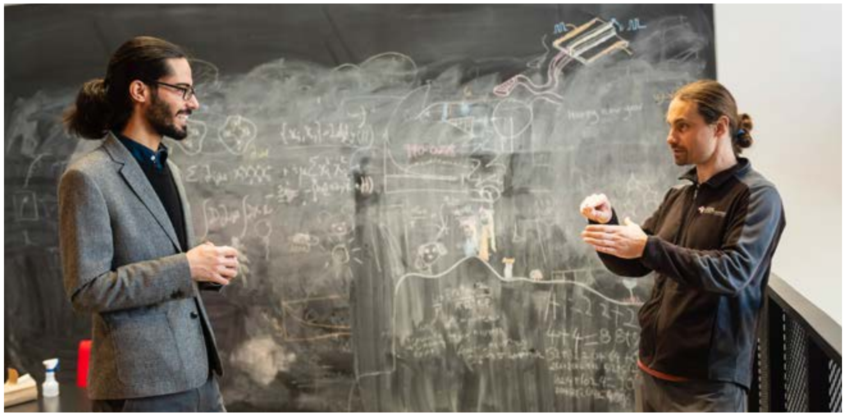
While the pandemic forced a certain amount of creativity, it also enabled Amiri and team to see new opportunities for growth. By bringing educational activities and programming to kids online, quantum computing experiences were more accessible to kids in remote areas of British Columbia. But it wasn't all for kids—in addition to online summer camps, Amiri and colleagues with Geering Up and the Quantum Computing Outreach Program (QCOP) ran virtual workshops on quantum computing for First Nations communities in the Cariboo Regional District. Launched with support from Canada's Digital Technology Supercluster, the QCOP is working to build diversity in the field of quantum computing, and the urgency to develop robust online programming will have lasting benefits, putting quantum computing education and experiences within reach for a greater number of interested learners.

Adaptation led to expansion, and by June, the QCOP was able to hire three UBC co-op students to develop new software, offer paid part-time positions to three graduate students, and worked with 11 undergraduate students.

"We were also excited to offer three-week internships to two Indigenous high school students this summer to work on curriculum development for the Quantum Computing Outreach program," said Amiri.

The interns worked with Amiri and colleagues to develop a number of games and apps to make quantum computing fun.

"Our team built a hub of web applications that allow players to make use of D-Wave's 2000Q solver via games, sudoku solvers, and a 'travelling salesperson' app," said Amiri. "We also created a 'Quantum Navigator' 8-bit video game for kids that introduces key quantum concepts such as entanglement, quantum teleportation, decoherence, and qubits."



Parham Pashaei (left) with Lukas Chrostowski (right)

QUANTUM BITS PODCAST

Quantum computing has enormous potential, and the success of quantum technology development and innovation will change many aspects of our lives. It is also a topic that is largely inaccessible to the average person. Parham Pashaei, a PhD student in the Department of Electrical and Computer Engineering (PI: Lukas Chrostowski), saw an opportunity to speak to a more general audience directly through podcasting; Pashaei finds that podcasting is a strong medium for quantum computing content, as the format allows for long, in-depth discussions that facilitate more context and analogy-making on complex topics.

He launched Quantum Bits in December 2020, engaging in one-on-one conversations with experts to explore concepts in quantum computing, simplifying complex quantum computing topics and making them accessible to a mainstream audience.

"Over the course of my studies, I have had the luxury of attending talks and seminars by some of the world's most interesting scientists, engineers, and entrepreneurs. Sometimes I am even able to meet with them and ask questions," said Pashaei, a former news anchor whose background in broadcast journalism is evident in his style of hosting. "Many people don't have access to these spaces or these discussions, so the purpose of this podcast is to invite listeners into conversations with some of the most interesting leaders in quantum computing right now."

"Lukas has been directly involved, and encouraged the podcast from the very beginning," said Pashaei. "I am very grateful for his support and have a lot of respect for his commitment to diversity and inclusion and the national effort in quantum computing. I am also grateful for the enthusiasm of Joe Salfi and Robert Raussendorf for the podcast. Joe has been very kind in proposing ideas for better reach."

COMMUNICATING QUANTUM PHYSICS THROUGH ART

The relationship between art and science, and physics in particular, is something that the leadership at Blusson QMI has been eager to draw out for some time. Art and science look to explain the world from different perspectives; the artist and the scientist speak different dialects within the same language, but it is becoming increasingly apparent that when the artist and the scientist work together, they can tell a much richer story. Visual art in particular offers a shared language through which to describe what the artist and the scientist see.

To draw in a broader audience, we must first establish ways of speaking that connect with those outside our community. This year, we worked to establish collaborations with artists and art communities in order to find new ways to communicate about our research and connect complex ideas in quantum physics with more abstract ways of thinking.

ARS SCIENTIA RESEARCH CLUSTER PROPOSED

In late 2020, Blusson QMI joined the Morris and Helen Belkin Art Gallery and UBC's Department of Physics and Astronomy to put forward a proposal for UBC Research Excellence Cluster funding for a project called *Ars Scientia.* The project grew out of *DRIFT: Art and Dark Matter,* an exhibition planned for the gallery in fall 2021, and the possibility of bringing artists into lab spaces in a series of residencies that is expected to produce enriching researcher, artist and public engagement opportunities.

METAPHORICALLY SPEAKING

In a December 2020 publication in the journal *The Physics Teacher,* Research Associate James Day and colleagues detailed their approach to teaching quantum physics to lay audiences, developed together with artists ahead of Quantum Futures, a 2018 event at the Museum of Anthropology. The event, a visual and performing arts event curated by local art-science non-profit Curiosity Collider, in collaboration with UBC Physics & Astronomy (PHAS) and Blusson QMI, brought scientists and artists together to make abstract concepts in quantum mechanics make sense outside the lab.

The paper, titled "Quantum Matter on the Table: A Pretty, Simple Hands-on Activity," detailed the team's approach to communicating about quantum materials by connecting visual art and condensed matter physics; the paper is the first in a series on the team's artist-driven approaches to teaching and learning.

"Languages and analogies link artists and scientists," Day explained. "Using the analogy as our primary tool, we can take very complex ideas and make them familiar; one way that physicists use analogical thinking is with models, which provide helpful ways to visualize abstract concepts for experts and non-experts alike."

Once they had established a shared language, the team designed their activities, focusing on opportunities to learn through play. Using tools available at any dollar store—including plastic shot glasses, Styrofoam balls, paint, and sticky arrows—participants were invited to engage in hands-on explorations of the microscopic structure of magnets and more complex lattice structures, giving a tangible experience with concepts that are otherwise inaccessible to the general public.

"For quantum tools and technology to work for everyone, we need to make the field accessible to everyone," said Day. "It is not enough to simply talk about quantum physics; we need to teach quantum physics to people who may then see opportunities for themselves in the field. Public outreach needs to be about ensuring an equitable, diverse, and inclusive future for quantum technology fields in Canada."

Image credit: Pinder Dosanjh.

ART IN OUR SPACE

A new mural at the Stewart Blusson Quantum Matter Institute (Blusson QMI) greets entrants to the Brimacombe Building. Positioned on the landing between the first and second floors, it is a playful representation of the relationship between art and science. The mural was painted by artist Gina Leon (pictured) and is the result of a proposal by Kassandra Darbel, James Day, and Vis Naidoo in early 2020 to bring wellness elements, such as artwork and plants, into shared Blusson QMI spaces.

Leon worked with a committee comprised of Darbel, Day, PhD student Amy Qu, and Ziliang Ye to establish a direction and inform the work; the result is a piece that demonstrates the dialogue between art and condensed matter physics, placing images of researchers and their work on a backdrop that reflects the natural world.

The work includes an acknowledgement of the land, and a nod to our Musqueam hosts; viewers will see different images that, taken together, show an active environment and represent the diversity and scope of Blusson QMI.

In addition to guiding the creative direction of the visuals, Ye and Qu, an artist in her own right, provided the factual basis for some of the scientific elements, so the work is grounded in the day-to-day research that takes place in the building. Some of the images were provided by former Damascelli lab postdoctoral fellow and newly appointed Assistant Professor at the University of California-Los Angeles, Christopher Gutiérrez, who is a visual artist as well; these became a source of inspiration as the work evolved.

The result is a piece in which moments of realism are punctuated by images that are slightly surreal, implying the fun and creativity that often goes unseen in natural science research.

It was important to the committee that the mural reflect more than scientists at work; it shows why that work is meaningful, placing Blusson QMI and its people within a larger story.

Ideally, a mural is just the start.

PEOPLE

LUNA LIU, *Quantum Pathways Student*

Luna Liu is in the process of completing her third year in UBC's undergraduate honours physics program, with particular interest in experimental condensed matter physics. Through the Quantum Pathways program at Blusson QMI, she has been working to develop her research and professional skills; the program has helped her identify and plot her path to graduate school.

"It can be hard for a student in the early years of their undergraduate program to gain research experience, as students will not yet have taken many core physics courses," said Liu. "Quantum Pathways has given me these opportunities, which in turn has helped me determine what courses I need to take to supplement my work at Blusson QMI."

Ordinarily, students would work in the lab throughout the summer, learning technical and laboratory skills, but the pandemic changed how the Quantum Pathways program would unfold in 2020 (see page 6). For Liu, this meant that she spent much of her summer working closely with Doug Bonn to adapt first-year undergraduate physics courses to virtual learning. Liu wrote data analysis programs and created laboratory simulations to supplement online classes; because of this, she was able to work as a Teaching Assistant for the course in Term 1 of the 2020 Winter Session.

"Quantum Pathways has given me access to workshops and courses to develop my skills, and I've been fortunate to be able to work with graduate students and faculty on real research projects in a way that I would not have been able to outside the program," said Liu. "I'm looking forward to participating in a year-long internship through the program and further developing as a scientist."

SAMIKSHYA SAHU, *MSc Student*

Samikshya Sahu started at Blusson QMI in January 2020, and has spent her time in Alannah Hallas' lab studying a series of intermetallic topological quantum materials. Following completion of her undergraduate degree at the Indian Institute of Science Education and Research, Sahu came to UBC specifically to work at Blusson QMI, with Hallas in particular. While she enrolled as a Master's student, she will be shifting to a PhD program beginning in May 2021. Her research focuses on design, crystal synthesis, and the characterization of exotic states of matter. Sahu was drawn to working with Hallas, whose research program aligns with Sahu's research objectives, which include unfolding the hidden properties in novel materials.

For Sahu, the fun of working in the lab is the sense of adventure, and the process of discovery that emerges from creativity, improvisation, and learning from mistakes.

"Working with Alannah is enabling me to channel my logical, quantitative, experimental, and theoretical skills, and is an opportunity to learn new techniques and further develop my research skills," said Sahu. "Working with Alannah is a great learning opportunity, and I am glad that when I had the chance to join her team, I took it."

AMY QU, *PhD Student*

When she completes her PhD in spring 2021, Amy Qu will take on a highly specialised role at Scienta Omicron, a German manufacturer of microscopy and spectroscopy equipment. Qu, who has been involved with both time- and angle-resolved photoemission spectroscopy (TR-ARPES) and scanning tunneling microscopy (STM), including the building and testing of the STM device in the Laboratory for Atomic Imaging Research (LAIR), brings a wealth of experience and insight into her new role.

For Qu, an industry position made a lot of sense. Scienta Omicon is a company that builds custom equipment to specific user needs, so each STM or ARPES instrument needs to be engineered for each individual lab. Qu will test the equipment, ensuring it works as designed.

"I have always really enjoyed building things, and the hands-on aspects of research have been my favourite part of working in the lab," said Qu, who is co-supervised by Sarah Burke and Andrea Damascelli, which has allowed her to feel equally at home with ARPES and STM systems.

Qu credits Blusson QMI's investment in its students for much of her success. During her time at Blusson QMI, she has felt supported by the Institute, having always had the resources, including highly specialised equipment, to pursue research questions.

"I appreciated how much interaction there is between groups at Blusson QMI—teams are happy to share equipment and expertise, there's a ton of collaborative projects, many students are co-supervised," said Qu, who completed the QuEST program in 2020. "The way that Blusson QMI prioritizes learning and discovery means that you get what you need, whether that is funding for equipment, or support to learn new skills, or connections with other students or faculty."

"The Blusson QMI Institute is one of very few places in the world to provide such comprehensive support for trainees … I was supported to do research I was interested in, and I am still being supported by Blusson QMI as I find my way as a new faculty member."

"Science is very social, and my success is a credit to the support from Blusson QMI that enabled me to travel, to meet new collaborators and coworkers, and to establish my research program in my first faculty role," said Fabio Boschini.

Boschini is an Assistant Professor in Ultrafast Science, at Quebec's Institut national de la recherche scientifique (INRS), Energy Materials and Telecommunications research center, and newly appointed Affiliate Investigator at Blusson QMI. After completing his postdoctoral studies at Blusson QMI, he began working to establish his lab at the Advanced Laser Light Source (ALLS) user facility at INRS in November 2020.

At INRS, Boschini is working with François Légaré to build a next-generation time-resolved angle-resolved photoemission spectroscopy (TR-ARPES) system. It will be the second system in Canada after the one housed at Blusson QMI and employed by Andrea Damascelli and David Jones; for Boschini, this represents a crucial opportunity to further materials research in Canada by establishing a complementary facility.

"This is why I am so excited to be an affiliate member of Blusson QMI," said Boschini. "We are building the capacity to thoroughly explore the ultrafast dynamics of quantum materials using complementary systems."

Boschini and Légaré are developing a high-harmonic-based TR-ARPES system with high-intensity long-wavelength pump capabilities.

"The idea is to employ high-intensity optical excitations in the mid-infrared—THz range to excite specific collective excitations of matter and change its properties in a dynamic way," explained Boschini. "Our ultimate goal is to access new states of matter with no equilibrium counterpart in an effort to understand the dynamical properties of quantum materials."

Boschini first came to Blusson QMI as a postdoctoral fellow in 2015, with expertise in TR-ARPES gleaned from his PhD work at Politecnico di Milano. He worked closely with Damascelli and colleagues, their early efforts culminating in the publication of a paper titled *Collapse of superconductivity in cuprates via ultrafast quenching of the phase coherence* in *Nature Materials* in 2018.

"The *Nature* paper was a huge milestone, and I'm also very proud of my collaboration with graduate student MengXing Na, which resulted in a publication in December 2019 in *Science*," said Boschini. "MengXing did most of the analysis, and I was mentoring her the whole time; it was just a really important project and I'm proud of what we accomplished together."

For Boschini, collaboration is everything; the relationships he developed at Blusson QMI have propelled him forward, linking him with an emerging network of early career and established researchers both in Canada and universities and research institutes around the world, including with fellow Blusson QMI alum Eduardo H. Da Silva Neto, with whom he recently published new work: See page 26.

"I am grateful to have had the opportunity to work with Blusson QMI researchers, including Andrea and David," said Boschini. "Blusson QMI is one of very few places in the world to provide such comprehensive support for trainees; there's this understanding that in order to be successful, you have to connect with other people, to showcase your work and know what's going on in the community and in other labs. I was supported to do research I was interested in, and I am still being supported as I find my way as a new faculty member and work to establish my own lab. Blusson QMI helped me achieve my goals."

CHRISTOPHER GUTIÉRREZ

Christopher Gutiérrez joined the Department of Physics and Astronomy at the University of California, Los Angeles (UCLA) in July 2020 with the intent to "pay it forward." Gutiérrez, who came to Blusson QMI to work with Andrea Damascelli and learn angle-resolved photoemission spectroscopy (ARPES), recently established the Quantum Matter Design Studio at UCLA and looks forward to filling it with a collaborative team of students and faculty researchers in order to pursue big questions in condensed matter physics.

"While we will be combining techniques from my PhD and first postdoctoral position (scanning tunneling microscopy) and my postdoctoral work at Blusson QMI (ARPES), ever since I was a graduate student, I have always focused more on tackling interesting research questions than on specific techniques," said Gutiérrez. "I see our group employing many experimental methods, including Raman spectroscopy, photo- and electro-luminescence, and electron diffraction, to name a few."

"It's really exciting to be the leader of your own research program," said Gutiérrez. "It's the chance to finally pursue experiments that I've been dreaming of since I was a student."

Gutiérrez is a curious, creative researcher, and the opportunities to pursue research questions independently while working with a supportive team of faculty, students and staff at Blusson QMI allowed him to develop his interests and build his network. In the lab, his focus is on understanding how natural and artificial defects or modifications can affect the electronic properties of quantum materials.

"We typically think of quantum properties only emerging at very small scales or at very cold temperatures, but in quantum materials we can see such phenomena at large, millimetre-scales and up to relatively 'warm' temperatures like 77 Kelvin (-196 Celsius), the temperature at which certain fancy ice creams are prepared," said Gutiérrez. "Some of these human-scale phenomena include electrons behaving as though they had no mass in so-called Dirac semi-metals like graphene or conducting electricity without resistance in high-temperature superconductors."

His goal is two-fold: to understand how defects affect materials and to then use this knowledge to purposely design new physical behavior.

While he will begin new projects and expand his research program, including visualizing nanoscale light-matter interactions in 2D material heterostructures, his connection to Blusson QMI will continue via two on-going projects that stem from work that was begun at Blusson QMI that will leverage a new device that Gutiérrez and colleagues designed for applying strain to materials, literally stretching them, while performing sensitive spectroscopy experiments.

"In these projects, which are a collaboration between UCLA and Blusson QMI, we will be looking to understand how the electronic properties of different quantum materials are affected by the application of controllable physical strain," said Gutiérrez. Both Gutiérrez and Damascelli received UBC-UCLA Collaborative Research Mobility Awards to pursue this research; the goal of the awards is to catalyze and deepen connections between the two universities.

"In these projects we will additionally collaborate with beamline scientists at international user facilities at the Advanced Light Source at Berkeley National Lab and the Canadian Light Source," said Gutiérrez.

Gutiérrez's time at Blusson QMI was not strictly academic, and the wealth of experiences available to him at Blusson QMI and UBC enabled his growth and prepared him for a faculty position. He credits inclusion in broader institute initiatives, such as working with Blusson QMI leadership to organize monthly research meetings aimed at nurturing new collaborations between research teams, and volunteering as an instructor for the Summer Skills Workshops organized by Natalia Bussard.

"For the summer programs, I designed and led two popular workshops to teach students and researchers how to make scientific figures and illustrations," said Gutiérrez. "I had recorded and edited these workshops for students to watch later, which really came in handy when I taught classes virtually during the pandemic." His figure-making workshops have since been turned into successful instructional videos that have been watched on YouTube in over 30 countries, and have been incorporated into scientific training sessions around the world.

Christopher Gutiérrez recognizes the value of mentorship and supportive outreach, and looks forward to making a difference in his community through science outreach.

"I'm the child of immigrants and was born and raised in one of the more under-resourced parts of Los Angeles. As a young teen, I benefitted from many programs aimed at encouraging students from my socioeconomic background to pursue higher education," said Gutiérrez. "Now as faculty, my colleagues and I have initiated an outreach program with my former high school that will bring students to the UCLA campus for a day of science experiments and research talks that will additionally include long-term mentoring."

ROMAN KREMS

> I wake up excited every morning because in my current research, there are a lot of interesting opportunities to learn new physics, new mathematics, new computational techniques.

At the intersection of quantum physics, theoretical chemistry and machine learning, Roman Krems is working to understand realities outside the mathematical limitations of the known world. But his approach is novel; rather than harnessing the power of artificial intelligence to wade through quantum mechanical data, he is hoping to train machines to approach physics exploration the way a human physicist would.

"I wake up excited every morning because in my current research, there are a lot of interesting opportunities to learn new physics, new mathematics, new computational techniques," said Krems, a Professor in the Department of Chemistry, and Distinguished University Scholar. Krems was appointed a member of Blusson QMI in June.

"Quantum problems are very difficult; as the complexity of quantum systems increases, you eventually hit a wall in terms of what you can achieve using conventional approaches," explained Krems. "We're using theoretical and machine learning models to go over (or through) the wall, to solve bigger problems than are currently feasible."

Think about an electron in a complex material. At the microscopic level, atoms in materials assemble into lattice formations, and electrons are affected by the lattice vibrations.

Atomic vibrations affect how the electrons behave. The theories Krems and colleagues have developed allow them to look at what happens to electrons under certain conditions (for example: temperature, type of lattice vibration, strength of coupling between electrons and lattice vibrations).

"But we can't really generalize these theories for all conditions," said Krems. "As one approaches interesting regimes of conditions, where the physics is still unexplored, the complexity of problems often grows so quickly that current numerical techniques do not allow us to solve them. We're looking at patterns for simpler systems and parameter regimes in order to make predictions about new physics under previously unexamined conditions."

Krems and his team work at the forefront of quantum research, developing tools to compensate for the limitations of traditional quantum theories and working with experimentalists to test and refine those theories in order to understand the quantum dynamics of increasingly complex systems. For example, molecules, comprised of atoms sharing electrons, are inherently quantum objects. Krems employs quantum theory to investigate the nature and behavior of molecules and their chemical interactions, but it can be hard to extrapolate these interactions beyond a few small molecules; the limitations of quantum mechanics calculations have been a major problem for researchers since the field was conceived in the early twentieth century.

"More than four quantum particles, and you have to be creative," says Krems.

"The data we're using to train machine learning models come from quantum equations," explained Krems. Perhaps the most widely known of these is the Schrödinger equation, a mathematical model to predict how the wave-like properties of matter would behave under set conditions. "We're trying to either improve the accuracy of the data, or extrapolate the interplay between the data. You can solve fundamental equations in certain limits, which are often different from normal experimental conditions. We're using machine learning to find correlations between simple and complex systems, between simple and tangled conditions."

Krems and colleagues work with small data, specifically isolated measurements or solutions to complex equations.

"We want to know: can you design models that take isolated results and make sense of them, like a physicist would? When problems are complex enough and solutions are limited, you can't analyze them using traditional machine learning," said Krems. "Our applications are not one of the typical big data applications. We believe there is more to gain from making sense of small data in limits hard to explore than from solving big data problems."

Some real-world applications don't have the luxury of big data. There are some natural phenomena that can be difficult to replicate or build in large numbers; for such applications, a researcher must make predictions based on small data. Krems and his team ask: is it possible to learn correlations in small data that humans can't see? Can these correlations be used to make predictions of physical properties under conditions that can't be probed by existing theory and/or experiment?

Theory in practice

"One of our big goals is to build methods that would accelerate experiments aimed at discovering new physics or designing new materials," said Krems. "When you design materials for airplanes, for example, you develop alloys by combining elements; but the chemical space is so large it cannot be explored piece by piece."

As experiments are underway to discover new alloys, Krems and colleagues are developing approaches to accelerate the discovery process. Learning from one experiment and applying sound theories to the next in order to make predictions based on the output of previous experiments about how to optimize the process, Krems and his team hope to arrive at alloys with desired properties as quickly as possible.

"It takes up to 10 years from idea to introduction of a new alloy into manufacturing process; if we could reduce that time by even a factor of two, it would reduce the cost of the discovery process dramatically," explained Krems, who is currently building a collaboration with the German Aerospace Center (DLR).

The important thing for Krems is that his theoretical models find a home in the real world, and so frequent collaboration with experimentalists, both at Blusson QMI and around the world, is critical.

"As a theoretician, you need to work with experimentalists; you don't want to find yourself working on something that's only of interest to you and no one else," Krems said. "One thing that excites me about joining Blusson QMI is that some of the methods we're developing could be applied to a wide variety of experimental problems that other researchers at the institute are looking at."

Despite his theoretical approaches to quantum materials research, he also enjoys proving to experimentalists that they can occasionally do away with theory, as he did in his recent collaboration with two experimental groups at UBC and BCIT that resulted in the development of a universal pressure standard.

"If you know where to look and how to look, a lot of times, Nature gives you the answer and there's no need for tedious calculations."

JOSEPH SALFI

> The idea of bringing people together is so simple, but it is so crucial to be in an environment with that critical mass of expertise, support, and infrastructure.

In 1943, Thomas Watson, then president of IBM, said "I think there is a world market for maybe five computers."

"I bet you've got three computers on your desk right now," said Joseph Salfi, a newly appointed researcher at the Stewart Blusson Quantum Matter Institute (Blusson QMI). Salfi is an Assistant Professor in the Department of Electrical and Computer Engineering in the Faculty of Applied Science, and his work as an experimentalist in the area of quantum information science and computing has brought him into collaboration with researchers including Lukas Chrostowski, Jeff Young, Joshua Folk, Roman Krems, Robert Raussendorf, Mona Berciu, and others.

Quantum computation, which falls under the umbrella of quantum information science, is an extremely exciting research field and rapidly emerging industry where researchers are developing science and technology with the potential to revolutionize computation. Applications for quantum computers involve calculations on complex systems to answer very difficult questions, from how to optimize aircraft maintenance to how to build more powerful systems of artificial intelligence.

"I tell my students that they will be among the first people trained in the field who will not just become researchers in quantum computing, but who will also have the opportunity to translate the science into practice to make industrially relevant quantum computers. Small quantum computers already work, and larger ones are on the cusp of delivering their promise," said Salfi. "It's up to us to figure out what we are going to do with quantum computers; how to build them and make them better, and how to make them accessible. That's what's really exciting right now."

Salfi led UBC's first graduate level quantum computing foundations course for both engineers and physicists, EECE 571S, in 2019, and has partnered with Chrostowski and the CREATE program (page 25) in order to train the next generation of quantum computing leaders. The program unites faculty across three universities, and offers foundational, technical and career training for students in a range of disciplines, from engineering and computer science to physics and chemistry.

"I really enjoyed teaching this course; teaching foundational material is really fun because there are so many surprising ideas in quantum computing," said Salfi. "You also interact with a greater number of students, and you explore ideas outside your traditional area of focus in research."

Salfi is a collaborative researcher, and one of the major things that drew him to Blusson QMI is its proclivity for collaboration and engagement, both among members of the academic research community and more broadly with administrative staff, industry partners, and other universities.

"The idea of bringing people together is so simple, but it is so crucial to be in an environment with that critical mass of expertise, support, and infrastructure," said Salfi. "From the cutting-edge research facilities to scientific leadership to the presence of skilled scientific staff; as individual investigators we can build capable laboratories, but there is so much that you simply cannot do on your own."

In the lab, Salfi and his team are working to build controllable quantum systems in order to do calculations that are hard or impossible to do on classical computers.

“We build chips that house qubits, and we manipulate quantum information in those qubits so that we can try to understand how they work, and then use them to build more powerful quantum computers that can deliver practical applications,” Salfi said.

A qubit is the quantum version of the classical bit, the unit of information that in conventional computers can either be a one or a zero. The difference between a qubit and a classical bit is that a qubit can exist in a state that is simultaneously one and zero at the same time. This key difference is what gives quantum computers their potential to solve complex problems; the way that they process information follows the laws of quantum mechanics.

While researchers and entrepreneurs have ideas about what they might be able to achieve with a robust quantum computer, building one is very challenging for very fundamental reasons: usually, the easier it is to manipulate quantum systems, the more fragile the quantum states are.

With increased investment coming from government sources and more recently from the private sector, research has progressed to the point where the first quantum computers now exist, and some can even complete tasks outside the capabilities of classic supercomputers. However, solving real-world problems is likely to require much more powerful quantum computers. For Salfi, this represents a future full of possibility; the combination of fundamental discovery —both up until now and ongoing—and the potential for real social and technological benefits is what attracted him to this field of work.

“Advances in fundamental physics can really make a technological difference. There’s a right time to be in a research field, and this is just a time when there has been enough success in understanding the fundamental aspects of quantum computing that it has drawn a lot of industrial interest,” said Salfi. “When you have industrial interest, it enhances what you are able to accomplish.”

As Salfi looks to the future, both as a researcher and an educator, he envisions some critical milestones over the next five to ten years.

“To enable more powerful general quantum computers —that’s a goal that’s at least five, maybe ten years away, but we’re going to do it and it’s going to give birth to a new industry,” said Salfi. “Another area where we’re hoping to see more immediate progress is in special purpose problems; we’re using quantum simulation to tackle specific types of problems, especially around quantum materials.”

For Salfi, this offers compelling synergy between his research program and Blusson QMI.

“The majority of supercomputer use at universities right now is to solve materials problems, things that you can’t do effectively with a classical computer,” said Salfi. “To be able to predict chemical reaction rates, train machines, or to calculate the properties of molecules—these are useful applications of quantum computing. This will accelerate the pace of discovery. That’s what excites me about quantum computing; that the physics we’re exploring are going to have real-world impact in one form or another.”

AWARDS AND RECOGNITION

Join us in congratulating the Blusson QMI team members who this year were deservedly recognized for their achievements in research, education, or outreach.

FACULTY

Alannah Hallas
CIFAR Azrieli Global Scholar

Alannah Hallas has a seat in one of the most exclusive rooms in quantum physics for the next two years, thanks to the support of a CIFAR Azrieli Global Scholars award. Hallas, who began her role as Assistant Professor in the Department of Physics and Astronomy in UBC's Faculty of Science and established the Quantum Materials Design Lab at Blusson QMI just over a year ago, will join a Canadian and international cohort of leaders in CIFAR's Quantum Materials program.

CIFAR's Global Scholars award, offered to exceptional researchers who are within the first five years of their academic appointment, provides unrestricted start-up funds, access to a global network of interdisciplinary scholars, and opportunities for mentorship and training. For Hallas, this award will connect her with other experts in quantum fields, enabling her to establish a community of potential collaborators that she will carry with her throughout her career.

Hallas credits a CIFAR summer school program she attended during graduate school for helping establish her research direction.

"As a graduate student working in chemistry, I had the opportunity to attend the 2013 summer school and meeting, which is where I first met my future PhD advisors and where I was first inspired to delve more deeply into physics," said Hallas. "CIFAR has played a huge role in my career path to date, and I am proud to be a CIFAR Azrieli Global Scholar in 2020."

Hallas is a "crystal grower" and solid-state chemist who is creating materials that do not exist in the natural world, combining elements and conditions that may not organically align in nature to produce new quantum materials, whose properties are derived from intense quantum mechanical effects. In order to understand the properties of these materials, Hallas seeks collaborations across the spectrum of experimental and theoretical physics and chemistry.

"We are making quantum materials to search for new phenomena: properties that we didn't even know materials could have," she explains. "Our research falls into the category of fundamental science; we want to understand how the elements in these systems interact to produce their quantum magnetic and electronic properties. But the potential applications of quantum materials go far beyond fundamental science."

Hallas and her team work to design concepts for new materials, then head into the lab to make them through a process known as crystal growth. Crystal growth occurs when different elements from the periodic table are combined and heated, sometimes with the addition of pressure, in order to instigate a chemical reaction and form a novel compound. How the electrons in a material will behave in a given compound are dependent on its ingredients and the fabrication process; carbon can become graphite or diamond, for example, depending on how it is treated.

Once Hallas and colleagues have a material, they will work with theorists to develop a mathematical model for how the material will behave, before taking it back to the lab to refine and inform future, even better models with stronger quantum properties.

"My group at UBC is developing some incredibly powerful tools for crystal growth, and to be able to bring that expertise into the room where so many breakthroughs have been made and so many collaborations have been established is a huge opportunity," said Hallas.

"The new materials my group is synthesizing will catalyze collaborations and open new research directions within the CIFAR Quantum Materials program," said Hallas. "The CIFAR Quantum Materials meetings, which occur twice per year, are often where discoveries are initially shared with the community, and I am excited to be part of and contribute to this incredible program."

Hallas is also the recipient of a 2020 UBC Science Co-op Supervisor Award. Hallas was nominated by Quantum Pathways student Sam Mugiraneza. These awards are held annually to celebrate exceptional employers who have supported the Science Co-op Program and its students through work integrated learning opportunities.

Mona Berciu

Fellow of the American Physical Society (APS)

The APS Fellowship program recognizes members who have made advances in physics through original research and publication, made innovative contributions in the application of physics, made significant contributions to the teaching of physics, or service to the Society. Mona was elected "for outstanding contributions to the theory of dilute magnetic semiconductors and polarons."

Lukas Chrostowski

IEEE Quantum Week Best Paper Award

During the IEEE International Conference on Quantum Computing and Engineering, Lukas Chrostowski and co-authors Parham Pashaei, Haris Amiri, Rafael Haenel, and Pedro Lopes were awarded "Best Paper" in the Quantum Education Track for their publication *Educational Resources for Promoting Talent in Quantum Computing*, which provides a toolkit to help educators introduce quantum science and technology concepts to elementary and high school students.

Robert Raussendorf

Physical Review A: most influential papers of the past 50 years

To celebrate 50 years in print, the journal Physical Review A compiled a list of its 26 most influential papers of the past half-century, and Robert Raussendorf and Hans Briegel's milestone 2003 paper *Measurement-based quantum computation on cluster state*s was included in this prestigious list. The publication challenged perceptions of measurement and entanglement in quantum physics and altered the course of quantum computing research and development.

STUDENTS

Ryan Day
Willa and Stuart B. Woods Graduate Scholarship in Physics
Andrea Damascelli Group

Ryan was awarded the Willa and Stuart B. Woods Graduate Scholarship, an annual award granted to an outstanding graduate student in physics who specializes in experimental studies in quantum materials.

Rysa Greenwood
British Columbia Graduate Scholarship
Sarah Burke and David Jones Groups

Rysa received a British Columbia Graduate Scholarship, a program established by the Province in 2018. The Graduate Scholarships support research in the fields of science, technology, engineering, and mathematics as well as support for Indigenous and regional programs.

Tiffany Matthé
Erich Vogt First Year Summer Research Experience (FYSRE)
Sarah Burke Group

Tiffany, a Quantum Pathways student, received a FYSRE award; FYSRE offers research opportunities to budding academic stars after their First Year Physics courses. Tiffany started her summer research program by working on adapting code for analyzing electron spectroscopy measurements for one of the lab's new instruments with PhD student Amy Qu. Then, with Tiffany's design experience from her first year as an undergraduate, she worked closely with Amy and Research Associate Jisun Kim on design projects to support the research team's involvement in one of Blusson QMI's Grand Challenges projects.

Rebecca Sherbo
Governor General's Gold Medal
Curtis Berlinguette Group

Rebecca received the Governor General's Gold Medal which honours the best in the graduating class within the Faculty of Graduate and Postdoctoral Studies. Only one Gold medal is awarded every year to the doctoral student with the "most outstanding academic record".

John Sous
Justin Jankunas Doctoral Dissertation Award in Chemical Physics Finalist
Mona Berciu Group

John was a finalist of the Justin Jankunas Doctoral Dissertation Award in Chemical Physics from the American Physical Society (APS). The award recognizes "doctoral thesis research of outstanding quality and achievement in chemical physics". He was one of the three finalists invited to the APS March Meeting to present a 24-minute talk based on his research.

Alexandra Tully
NSERC Postgraduate Scholarship—Doctoral (NSERC PGS-D) and the Tyler Lewis Clean Energy Research Foundation Award
Sarah Burke and David Jones Groups

Alexandra was awarded an NSERC PGS-D. The program provides financial support for high-calibre scholars, allowing them to fully concentrate on their studies and seek out the best research mentors in their fields.

She also received the Tyler Lewis Clean Energy Research Foundation Award in support of her project investigating charge transfer in organic solar cells. The funding will facilitate travel to work with collaborators in the UK and Sweden in support of this exciting work.

Members of the Sarah Burke group. Photographed by Amy Qu.

Vedanshi Vala
Outstanding Young Ambassador Award
Ziliang Ye Group

Vedanshi Vala was the recipient of an Outstanding Young Ambassador Award for Outstanding Leadership from the VGH + UBC Hospital Foundation. This award recognizes the exemplary contributions that young British Columbians have made to our community.

Xiruo Yan
Best poster prize—Quantum BC Virtual Poster Session on Quantum Computing
Jeff Young Group

Quantum BC is a joint initiative led by British Columbia's top three universities, which aims to stimulate and deepen collaborative efforts between the institutions. Xiruo Yan presented his poster titled "A Quantum Computer Architecture based on Silicon Donor Qubits Coupled by Photons" at the virtual poster session—a student-focused event from Quantum BC. The event included 22 participants who presented for three minutes or less each, and Xiruo was awarded first prize.

PRINCIPAL INVESTIGATORS

IAN AFFLECK

RESEARCH FOCUS

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 Frederic Mila at École Polytechnique Fédérale de Lausanne and Charles Kane at U. Pennsylvania.

CURRENT PROJECTS

- Self-interacting Majorana modes (the Majorana-Hubbard model)
- A Majorana mode interacting with a multi-channel Luttinger liquid
- Quantum spin chains with SU(n) symmetry
- Phase diagram of the generalized Kitaev spin chain model
- Gapless phases in integer spin chains
- Observing impurity entropy in the multi-channel Kondo effect (in collaboration with Joshua Folk)
- The Kitaev spin model

CAREER HIGHLIGHTS

PhD Harvard University 1976 – 1979
Asst. Professor Princeton University 1981 – 1987
Professor UBC 1987 – present

GRADUATE STUDENTS

Samuel Gozel (EPFL), Mobin Shakeri, Kyle Wamer

POSTDOCTORAL FELLOWS

Wang Yang

SCIENTIFIC STAFF

Alberto Nocera

SELECTED PUBLICATIONS

I. Affleck, A.W.W. Ludwig. *Universal Non-Integer `Groundstate Degeneracy' in Critical Quantum Systems.* Phys. Rev. Lett. **67**, 161 (1991).

I. Affleck, J.B. Marston. *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, H. Tasaki. *Rigorous Results on Valence-Bond Ground States in Antiferromagnets.* Phys. Rev. Lett. **59**, 799 (1987).

MEIGAN ARONSON

RESEARCH FOCUS

Our group is focused on finding new materials that are at or near a quantum phase transition, where new phases of matter—including novel order—emerges at zero temperature. We carry out measurements of fundamental quantities, such as the transport of charge and heat, and especially their magnetic properties using a combination of lab-based techniques and also neutron scattering facilities. These materials form the basis of a number of different collaborations that leverage the experimental strengths within QMI.

CURRENT PROJECTS

- Search for metallic quantum spin liquids
- Moment compensation in topological materials
- Dimensional crossover in 1D and 2D heavy fermions
- Strongly interacting surface states in topological insulators

CAREER HIGHLIGHTS

PhD University of Illinois 1982 – 1988
Postdoc. Fellow Los Alamos National Laboratory 1987 – 1989
Asst. Professor University of Michigan 1990 – 1996
Assoc. Professor University of Michigan 1996 – 2002
Professor University of Michigan 2002 – 2006
Professor Stony Brook University 2007 – 2015
Group Leader, Brookhaven National Laboratory 2007 – 2015
Professor and Dean, Texas A&M University 2015 – 2018
Professor and Dean, UBC 2018 – present

UNDERGRADUATE STUDENTS

Divya Chari, Satyam Priyadarshi

GRADUATE STUDENTS

Joern Bannies

POSTDOCTORAL FELLOWS

Xiyang Li, Jannis Maiwald, Dalmau Reig-i-Plessis

SELECTED PUBLICATIONS

W.J. Gannon, I.A. Zaliznyak, L.S. Wu, A.E. Feiguin, A.M. Tsvelik, F. Demmel, Y. Qiu, J.R.D. Copley, M.S. Kim, M.C. Aronson. *Spinon confinement and a sharp longitudinal mode in Yb2Pt2Pb in magnetic fields.* Nat. Commun. **10**, 1123 (2019).

W.J. Gannon, L.S. Wu, I.A. Zaliznyak, W.H. Xu, A.M. Tsvelik, Y. Qiu, J.A. Rodriguez-Rivera, M.C. Aronson. *Local quantum phase transition in YFe2Al10*. Proc. Natl. Acad. Sci. U.S.A. **115**, 6995 (2018).

L.S. Wu, W.J. Gannon, I.A. Zaliznyak, A.M. Tsvelik, M. Brockmann, J.-S. Caux, M.-S. Kim, Y. Qiu, J.R. Copley, G. Ehlers, A. Podlesnyak, M.C. Aronson. *Orbital-Exchange and fractional quantum number excitations in an f-electron metal, Yb2Pt2Pb.* Science **352**, 1206 (2016).

MONA BERCIU

RESEARCH FOCUS
My current interests focus on developing accurate variational approximations for answering key questions that arise in the study of strongly correlated systems: (i) what are the characteristics of the quasiparticle (polaron) that forms when a charge carrier becomes “dressed” by a cloud of excitations such as phonons, magnons, etc.; (ii) what effective interactions arise between such quasiparticles through exchange of excitations between their clouds; and (iii) what is their combined influence on the properties of the host material. We use these methods to study effective models of materials such as the high-temperature cuprates and iron pnictides, rare-earth nickelates, bismuthates, etc., in a wide region of the parameter space. Such studies supplement numerical exact studies, which are usually rather 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. We are now attempting to expand our expertise to cover finite temperatures and finite particle densities.

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

CAREER HIGHLIGHTS
PhD University of Toronto 1995 – 1999
Postdoc. Fellow Princeton University 2000 – 2001
Research Assoc. Princeton University 2001 – 2002
Asst. Professor UBC 2002 – 2007
Assoc. Professor UBC 2007 – 2012
Professor UBC 2012 – present

UNDERGRADUATE STUDENTS
Rodrigo Chavez Zavaleta, Paul Froese, James Wu

GRADUATE STUDENTS
Stepan Fomichev, Oliver Yam

POSTDOCTORAL FELLOWS
Krzysztof Bieniasz, Mi Jiang, Leon Ruocco

SELECTED PUBLICATIONS
M.M. Moller, C.P.J. Adolphs, M. Berciu. *Magnon-mediated attraction between two holes doped in a CuO_2 layer.* Phys. Rev. B **100**, 165118 (2019).

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

D. Marchand, G. De Filippis, V. Cataudella, M. Berciu, N. Nagaosa, N.V. Prokof’ev, A.S. Mishchenko, P.C.E Stamp. *Sharp transition for single polarons in the one-dimensional Su-Schrieffer-Heeger mpdel.* Phys. Rev. Lett. **105**, 266605 (2010).

CURTIS BERLINGUETTE

RESEARCH FOCUS
The Berlinguette research program specializes in the discovery and translation of advanced materials for clean energy technologies, including CO_2 electroyzers, next-generation solar cells, and lower-temperature fusion reactors.

CURRENT PROJECTS
- CO_2 utilization
- Self-driving laboratories
- Next-generation solar cells
- Electrification of the chemical industry
- Lower-temperature fusion reactors

CAREER HIGHLIGHTS
PhD Texas A&M University 2000 – 2004
Postdoc. Fellow Harvard University 2004 – 2006
Asst. Professor UCalgary 2006 – 2011
Assoc. Professor UCalgary 2011 – 2013
Assoc. Professor UBC 2013 – 2017
Professor UBC 2017 – present

UNDERGRADUATE STUDENTS
Mohamad Abbas, Luigi Alde, Julian Black, Matheus Cassol, Alyssa Liu, Ryan Oldford, Oleksii Proskurin, Bonnie Russell, Grace Simpson, Tyler Wong, Wendie Wu, Ariel Zheng

GRADUATE STUDENTS
Roxanna Delima, Arthur Fink, Rebecka Forward, Aoxue Huang, Ryan Jansonius, Andrew Jewlal, Tengxiao (Alec) Ji, Cameron Kellett, Caroline Krzyszkowski, Eric Lees, Natalie LeSage, Nicholas Loo, Benjamin MacLeod, Thomas Morrissey, Benjamin Mowbray, Fraser Parlane, Shaoxuan Ren, Angelica Reyes, Connor Rupnow, Danielle Salvatore, Mia Stankovic, Danika Wheeler

POSTDOCTORAL FELLOWS
Edward Booker, Yang Cao, Saunak Das, Kevan Dettelbach, Faezeh Habib-Zadeh, Camden Hunt, Aiko Kurimoto, Xin Lu, Danielle Salvatore, Zishuai (Bill) Zhang

SCIENTIFIC STAFF
Nathan Chiu, David Dvorak, Michael Elliott, Ted Haley, Daniel Lin, Karry Ocean, Mike Rooney, Phil Schauer, Nina Taherimakhsousi, Chris Waizenegger

SELECTED PUBLICATIONS
C.W. Kellett, P. Kennepohl, C.P. Berlinguette. *π Covalency in the Halogen Bond.* Nat. Commun. **11**, 3310 (2020).

B.P. MacLeod, F.G.L. Parlane, T.D. Morrissey, F. Häse, L. Roch, K.E. Dettelbach, R. Moreira, L.P.E. Yunker, M.B. Rooney, J.R. Deeth, V. Lai, G.J. Ng, H. Situ, R.H. Zhang, M.S. Elliott, T.H. Haley, D.J. Dvorak, A. Aspuru-Guzik, J.E. Hein, C.P. Berlinguette. *Self-Driving Laboratory for Accelerated Discovery of Thin-Film Materials.* Sci. Adv. **6**, eaaz8867 (2020).

C.P. Berlinguette, Y.-M. Chiang, J.N. Munday, T. Schenkel, D.K. Fork, R. Koningstein, M.D. Trevithick. *Revisiting the cold case of cold fusion.* Nature **570**, 45 (2019).

DOUG BONN

RESEARCH FOCUS

We synthesize ultraclean samples of quantum materials, particularly superconductors and topological materials, 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 with atom-scale spatial resolution.

CURRENT PROJECTS

- Quasiparticle interference of unconventional superconducting state in Fe-based superconductors
- Microwave spectroscopy of long-lived quasiparticles in Fe-based superconductors
- Microwave electrodynamics due to ballistic and hydrodynamic flow in high mobility materials including PdCoO2 and WP2
- Quasiparticle interference in Weyl semimetal ZrSiTe: drumhead states and floating bands
- Development of ultra-low temperature STM with in situ MBE

CAREER HIGHLIGHTS

PhD McMaster University 1983 – 1989
Postdoc. Fellow UBC 1989 – 1991
Research Assoc. UBC 1992 – 1994
Asst. Professor UBC 1994 – 1997
Assoc. Professor UBC 1997 – 2000
Professor UBC 2000 – present

UNDERGRADUATE STUDENTS

Mariposa Casida, Luna Liu, Annika MacKenzie, Areesha Rizwan, Rio Weil

GRADUATE STUDENTS

Graham Baker, Jeff Bale, Tim Branch, Dong Chen, Aaron Kraft, Brandon Stuart, Ashley Warner

POSTDOCTORAL FELLOWS

Seokhwan Choi, Giang Nguyen, Mohamed Oudah

SCIENTIFIC STAFF

James Day, Jisun Kim

SELECTED PUBLICATIONS

J. Chang, E. Blackburn, A.T. Holmes, N.B. Christensen, J. Larsen, J. Mesot, R. Liang, D.A. Bonn, W.N. Hardy, A. Watenphul, M.v. Zimmermann, E.M. Forgan, S.M. Hayden. *Direct observation of competition between superconductivity and charge density wave order in YBa2Cu3O6:67*. Nat. Phys. **8**, 871 (2012).

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

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

SARAH BURKE

RESEARCH FOCUS

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 materials where a nanoscale view offers the potential for new understanding.

CURRENT PROJECTS

- Energetic landscapes of organic heterojunctions
- Light-matter interactions in organic semiconductors on a single molecule level using SPM
- Quasiparticle interference: understanding interactions with defects and mapping electronic properties of novel 2D materials and electronic states
- Dynamics of charge separation in organic solar cells using time- and angle-resolved photoemission spectroscopy
- Molecular imaging of heterogeneous catalysis in action

CAREER HIGHLIGHTS

PhD McGill University 2005 – 2009
Postdoc. Fellow UC Berkeley 2009 – 2010
Asst. Professor UBC 2010 – 2017
Assoc. Professor UBC 2017 – present

GRADUATE STUDENTS

Jörn Bannies, Rysa Greenwood, Vanessa King, Amy Qu, Brandon Stuart, Gary Tom, Alexandra Tully, Ashley Warner, Jiabin Yu

POSTDOCTORAL FELLOWS

Seokhwan Choi, Giang Nguyen

SCIENTIFIC STAFF

James Day, Jisun Kim

SELECTED PUBLICATIONS

P. Nigge, A.C. Qu, É. Lantagne-Hurtubise, E. Mårsell, S. Link, C. Gutiérrez, G. Tom, M. Zonno, M. Michiardi, M. Schneider, S. Zhdanovich, G. Levy, U. Starke, D. Bonn, S.A. Burke, M. Franz, A. Damascelli. *Room temperature strain-induced Landau levels in graphene on a wafer-scale platform.* Sci. Adv. **5**, eaaw5593 (2019).

S. Chi, R. Aluru, S. Grothe, A. Kreisel, U.R. Singh, B.M. Andersen, W.N. Hardy, R. Liang, D.A. Bonn, S.A. Burke, P. Wahl. *Imaging the real space structure of the spin fluctuations in an iron-based superconductor.* Nat. Commun. **8**, 15996 (2017).

K.A. Cochrane, A. Schiffrin, T.S. Roussy, M. Capsoni, S.A. Burke. *Pronounced polarization-induced energy level shifts at boundaries of organic semiconductor nanostructures.* Nat. Commun. **6**, 8312 (2015).

LUKAS CHROSTOWSKI

RESEARCH FOCUS

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.

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
- SiEPICfab consortium on chip prototyping and integration

CAREER HIGHLIGHTS

PhD UC Berkeley 1998 – 2004
Postdoc. Fellow UC Berkeley 2004 – 2005
Asst. Professor UBC 2005 – 2010
Assoc. Professor UBC 2010 – 2015
Professor UBC 2015 – present

GRADUATE STUDENTS

Abdelraman Afifi, Adan Azem, Rui Cheng, Adam Darcie, Leanne Dias, Sabastian Gitt, Jaspreet Jhoja, Becky Lin, Stephen Lin, Enxiao Luan, Minglei Ma, Connor Mosquera, Jake Osborne, Mohammed Shemis, Hossam Shoman, Iman Taghavi, Alexander Tofini, Jing Wang, Donald Witt

POSTDOCTORAL FELLOWS

Matthew Mitchell, Andreas Pfenning, Reza Sanadgol Nezami, Jingda Wu

SCIENTIFIC STAFF

Mahssa Abdolahi, Kashif Awan

PROJECT MANAGERS

Steven Gou, Stephen Lin

SELECTED PUBLICATIONS

L. Chrostowski, H. Shoman, M. Hammood, H. Yun, J. Jhoja, E. Luan, S. Lin, A. Mistry, D. Witt, N.A.E. Jaeger, S. Shekhar, H. Jayatilleka, P. Jean, S.B. Villers, J. Cauchon, W. Shi, C. Horvath, J.N. Westwood-Bachman, K. Setzer, M. Aktary, N.S. Patrick, R.J. Bojko, A. Khavasi, X. Wang, T.F.d. Lima, A.N. Tait, P.R. Prucnal, D.E. Hagan, D. Stevanovic, A.P. Knights. *Silicon photonic circuit design using rapid prototyping foundry process design kits.* IEEE J. Sel. Top. Quantum Electron. **25**, 8201326 (2019).

L. Chrostowski, 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, L. Chrostowski. *Narrow-band waveguide Bragg gratings on SOI wafers with CMOS-compatible fabrication process.* Opt. Express. **20**, 15547 (2012).

ANDREA DAMASCELLI

RESEARCH FOCUS

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 established at Blusson QMI in the UBC-Moore Centre for Ultrafast Quantum Matter 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.

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

PhD University of Groningen 1994 – 1999
Postdoc. Fellow Stanford University 1999 – 2002
Asst. Professor UBC 2002 – 2007
Assoc. Professor UBC 2007 – 2013
Professor UBC 2013 – present
Scientific Director, Blusson QMI 2015 – present
Co-Director, MP-UBC-UTokyo Centre for Quantum Materials 2015 – present

GRADUATE STUDENTS

Ryan Day, Sydney Dufresne, MengXing Na, Amy Qu, Alexander Sheyerman, Cissy Suen (Joint PhD), Christine Au-Yeung, Marta Zonno

POSTDOCTORAL FELLOWS

Martin Bluschke, Hao Chu, Ryan Day, Sean Kung, Dan Sun, Marta Zonno, Berend Zwartsenberg

SCIENTIFIC STAFF

Ilya Elfimov, Giorgio Levy, Matteo Michiardi, Arthur Mills, Sergey Zhdanovich

SELECTED PUBLICATIONS

B. Zwartsenberg, R.P. Day, E. Razzoli, M. Michiardi, N. Xu, M. Shi, J.D. Denlinger, G. Cao, S. Calder, K. Ueda, J. Bertinshaw, H. Takagi, B.J. Kim, I.S. Elfimov, A. Damascelli. *Spin-orbit-controlled metal-insulator transition in Sr2IrO4*. Nat. Phys. **16**, 290 (2020).

M.X. Na, A.K. Mills, F. Boschini, M. Michiardi, B. Nosarzewski, R.P. Day, E. Razzoli, A. Sheyerman, M. Schneider, G. Levy, S. Zhdanovich, T.P. Devereaux, A.F. Kemper, D.J. Jones, A. Damascelli. *Direct determination of mode-projected electron-phonon coupling in the time-domain.* Science **366**, 1231 (2019).

F. Boschini, E.H. da Silva Neto, E. Razzoli, M. Zonno, S. Peli, R.P. Day, M. Michiardi, M. Schneider, B. Zwartsenberg, P. Nigge, R.D. Zhong, J. Schneeloch, G.D. Gu, S. Zhdanovich, A.K. Mills, G. Levy, D.J. Jones, C. Giannetti, A. Damascelli. *Collapse of high-Tc superconductivity via ultrafast quenching of the phase coherence.* Nat. Mater. **17**, 416 (2018).

STEVE DIERKER

RESEARCH FOCUS

Our new Quantum Materials Electron Microscopy Centre will have two state of the art electron microscopes for atomic imaging and characterization of materials and for carrying out electron energy loss measurements as a function of momentum with unprecedented energy resolution. Research with this latter capability may include measurements of the momentum dependence of the dielectric function of quantum materials, studies of collective excitations in inhomogeneous strongly correlated matter, and studies of the spectrum of confined optical modes in polaritonic media. We are also developing a nanospectroscopy laboratory for conducting optical spectroscopy measurements with ~10 nm spatial resolution and at temperatures from ~2.5K to 450K. This will aid in discovery of new polaritonic materials based on 2D electrides and layered transition metal oxides, and developing means for controlling them by integrating them with quantum materials.

CURRENT PROJECTS

- Development of the Quantum Materials Electron Microscopy Centre
- Development of a Nanospectroscopy Laboratory for studying polaritonic quantum materials
- Raman scattering studies of topological materials
- 2D electride materials and layered transition metal oxides

CAREER HIGHLIGHTS

PhD University of Illinois 1977 – 1983
Member of Technical Staff, AT&T Bell Laboratories 1983 – 1990
Assoc. Professor University of Michigan 1990 – 1999
Professor University of Michigan 1999 – 2006
Director, National Synchrotron Light Source, BNL 2001 – 2006
Director, National Synchrotron Light Source II Project, BNL 2006 – 2015
Associate Laboratory Director for Photon Sciences, BNL 2003 – 2015
Professor Texas A&M University 2015 – 2018
Professor UBC 2018 – present

POSTDOCTORAL FELLOWS

Ali Abdullah Husain, Hsiang-His (Sean) Kung

SCIENTIFIC STAFF

Alan Maigné

SELECTED PUBLICATIONS

S.B. Dierker, M. C. Aronson. *Reduction of Raman scattering and fluorescence from anvils in high pressure Raman scattering.* Rev. Sci. Instrum. **89**, 053902 (2018).

S.B. Dierker, R. Pindak, R.M. Fleming, I.K. Robinson, L. Berman. *X-Ray Photon Correlation Spectroscopy Study of Brownian Motion of Gold Colloids in Glycerol.* Phys. Rev. Lett. **75**, 449 (1995).

M.V. Klein, S.B. Dierker. *Theory of Raman Scattering in Superconductors.* Phys. Rev. B **29**, 4976 (1984).

JOSHUA FOLK

RESEARCH FOCUS

We perform ultra-low temperature electronic measurements, often at high magnetic fields, of devices defined by micro- and nanolithography, 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.

CURRENT PROJECTS

- van der Waals heterostructures
- Non-abelian electronic states
- Mesoscopic physics

CAREER HIGHLIGHTS

PhD Stanford University 1998 – 2003
Postdoc. Fellow MIT 2003 – 2004
Postdoc. Researcher Delft Technical University 2005
Asst. Professor UBC 2005 – 2010
Assoc. Professor UBC 2010 – present

UNDERGRADUATE STUDENTS

Sean Ghaeli, Owen Sheekey, Teri Siu

GRADUATE STUDENTS

Tim Child, Christian Olsen, Ebrahim Sajadi, Aswin Vishnuradhan

POSTDOCTORAL FELLOWS

Manabendra Kuiri

SCIENTIFIC STAFF

Silvia Lüscher

SELECTED PUBLICATIONS

E. Sajadi, T. Palomaki, Z. Fei, W. Zhao, P. Bement, C. Olsen, S. Lüscher, X. Xu, J.A. Folk, D.H. Cobden. *Gate-induced superconductivity in a monolayer topological insulator.* Science **362**, 922 (2018).

N. Hartman, C. Olsen, S. Lüscher, M. Samani, S. Fallahi, G.C. Gardner, M. Manfra, J. Folk. *Direct entropy measurement in a mesoscopic quantum system.* Nat. Phys. **14**, 1083 (2018).

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, C.M. Marcus. *Quantized conductance doubling and hard gap in a two-dimensional semiconductor-superconductor heterostructure.* Nat. Commun. **7**, 12841 (2016).

MARCEL FRANZ

RESEARCH FOCUS

We formulate and study simple models of solids that are relevant to topological states of quantum matter, including topological insulators, superconductors and semimetals as well as models of strongly interacting many-body systems. The key criteria driving our research are: (i) cutting edge theoretical developments and (ii) relevance to real physical systems as studied by our experimental colleagues.

CURRENT PROJECTS

- Topological superconductivity in twisted double layer cuprates
- Quantum models of traversable wormholes
- Magic angle physics in dichalcogenides and nodal superconductors
- Majorana fermions for topological quantum computation

CAREER HIGHLIGHTS

PhD University of Rochester 1992 – 1994
Postdoc. Fellow McMaster University 1994 – 1996
Postdoc. Fellow Johns Hopkins University 1996 – 2000
Asst. Professor UBC 2000 – 2005
Assoc. Professor UBC 2005 – 2010
Professor UBC 2010 – present

UNDERGRADUATE STUDENTS

Amrit Guha

GRADUATE STUDENTS

Oguzhan Can, Shannon Egan, Rafael Haenel, Étienne Lantagne-Hurtubise, Chengshu Li, Vedangi Pathak, Alejandro Mercado Tejerina, Tarun Tummuru

POSTDOCTORAL FELLOWS

Sayak Dasgupta, Stephan Plugge, Sharmishta Sahoo, Tong Zhou

SCIENTIFIC STAFF

Alberto Nocera

SELECTED PUBLICATIONS

S. Plugge, É. Lantagne-Hurtubise, M. Franz. *Revival Dynamics in a Traversable Wormhole.* Phys. Rev. Lett. **124**, 221601 (2020).

C. Li, H. Ebisu, S. Sahoo, Y. Oreg, M. Franz. *Coupled wire construction of a topological phase with chiral tricritical Ising edge modes.* Phys. Rev. B **102**, 165123 (2020).

R. Haenel, T. Branch, M. Franz. *Chern insulators for electromagnetic waves in electrical circuit networks.* Phys. Rev. B **99**, 235110 (2019).

ALANNAH HALLAS

RESEARCH FOCUS

Our group is focused on the design and discovery of new quantum materials using a broad range of crystal growth techniques, including metallic flux, vapour transport, high-pressure synthesis, and floating zone growth. We are particularly interested in establishing structure-function relationships in quantum materials via characterization of their structural, magnetic, and electronic behaviors in order to facilitate the targeted design of materials with novel or useful properties. This research is performed in our state-of-the-art crystal growth laboratories at Blusson QMI as well as international neutron scattering and muon spin relaxation user facilities.

CURRENT PROJECTS

- Design and crystal growth of new quantum materials
- Structural and magnetic properties of high entropy oxides
- Magnetic frustration in the local to itinerant crossover
- Multipolar interactions in rare earth magnets
- Topological semimetals with strong spin-orbit coupling

CAREER HIGHLIGHTS

PhD (Vanier Scholar) McMaster University 2013 – 2017
Smalley-Curl Postdoc. Fellow, Rice University 2017 – 2019
Asst. Professor UBC 2019 – present

UNDERGRADUATE STUDENTS

Sam Mugiraneza

GRADUATE STUDENTS

Graham Johnstone, Samikshya Sahu

POSTDOCTORAL FELLOWS

Dalmau Reig-i-Plessis

SELECTED PUBLICATIONS

A.M. Hallas, A.Z. Sharma, C. Mauws, Q. Chen, H.D. Zhou, C. Ding, Z. Gong, M. Tachibana, P.M. Sarte, J.P. Attfield, G.M. Luke, and C.R. Wiebe. *Coexistence of metallic and nonmetallic properties in the pyrochlore Lu2Rh2O7.* npj Quantum Mater. **4**, 9 (2019).

A.M. Hallas, J. Gaudet, B.D. Gaulin. *Experimental insights into ground-state selection of quantum XY pyrochlores.* Annu. Rev. Condens. Matter Phys. **9**, 105 (2018).

A.M. Hallas, J. Gaudet, N.P. Butch, G. Xu, M. Tachibana, C.R. Wiebe, G.M. Luke, B.D. Gaulin. *Phase Competition in the Palmer-Chalker X Y Pyrochlore* $Er_2Pt_2O_7$. Phys. Rev. Lett. **119**, 187201 (2017).

DAVID JONES

RESEARCH FOCUS

Our research lies at the convergence of condensed matter physics, ultrafast photonics, and spectroscopy. It encompasses the development of new and customized femtosecond laser sources and accompanying spectroscopic techniques and employing them in tandem to unravel properties of quantum materials when they are at equilibrium and when they are in excited states. In a long-term scientific goal, we seek to implement photonic manipulation and control of quantum states/phases within solids.

CURRENT PROJECTS

- Femtosecond XUV sources for TR-ARPES over the full Brillioun zone with tunable energy/time resolution
- 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 for studying coherence in solids
- Exciton dynamics in 2-D materials

CAREER HIGHLIGHTS

PhD MIT 1994 – 1999
Research Assoc. NIST Boulder Labs 1998 – 2000
Senior Research Assoc. CU Boulder 2001 – 2003
Asst. Professor UBC 2004 – 2010
Assoc. Professor UBC 2010 – 2020
Professor UBC 2020 – present

GRADUATE STUDENTS

Rysa Greenwood, Bradley Guislain, Michael Hemsworth, MengXing Na, Alexandra Tully, Max Warner

POSTDOCTORAL FELLOWS

Hao Chu, Philipp Sulzer

SCIENTIFIC STAFF

Arthur Mills, Evgeny Ostroumov, Sergey Zhdanovich

SELECTED PUBLICATIONS

A.K. Mills, S. Zhdanovich, M.X. Na, F. Boschini, E. Razzoli, M. Michiardi, A. Sheyerman, M. Schneider, T.J. Hammond, V. Suess, C. Felser, A. Damascelli, D. J. Jones. *Cavity-enhanced high harmonic generation for XUV time- and angle-resolved photoemission spectroscopy.* Rev. Sci. Instrum. **90**, 083001 (2019).

M.X. Na, A.K. Mills, F. Boschini, M. Michiardi, B. Nosarzewski, R.P. Day, E. Razzoli, A. Sheyerman, M. Schneider, G. Levy, S. Zhdanovich, T.P. Devereaux, A.F. Kemper, D.J. Jones, A. Damascelli. *Direct determination of mode-projected electron-phonon coupling in the time-domain.* Science **366**, 1231 (2019).

A.K. Mills, T.J. Hammond, M.H.C. Lam, D.J. Jones. *XUV frequency combs via femtosecond enhancement cavities.* J. Phys. B **45**, 14 (2012).

ROB KIEFL

RESEARCH FOCUS

Our main objective is to explore the novel magnetic and electronic properties of quantum materials using nuclear methods such as muon spin rotation and beta-detected NMR. In particular we are interested in finding out how their properties change in the bulk compared to the near surface region, near interfaces, and near a point charge such as the positive muon. For example, in some magnetic materials positive muon is expected to mimic a magnetic monopole or form a bound state with a polaron. We are also interested in studying how Li diffuses in battery electrode materials using nuclear tracer methods.

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
- Neutral charge state of the muon in magnetic materails

CAREER HIGHLIGHTS

PhD UBC 1978 – 1982
Research Assoc. TRIUMF 1982
Postdoc. Fellow Physics Institute, University of Zurich 1982 – 1984
Research Scientist TRIUMF 1984 – 1987
University Research Fellow UBC 1987 – 1990
Asst. Professor UBC 1990 – 1992
Assoc. Professor UBC 1992 – 1995
Professor UBC 1995 – present

GRADUATE STUDENTS

Aris Chatzichristos, Martin Dehn, Derek Fujimoto, Victoria Karner, Ryan McFadden, John Ticknor

SELECTED PUBLICATIONS

M.H. Dehn, J.K. Shenton, S. Holenstein, Q.N. Meier, D.J. Arseneau, D.L. Cortie, B. Hitti, A.C.Y. Fang, W.A. MacFarlane, R.M.L. McFadden, G.D. Morris, Z. Salman, H. Luetkens, N.A. Spaldin, M. Fechner, R.F. Kiefl. *Observation of charge-neutral Muon-Polaron Complex in Antiferromagnetic Cr2O3.* Phys. Rev. X **10**, 011036 (2020).

A. Chatzichristos, R.M.L. McFadden, M.H. Dehn, S.R. Dunsiger, D. Fujimoto, V.L. Karner, I. McKenzie, G.D. Morris, M.R. Pearson, M. Stachura, J. Sugiyama, J.O. Ticknor, W.A. MacFarlane, R.F. Kiefl. *Bi-Arrhenius Diffusion and Surface Trapping of* ^{8}*Li+ in Rutile TiO2.* Phys. Rev. Lett. **123**, 095901 (2019).

D.L. Cortie, T. Buck, M.H. Dehn, V.L. Karner, R.F. Kiefl, C.D.P. Levy, R.M.L. McFadden, G.D. Morris, I. McKenzie, M.R. Pearson, X.L. Wang, W.A. MacFarlane. *beta-NMR investigation of the depth dependent magnetic properties of an antiferromagnetic surface.* Phys. Rev. Letts. **116**, 106103 (2016).

ROMAN KREMS

RESEARCH FOCUS

Our work is at the intersection of quantum physics, machine learning and chemistry on problems of relevance to quantum materials and quantum technologies, including quantum computing, quantum sensing and quantum algorithms. We are particularly excited about applications of machine learning for solving complex quantum problems and applications of quantum hardware for machine learning.

CURRENT PROJECTS

- Exploring ways to accelerate quantum dynamics calculations with machine learning and combine quantum computing with machine learning for interesting applications

CAREER HIGHLIGHTS

PhD Goteborg University 1999 – 2002
SAO Predoc. Fellow Harvard-Smithsonian Center for Astrophysics 2001 – 2002
Postdoc. Fellow Harvard University 2003 – 2005
Asst. Professor UBC 2005 – 2009
Assoc. Professor UBC 2009 – 2013
Professor UBC 2013 – Present

GRADUATE STUDENTS

Kasra Asnaashari, Jun Dai, Dawn Mao, Elham Torabian

POSTDOCTORAL FELLOWS

Ludmila Szulakowska

SCIENTIFIC STAFF

Nayyereh Hatefi, Sassan Moradi

SELECTED PUBLICATIONS

R.A. Vargas-Hernández, J. Sous, M. Berciu, R.V. Krems. *Extrapolating Quantum Observables with Machine Learning: Inferring Multiple Phase Transitions from Properties of a Single Phase.* Phys. Rev. Lett. **121**, 255702 (2018).

J. Sous, M. Chakraborty, R.V. Krems, M. Berciu. *Light Bipolarons Stabilized by Peierls Electron-Phonon Coupling.* Phys. Rev. Lett. **121**, 247001 (2018).

J. Huang, S. Liu, D.H. Zhang, R.V. Krems. *Time-Dependent Wave Packet Dynamics Calculations of Cross Sections for Ultracold Scattering of Molecules.* Phys. Rev. Lett. **120**, 143401 (2018).

W. ANDREW MACFARLANE

RESEARCH FOCUS

Using radioactive beta-detected NMR, we study the electromagnetic properties of single crystals, thin films, and multilayers. Our main probe is the short-lived isotope ^{8}Li. 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.

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
- ^{31}Mg, a new beta NMR probe

CAREER HIGHLIGHTS

PhD UBC 1992 – 1997
NSERC Postdoc. Fellow Laboratoire de Physique des Solides, Université Paris-Sud 1997 – 1999
Postdoc. Fellow University of Toronto 1999 – 2001
Research Assoc. TRIUMF 2001 – 2002
Asst. Professor UBC 2002 – 2008
Assoc. Professor UBC 2008 – present

GRADUATE STUDENTS

Martin Dehn, Luca Egoriti, Derek Fujimoto, Victoria Karner, Edward Thoeng, John Ticknor

SELECTED PUBLICATIONS

V.L. Karner, A. Chatzichristos, D.L. Cortie, M.H. Dehn, O. Foyevstov, K. Foyevtsova, D. Fujimoto, R.F. Kiefl, C.D.P. Levy, R.H. Li, R.M.L. McFadden, G.D. Morris, M.R. Pearson, M. Stachura, J.O. Ticknor, G. Cristiani, G. Logvenov, F. Wrobel, B. Keimer, J.J. Zhang, J.F. Mitchell, W.A. MacFarlane. *Local metallic and structural properties of the strongly correlated metal LaNiO3 using Li-8 beta-NMR.* Phys. Rev. B **100**, 165109 (2019).

R.M.L. McFadden, A. Chatzichristos, K.H. Chow, D.L. Cortie, M.H. Dehn, D. Fujimoto, M.D. Hossain, H. Ji, V.L. Karner, R.F. Kiefl, C.D.P. Levy, R. Li, I. McKenzie, G.D. Morris, O. Ofer, M.R. Pearson, M. Stachura, R.J. Cava, W.A. MacFarlane. *Ionic and electronic properties of the topological insulator Bi2Te2Se investigated via β-detected nuclear magnetic relaxation and resonance of ^{8}Li.* Phys. Rev. B **99**, 125201 (2019).

R.M.L. McFadden, T.J. Buck, A. Chatzichristos, C. Chen, K.H. Chow, D.L. Cortie, M.H. Dehn, V.L. Karner, D. Koumoulis, C.D. Philip Levy, C. Li, I. McKenzie, R. Merkle, G.D. Morris, M.R. Pearson, Z. Salman, D. Samuelis, M. Stachura, J. Xiao, J. Maier, R.F. Kiefl, W.A. MacFarlane. *Microscopic Dynamics of Li^+ in Rutile TiO2 Revealed by ^{8}Li β-Detected Nuclear Magnetic Resonance.* Chem. Mater. **29**, 10187 (2017).

MARK MACLACHLAN

RESEARCH FOCUS
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.

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
PhD University of Toronto 1995 – 1999
Postdoc. Fellow MIT 1999 – 2001
Asst. Professor UBC 2001 – 2007
Assoc. Professor UBC 2007 – 2011
Professor UBC 2011 – present

GRADUATE STUDENTS
Mohammad Chaudhry, Francesco D'Acierno, Madhureeta Das Gupta, Raksha Kandel, Jeanette Loos, Gunwant Matharu, Yihan Shi, Chris Walters, Yitao Xu

POSTDOCTORAL FELLOWS
Charlotte Boott, Michael Duss, Arash Momeni, Miguel Angel Soto Munoz, Joanna Szymkowiak, Gosuke Washino

SELECTED PUBLICATIONS
Y. Cao, P.-X. Wang, F. D'Acierno, W.Y. Hamad, C.A. Michal, M.J. MacLachlan. *Tunable Diffraction Gratings from Biosourced Lyotropic Liquid Crystals*. Adv. Mater. **32**, 1907376 (2020).

C.E. Boott, A. Tran, W.Y. Hamad, M.J. MacLachlan. *Cellulose Nanocrystal Elastomers with Reversible Visible Color.* Angew. Chem. Int. Ed. **59**, 226 (2020).

M.A. Soto, V. Carta, R.J. Andrews, M.T. Chaudhry, M.J. MacLachlan. *Structural Elucidation of Selective Solvatochromism in a Responsive-at-metal Cyclometalated Platinum(II) Complex.* Angew. Chem. Int. Ed. **59**, 10348 (2020).

ALIREZA NOJEH

RESEARCH FOCUS
Our research activities centre on the study of the interaction of light with nanostructures leading to highly localized heating and thermal electron and photon emission. Our work involves device design, micro/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 theory and simulation using methods ranging from continuum modelling 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.

CURRENT PROJECTS
- Heat localization in carbon nanotubes
- Thermionic energy conversion
- Compact, low-cost scanning electron microscope

CAREER HIGHLIGHTS
PhD Stanford University 2000 – 2006
Asst. Professor UBC 2006 – 2011
Assoc. Professor UBC 2011 – 2016
Professor UBC 2016 – present

UNDERGRADUATE STUDENTS
Alexander Dimitrakopoulos, Maryam Rahbaran, Gabriel Robinson-Leith

GRADUATE STUDENTS
Aashish Bhardwaj, Daniel Bruns, Mike Chang, Mokter Mahmud Chowdhury, Mohab Hassan, Robyn McNeil, Ehsanur Rahman, Kevin Voon

POSTDOCTORAL FELLOWS
Shreyas Patankar

SCIENTIFIC STAFF
Casimir Kuzyk

SELECTED PUBLICATIONS
F. Mohammadbeigi, L.A. Whitehead, R. Divigalpitiya, A. Nojeh. *Observations of radiation dominated rapid cooling of structures based on carbon nanotubes and graphene.* Adv. Eng. Mater. **22**, 1901315 (2020).

M. Chang, H.D.E. Fan, M.M. Chowdhury, G.A. Sawatzky, A. Nojeh. *Heat localization through reduced dimensionality.* Phys. Rev. B **98**, 155422 (2018).

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

ROBERT RAUSSENDORF

RESEARCH FOCUS

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.

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

PhD University of Munich (LMU) 1999 – 2003
Postdoc. Fellow Caltech 2003 – 2006
Postdoc. Fellow Perimeter Institute for Theoretical Physics 2006 – 2007
Asst. professor UBC 2008 – 2013
Assoc. Professor UBC 2013 – present

GRADUATE STUDENTS

Arnab Adhikary, Poya Hagnehgahdar, Paul Herringer, Oleg Kabernik, Arman Zaribafiyan, Michael Zurel

POSTDOCTORAL FELLOWS

Stephan Plugge

SELECTED PUBLICATIONS

R. Raussendorf, C. Okay, D. Wang, D.T. Stephen, H.P. Nautrup. *Computationally universal phase of quantum matter.* Phys. Rev. Lett. **122**, 090501 (2019).

X.-C. Yao, T.-X. Wang, H.-Z. Chen, W.-B. Gao, A.G. Fowler, R. Raussendorf, Z.-B. Chen, N.-L. Liu, C.-Y. Lu, Y.-J. Deng, Y.-A. Chen, J.-W. Pan. *Experimental demonstration of topological error correction*. Nature **482**, 489 (2012).

T.-C. Wei, I. Affleck, R. Raussendorf. *The 2D AKLT state is a universal quantum computational resource.* Phys. Rev. Lett. **106**, 070501 (2011).

JOERG ROTTLER

RESEARCH FOCUS

With computational techniques ranging from density functional theory (DFT), molecular dynamics and Monte Carlo simulations on the atomic scale, to field theoretic (phase field) methods on the mesoscale, the group studies a diverse range of materials that include amorphous solids, polymers, and nanomaterials. Computer simulations facilitate the discovery of emergent phenomena, test theories and generic trends, reveal quantities that are difficult or impossible to obtain in experiments, and thus provide essential input into the design of new functional materials. The group maintains close collaborations with several experimental groups at Blusson QMI.

CURRENT PROJECTS

- Surface relaxation in amorphous polystyrene films via molecular simulations and beta-NMR measurements (collaboration with MacFarlane/ Kiefl groups)
- Nanoscale phononics and thermal transport in carbon nanotubes (collaboration with Nojeh group)
- Statistical physics of driven amorphous materials
- Macromolecular engineering of morphology and thermal transport in organic solids
- Amorphous metal oxide coatings with low mechanical loss

CAREER HIGHLIGHTS

PhD Johns Hopkins University 1999 – 2003
Chercheur Associé E.S.P.C.I. (Paris) 2003 – 2003
Postdoc. Fellow Princeton University 2003 – 2005
Asst. Professor UBC 2005 – 2010
Assoc. Professor UBC 2010 – 2016
Professor UBC 2016 – present

GRADUATE STUDENTS

Daniel Bruns, Derek Fujimoto, Daniel Korchinski, Vasiliy Triandafilidi (co-supervised with CHBE), Daniel Wong

SCIENTIFIC STAFF

Debashish Mukherji

SELECTED PUBLICATIONS

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

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

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

JOESEPH SALFI

RESEARCH FOCUS
My group's main research interest is the physical implementation of quantum computers and quantum simulators. Our research expertise is in spin physics and quantum devices. We work with spin-based qubits to investigate and build prototypes of future large-scale quantum computers based on silicon materials that underpin classical computer technologies, of very high industrial relevance. We employ similar techniques to build quantum simulators, which are anticipated to be one of the first technological applications of quantum information science, to help design materials. Quantum simulators are also anticipated to enable real laboratory tests of exotic aspects of many-body quantum theory, beyond that which can be tested by traditional experiments in, e.g., of relevance to e.g. condensed matter physics.

CURRENT PROJECTS
- Physical implementation of quantum computers using spin qubits
- Quantum simulation using spin qubits

CAREER HIGHLIGHTS
PhD University of Toronto 2005 – 2011
Postdoc. Fellow CQC2T University of New South Wales 2011 – 2015
ARC DECRA Fellow and Lecturer CQC2T University of New South Wales 2016 – 2018
Asst. Professor UBC 2019 – present

UNDERGRADUATE STUDENTS
Sri Vasudha Hemadri Bhotla, Ryan Payne, Victor Sira

GRADUATE STUDENTS
Hanieh Aghaee, Ana Ciocoiu, Karim Elkholy, Mohammad Khalifa, Mukhlasur Rahman Tanvir

POSTDOCTORAL FELLOWS
Ebrahim Sajadi

SELECTED PUBLICATIONS
J. Salfi, J.A. Mol, D. Culcer, S. Rogge. *Charge-insensitive single-atom spin-orbit qubit in silicon.* Phys. Rev. Lett. **116**, 246801 (2016).

J. Salfi, J.A. Mol, R. Rahman, G. Klimeck, M.Y. Simmons, L.C.L. Hollenberg, S. Rogge. *Quantum simulation of the Hubbard model with dopant atoms in silicon.* Nat. Commun. **7**, 11342 (2016).

J. Salfi, J.A. Mol, R. Rahman, G. Klimeck, M.Y. Simmons, L.C.L. Hollenberg, S. Rogge. *Spatially resolving valley quantum interference of a donor in silicon.* Nat. Mater. **14**, 605 (2014).

GEORGE SAWATZKY

RESEARCH FOCUS
We use a combination of advanced experimental and theoretical methods in studies of quantum materials exhibiting interesting and not well-understood physical properties. We are particularly interested in using inelastic electron scattering, also known as electron energy-loss spectroscopy, to probe the static and dynamic interactions between charge degrees of freedom in solids, especially at short wavelengths. 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.

CURRENT PROJECTS
- Q-resolved electron energy-loss spectroscopy of charge excitations in strongly-correlated systems
- Screening of short-range Coulomb interactions in materials with strongly non-uniform polarizability
- Dynamical charge fluctuations, bond disproportionation, and negative charge transfer gap in systems such as $BaBiO^3$ and the perovskite rare-earth nickelates
- Electron-magnon-phonon coupling and their role in high Tc superconductors and topology
- Resonant soft x-ray reflectometry and the study of buried interfaces in heterostructures

CAREER HIGHLIGHTS
PhD University of Manitoba 1965 – 1969
Postdoc. Fellow Groningen University 1969 – 1971
Assoc. Professor Groningen University 1971 – 1979
Professor Groningen University 1979 – 2001
Professor UBC 2002 – present

GRADUATE STUDENTS
Nassim Derriche, Kevin Voon, Yau Chuen (Oliver) Yam

POSTDOCTORAL FELLOWS
Ali A. Husain, Mi Jiang

SCIENTIFIC STAFF
Ilya Elfimov, Oleksandr Foyevstov, Kateryna Foyevtsova, Fengmiao Li, Debashish Mukherji

SELECTED PUBLICATIONS
S. Johnston, A. Mukherjee, I. Elfimov, M. Berciu, G.A. Sawatzky. *Charge Disproportionation without Charge Transfer in the Rare-Earth-Element Nickelates as a Possible Mechanism for the Metal-Insulator Transition.* Phys. Rev. Lett. **112**, 106404 (2014).

M.T. Czyżyk, G.A. Sawatzky. *Local-density functional and on-site correlations: The electronic structure of La_2CuO_4 and $LaCuO_3$.* Phys. Rev. B **49**, 14211 (1994).

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

ZILIANG YE

RESEARCH FOCUS

We are an optical spectroscopy group studying light matter interaction in low-dimensional materials. We are currently focused on exploring how topology, correlation effects, and other emergent degrees of freedom interact with each other in two-dimensional van der Waals materials such as graphene, phosphorene, transition metal dichalcogenide, hexagonal boron nitride, and their heterostructures. Our expertise includes ultrafast optical spectroscopy with diffraction-limited resolution at low temperatures and strong magnetic fields as well as nearfield optical microscopy. In the past, we have utilized ultrafast nonlinear optical spectroscopies to reveal the crystal and electronic structure of TMDCs. We are currently interested in developing novel scanning near-field optical microscopy techniques to interrogate the material's intrinsic response with subdiffractional resolution. We hope to leverage the extreme thickness of 2D materials and the ultra-strong field within the laser light to coherently control the material's electronic band structure. Novel devices such as photodetectors with bulk photovoltaic effect and topological superconductors are also under investigation within our group.

CURRENT PROJECTS

- Bose-Einstein condensate of interlayer excitons
- Topological superconductivity in van der Waals heterostructures
- Shift current and bulk photovoltaic effect at low-symmetry interfaces
- Multidimensional coherent spectroscopy of correlated materials
- Developing nearfield optical imaging and spectroscopy techniques

CAREER HIGHLIGHTS

PhD University of California, Berkeley 2008 – 2013
Postdoc. Fellow University of California, Berkeley 2014
Postdoc. Fellow Columbia and Stanford University 2014 – 2017
Asst. Professor UBC 2017 – present

UNDERGRADUATE STUDENTS

Raghav Chaturvedi, Sukhman Claire, Vedanshi Vala

GRADUATE STUDENTS

Eddie Ji, Sean Raglow, Yunhuan Xiao, Dongyang Yang

SELECTED PUBLICATIONS

Z. Ye, L. Waldecker, E.Y. Ma, D. Rhodes, A. Antony, B. Kim, X. Zhang, M. Deng, Y. Jiang, Z. Lu, D. Smirnov, K. Watanabe, T. Taniguchi, J. Hone, T.F. Heinz. *Efficient generation of neutral and charged biexcitons in encapsulated WSe2 monolayers.* Nat. Commun. **9**, 3718 (2018).

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

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

JEFF YOUNG

RESEARCH FOCUS

Our group develops new optical materials and devices by controlling composition on lengthscales from 5 nm -500 nm. Electron-beam, atomic-force-microscopy (AFM), and optical lithographies are used in conjunction with a variety of etching and deposition technologies to produce 3D-textured structures in which the electronic and photonic eigen states can be “designed” by judicious choice of patterns, lengthscales, and material combinations. The motivation is to offer optical device engineers a more diverse range of material options when developing next and next-next generation technologies.

CURRENT PROJECTS

- Nonlinear properties of high-Q SOI-based photonic microcavities
- Integrated non-classical light sources in SOI based on parametric down conversion
- Integrated superconducting single photon detectors on silicon waveguides in SOI
- Scalable architectures for fault-tolerant photon-spin enabled quantum computing

CAREER HIGHLIGHTS

PhD University of Toronto 1979 – 1983
Research Assoc., Asst., Assoc. Research Officer, NRC 1983 – 1988
Section Head, NRC 1988 – 1990
Senior Research Officer and Group Leader, NRC 1990 – 1992
Assoc. Professor UBC 1992 – 1996
Professor UBC 1996 – present

GRADUATE STUDENTS

Abdelrahman E. Afifi, Adan Azem, Adam Darcie, Sebastian Gitt, Becky Lin, David Roberts, Donald Witt, Xiruo Yan

POSTDOCTORAL FELLOWS

Matthew Mitchell, Jingda Wu

SCIENTIFIC STAFF

Kashif Awan

SELECTED PUBLICATIONS

X. Yan, W. Asavanant, H. Kamakari, J. Wu, J.F. Young, R. Raussendorf. *A quantum computer architecture based on silicon donor qubits coupled by photons.* Adv. Quantum Technol. **3**, 2000011 (2020).

E. Schelew, R.C. Ge, S. Hughes, J. Pond, J.F. Young. *Self-consistent numerical modeling of radiatively damped Lorentz oscillators.* Phys. Rev. A **95**, 063853 (2017).

M.K. Akhlaghi, E. Schelew, J.F. Young. *Waveguide integrated superconducting single-photon detectors implemented as near-perfect absorbers of coherent radiation.* Nat. Commun. **6**, 8233 (2015).

KE ZOU

RESEARCH FOCUS
Our research interests are in the growth of complex oxide and chalcogenide films by molecular beam epitaxy and the studies of their properties and functions. We aim to achieve scientific and technological breakthroughs in new materials and new functional devices. We 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.

CURRENT PROJECTS
- Superconducting oxide thin films and heterostructures
- Emergent magnetism in oxide thin films and heterostructures
- 2D monolayer and multilayer ferromagnetic chalcogenide films
- Fe-based high temperature superconductors

CAREER HIGHLIGHTS
PhD Pennsylvania State University 2006 – 2012
Postdoc. Fellow Yale University 2012 – 2018
Asst. Professor UBC 2018 – present

UNDERGRADUATE STUDENTS
Park Chong, Andree Coschizza, Rayan Farid

GRADUATE STUDENTS
Simon Godin, Ryan Roemer, Hyungki Shin

POSTDOCTORAL FELLOWS
Chong Liu, Srinivas Vanka

SCIENTIFIC STAFF
Bruce A. Davidson, Fengmiao Li

SELECTED PUBLICATIONS
R. Roemer, C. Liu, K. Zou. *Robust ferromagnetism in wafer-scale monolayer and multilayer Fe3GeTe2.* npj 2D Mater. Appl. **4**, 33 (2020).

H. Shin, C. Liu, F. Li, R. Sutarto, B.A. Davidson, K. Zou. *Controlling the electrical and magnetic ground states by doping in the complete phase diagram of titanate* Eu1−xLaxTiO3 thin films. Phys. Rev. B **101**, 214105 (2020).

C. Liu, K. Zou. *Tuning stoichiometry and its impact on superconductivity of monolayer and multilayer FeSe on SrTiO3.* Phys. Rev. B: Rapid Commun. **101**, 140502(R) (2020).

AFFILIATE INVESTIGATORS

FABIO BOSCHINI

RESEARCH FOCUS
We will take advantage of high-intensity long-wavelength light excitations to selectively explore and drive novel quantum phases of matter with no equilibrium counterpart. This research will be accomplished by accessing the dynamical properties of complex systems via state-of-the-art time- and angle-resolved photoemission spectroscopy (TR-ARPES) at INRS-EMT and Blusson QMI-UBC, as well as large-scale international user facilities, such as synchrotrons and free-electron lasers.

CURRENT PROJECTS
- Exploration of the dynamical nature of the charge-order in high-temperature superconductors via equilibrium and out-of-equilibrium x-ray scattering
- Probe light- and phonon-induced Floquet physics in Dirac-like systems via time-resolved photoemission spectroscopy
- Mapping resonant phonon pumping effects in complex materials via TR-ARPES imaging

CAREER HIGHLIGHTS
PhD Politecnico di Milano 2012 – 2014
Postdoc. Fellow 2015 – 2020
Asst. Professor INRS-EMT 2020 – present
Affiliate Asst. Professor Blusson QMI 2021 – present

GRADUATE STUDENTS
Sydney Dufresne at UBC (co-supervised with A. Damascelli at UBC)
Jean-Michel Parent at INRS (co-supervised with F. Légaré at INRS)

POSTDOCTORAL FELLOWS
Gaetan Jargot at INRS (co-supervised with F. Légaré at INRS)

SELECTED PUBLICATIONS
F. Boschini, M. Zonno, E. Razzoli, M. Michiardi, R.P. Day, B. Zwartsenberg, P. Nigge, M. Schneider, E.H. da Silva Neto, A. Erb, S. Zhdanovich, A.K. Mills, G. Levy, C. Giannetti, D.J. Jones, A. Damascelli. *Emergence of pseudogap from short-range spin-correlations in electron-doped cuprates.* npj Quantum Mater. **5**, 6 (2020).

M.X. Na, A.K. Mills, F. Boschini, M. Michiardi, B. Nosarzewski, R.P. Day, E. Razzoli, A. Sheyerman, M. Schneider, G. Levy, S. Zhdanovich, T.P. Devereaux, A.F. Kemper, D.J. Jones, A. Damascelli. *Direct determination of mode-projected electron-phonon coupling in the time domain*. Science **366**, 1231 (2019).

F. Boschini, E.H. da Silva Neto, E. Razzoli, M. Zonno, S. Peli, R.P. Day, M. Michiardi, M. Schneider, B. Zwartsenberg, P. Nigge, R.D. Zhong, J. Schneeloch, G.D. Gu, S. Zhdanovich, A.K. Mills, G. Levy, D.J. Jones, C. Giannetti, A. Damascelli. *Collapse of superconductivity in cuprates via ultrafast quenching of phase coherence.* Nat. Mater. **17**, 416 (2018).

ROBERT GREEN

RESEARCH FOCUS
Our group studies quantum materials using a combination of synchrotron x-ray spectroscopy and quantum many-body theory. We focus strongly on correlated oxide thin films and heterostructures, aiming to understand and develop control over their functionalities. In alignment with the goals of Blusson QMI, we strive to pave the way for upcoming generations of electronic and magnetic devices based on the quantum materials we study.

CURRENT PROJECTS
- Orbital and electronic reconstruction at correlated oxide interfaces studied with resonant x-ray reflectometry
- Multi-q, non-collinear magnetic order in $SrFeO_3$ heterostructures
- The impact of atomic physics on fluctuations in heavy fermion systems and correlated oxides
- Orbital imaging in multipolar-ordered compounds
- Resistive memories in correlated oxides

CAREER HIGHLIGHTS
PhD University of Saskatchewan 2009 – 2013
Postdoc. Fellow UBC 2013 – 2017
Research Assoc. UBC 2017
Affiliate Asst. Professor Blusson QMI 2017 – present
Asst. Professor University of Saskatchewan 2017 – present

GRADUATE STUDENTS
Patrick Braun, Jessie Freese, Grant Harris, Niyusha Hosseini, Lucas Korol, Skylar Koroluk

SELECTED PUBLICATIONS
Z. Liao, N. Gauquelin, R.J. Green, K. Müller-Caspary, I. Lobato, L. Li, S. Van Aert, J. Verbeeck, M. Huijben, M.N. Grisolia, V. Rouco, R. El Hage, J.E. Villegas, A. Mercy, M. Bibes, P. Ghosez, G.A. Sawatzky, G. Rijnders, G. Koster. *Metal-insulator Transition Engineering by Modulation Tilt-Control in Perovskite Nickelates for Room Temperature Optical Switching.* Proc. Natl. Acad. Sci. U.S.A. **115**, 9515 (2018).

M. Hepting, R.J. Green, Z. Zhong, M. Bluschke, Y.E. Suyolcu, S. Macke, A. Frano, S. Catalano, M. Gibert, R. Sutarto, F. He, G. Cristiani, G. Logvenov, Y. Wang, P.A. van Aken, P. Hansmann, M. Le Tacon, J.-M. Triscone, G.A. Sawatzky, B. Keimer, E. Benckiser. *Complex Magnetic Order in Nickelate Slabs.* Nat. Phys. **14**, 1097 (2018).

R.J. Green, M.W. Haverkort, G.A. Sawatzky. *Bond Disproportionation and Dynamical Charge Fluctuations in Perovskite Rare Earth Nickelates.* Phys. Rev. B **94**, 195127 (2016).

KENJI KOJIMA

RESEARCH FOCUS
Our group utilizes and develops muon spin rotation/relaxation/resonance (μSR) and beta-decay detected nuclear magnetic resonance (β-NMR) at the TRIUMF laboratory on UBC campus to understand the roles of spin and charge degrees of freedom in various kinds of quantum matter. They are sensitive magnetic probes; we utilize μSR and Li-NMR to probe and characterize magnetism and superconductivity. Muon is a light isotope of hydrogen, so the role of hydrogen is also investigated in quantum materials.

CURRENT PROJECTS
- Frustrated quantum magnets and their ground states
- Unconventional superconductivity with spin-orbit couplings and strong correlations
- Hydrogen roles in wide gap semiconductors
- Characterization of carrier motion and density via the Li β-NMR in semiconductors.

CAREER HIGHLIGHTS
PhD University of Tokyo 1991 – 1996
Postdoc. Fellow Columbia University 1996 – 1998
Research Assoc. University of Tokyo 1998 – 2009
Assoc. Professor High Energy Accelerator Research Organization 2009 – 2018
Research Scientist TRIUMF 2018 – present
Affiliate Assoc. Professor Blusson QMI 2018 – present

POSTDOCTORAL FELLOWS
Yipeng Cai, Sungwon Yoon

SELECTED PUBLICATIONS
K.M. Kojima, M. Hiraishi, H. Okabe, A. Koda, R. Kadono, K. Ide, S. Matsuishi, H. Kumomi, T. Kamiya, H. Hosono. *Electronic structure of interstitial hydrogen in In-Ga-Zn-O semiconductor simulated by muon.* Appl. Phys. Lett. **115**, 122104 (2019).

N. Funamori, K.M. Kojima, D. Wakabayashi, T. Sato, T. Taniguchi, N. Nishiyama, T. Irifune, D. Tomono, T. Matsuzaki, M. Miyazaki, M. Hiraishi, A. Koda, R. Kadono. *Muonium in Stishovite: Implications for the Possible Existence of Neutral Atomic Hydrogen in the Earth's Deep Mantle.* Sci. Rep. **5**, 8437 (2015).

M. Hiraishi, S. Iimura, K.M. Kojima, J. Yamaura, H. Hiraka, K. Ikeda, P. Miao, Y. Ishikawa, S. Torii, M. Miyazaki, I. Yamauchi, A. Koda, K. Ishii, M. Yoshida, J. Mizuki, R. Kadono, R. Kumai, T. Kamiyama, T. Otomo, Y. Murakami, S. Matsuishi, H. Hosono. *Bipartite magnetic parent phases in the iron oxypnictide superconductor.* Nat. Phys. **10**, 300 (2014).

INTERNATIONAL SCIENTIFIC ADVISORY BOARD (ISAB)

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 International Scientific Advisory Board complements Blusson QMI's multidisciplinary approach, with its balance of expertise in theoretical, experimental, and applied research, and representation of different scientific disciplines with strong links to academia and industry.

LESLEY COHEN

CHAIR OF THE BOARD

Consul for Faculty of Natural Sciences & Education Office
Professor, Department of Physics, Faculty of Natural Sciences, Imperial College London

Lesley Cohen is a Professor of Experimental Solid State Physics at Imperial College London and Editor in Chief of Applied Physics Letters. She received the inaugural Imperial College Julia Higgins Award for her contributions to the promotion and support of women in science, and remains committed to equality and diversity within STEM.

Her recent research work focuses on superconducting spintronics, chiral antiferromagnetism, nanostructured honeycomb artificial spin ices and quantum interference effects in organic self-assembled molecules.

J.C. SÉAMUS DAVIS

Professor of Physics, Oxford University
Senior Fellow Wadham College, Oxford University
Professor of Quantum Physics, University of College Cork
J.G. White Distinguished Professor Emeritus, Cornell University

Séamus Davis is a Professor of Physics at Oxford University, Professor of Quantum Physics at the University of College Cork, and Emeritus 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, and space-time; as well as developing new techniques for visualization and measurement of complex quantum matter.

GEORGE CRABTREE

Distinguished Fellow, Argonne National Laboratory
Distinguished Professor of Physics, Electrical and Mechanical Engineering, University of Illinois at Chicago
Director of the Joint Center for Energy Storage Research (JCESR)

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). He has testified before the U.S. Congress on the hydrogen economy, meeting sustainable energy challenges, and energy storage. His research interests include energy storage, materials science, nanoscale superconductors and magnets, superconductivity, and highly correlated electrons in metals.

BENJAMIN EGGLETON

Professor of Physics, University of Sydney
Director, The University of Sydney Nano Institute (Sydney Nano)
Co-Director, NSW Smart Sensing Network (NSSN)

Benjamin Eggleton is a Professor of Physics at the University of Sydney and the Director of the University of Sydney Nano Institute (Sydney Nano) and the co-Director of the NSW Smart Sensing Network (NSSN). He is a Fellow of the Australian Academy of Science (AA), the Australian Academy of Technology and Engineering (ATSE), the Optical Society of America, IEEE and SPIE. He was previously an ARC Laureate Fellow, and has twice been an ARC Federation Fellow. His research links fundamental science to applied science and spans physics and engineering with pioneering contributions in the areas of nonlinear optics and all-optical signal processing. Eggleton is Editor-in-Chief of APL Photonics.

ANTOINE GEORGES

Director, Center for Computational Quantum Physics, Flatiron Institute (New York)
Professor, Collège de France (Paris)

Antoine Georges is a theoretical physicist with expertise in condensed matter and quantum physics. He is one of the co-inventors of dynamical mean field theory, for which he shared the 2006 Europhysics Condensed Matter Prize and the 2020 Aneesur Rahman prize of the American Physical Society. This theory has deeply transformed our understanding of quantum materials with strong electronic correlations 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.

STUART PARKIN

Max Planck Institute for Microstructure Physics, Halle (Saale), Germany

Stuart Parkin is a Director of the Max Planck Institute for Microstructure Physics, Halle, Germany, and an Alexander von Humboldt Professor, Martin Luther University, Halle-Wittenberg. His research interests include spintronic materials and devices for advanced sensor, memory, and logic applications, oxide thin-film heterostructures, topological metals, exotic superconductors, and cognitive devices. Parkin's discoveries in spintronics enabled a more than 10000-fold increase in the storage capacity of magnetic disk drives. For his work that thereby enabled the "big data" world of today, Parkin was awarded the Millennium Technology Award from the Technology Academy Finland in 2014 (worth 1,000,000 Euro) and, most recently the King Faisal Prize for Science 2021 for his research into three distinct classes of spintronic memories. Parkin is a Fellow/ Member of: Royal Society (London), Royal Academy of Engineering, National Academy of Sciences, National Academy of Engineering, German National Academy of Science—Leopoldina, Royal Society of Edinburgh, Indian Academy of Sciences, and TWAS—academy of sciences for the developing world and has received numerous awards from around the world.

R. STANLEY WILLIAMS

Professor and holder of the Hewlett Packard Enterprise Company Chair
Department of Electrical and Computer Engineering
Texas A&M University

R. Stanley Williams is the Director of the Hewlett Packard Enterprise Center for Computer Architecture Research at Texas A&M University. For the past 40 years, his primary scientific research has been in the areas of solid-state chemistry and physics, and their applications to technology. This has taken him on a journey that began with surface science; expanded to electronic, photonic and ionic nanotechnologies; and now encompasses computation, chaos, complexity and neuroarchitectonics. In 2008, a team of researchers he led announced that they had built and demonstrated the first intentional memristor, the fourth fundamental nonlinear electronic circuit element predicted by Prof. Leon Chua in 1971. Williams has received 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 2004 Herman Bloch Medal for Industrial Research, and the 2000 Julius Springer Award for Applied Physics. He has published over 460 peer reviewed papers and been awarded more than 220 US patents.

2020 PUBLICATIONS

A.E. Afifi, J.F. Young, S. Shekhar, L. Chrostowski. *System analysis of Si-photonic receivers for differential phase shift quantum key distribution protocols*. 2020 IEEE Photonics Conference (IPC) (2020).

S.D. Albright, K. Zou, C. Lau, S. Eltinge, H. Hong, S. Ismail-Beigi, F.J. Walker, C.H. Ahn. *Identifying crystal structures and chemical reactions at the interface of stanene on Bi_2Te_3*. J. Appl. Phys. **128**, 165301 (2020).

D. Azses, R. Haenel, Y. Naveh, R. Raussendorf, E. Sela, E.G.D. Torre. *Identification of Symmetry-Protected Topological States on Noisy Quantum Computers*. Phys. Rev. Lett. **125**, 120502 (2020).

C.E. Boott, A. Tran, W.Y. Hamad, M.J. MacLachlan. *Cellulose Nanocrystal Elastomers with Reversible Visible Color*. Angew. Chem.-Int. Edit. **59**, 226 (2020).

F. Boschini, D. Bugini, M. Zonno, M. Michiardi, R.P. Day, E. Razzoli, B. Zwartsenberg, M. Schneider, E.H.d.S. Neto, S.d. Conte, S.K. Kushwaha, R.J. Cava, S. Zhdanovich, A.K. Mills, G. Levy, E. Carpene, C. Dallera, C. Giannetti, D.J. Jones, G. Cerullo, A. Damascelli. *Role of matrix elements in the time-resolved photoemission signal*. New J. Phys. **22**, 023031 (2020).

F. Boschini, M. Zonno, E. Razzoli, R.P. Day, M. Michiardi, B. Zwartsenberg, P. Nigge, M. Schneider, E.H.d.S. Neto, A. Erb, S. Zhdanovich, A.K. Mills, G. Levy, C. Giannetti, D.J. Jones, A. Damascelli. *Emergence of pseudogap from short-range spin-correlations in electron-doped cuprates*. npj Quantum Mater. **5**, 6 (2020).

M. Boulanger, G. Grissonnanche, S. Badoux, A. Allaire, E. Lefrancois, A. Legros, A. Gourgout, M. Dion, C.H. Wang, X.H. Chen, R. Liang, W.N. Hardy, D.A. Bonn, L. Taillefer. *Thermal Hall conductivity in the cuprate Mott insulators Nd_2CuO_4 and $Sr_2CuO_2Cl_2$*. Nat. Commun. **11**, 5325 (2020).

D. Bruns, A. Nojeh, A.S. Phani, J. Rottler. *Heat transport in carbon nanotubes: Length dependence of phononic conductivity from the Boltzmann transport equation and molecular dynamics*. Phys. Rev. B **101**, 195408 (2020).

J.T. Cantin, G. Alexandrowicz, R.V. Krems. *Transfer-matrix theory of surface spin-echo experiments with molecules*. Phys. Rev. A **101**, 062703 (2020).

Y. Cao, P. Wang, F. D'Acierno, W.Y. Hamad, C.A. Michal, M.J. MacLachlan. *Tunable Diffraction Gratings from Biosourced Lyotropic Liquid Crystals*. Adv. Mater. **32**, 1907376 (2020).

J. Chen, C.E. Boott, L. Lewis, A. Siu, R. Al-Debasi, V. Carta, A.A. Fogh, D.Z. Kurek, L. Wang, M.J. MacLachlan, G. Hum. *Amino Acid-Containing Phase-Selective Organogelators: A Water-Based Delivery System for Oil Spill Treatment*. ACS Omega **5**, 18758 (2020).

R. Cheng, N.A.F. Jaeger, L. Chrostowski. *Fully tailorable integrated-optic resonators based on chirped waveguide Moire gratings*. Optica **7**, 647 (2020).

R. Cheng, L. Chrostowski. *Apodization of Silicon Integrated Bragg Gratings Through Periodic Phase Modulation*. IEEE J. Sel. Top. Quantum Electron. **26**, 8300315 (2020).

N. Chepiga, I. Affleck, F. Mila. *Floating, critical, and dimerized phases in a frustrated spin-3/2 chain*. Phys. Rev. B **101**, 174407 (2020).

J. Choi, O. Ivashko, E. Blackburn, R. Liang, D.A. Bonn, W.N. Hardy, A.T. Holmes, N.B. Christensen, M. Hucker, S. Gerber, O. Gutowski, U. Ruett, M.v. Zimmermann, E.M. Forgan, S.M. Hayden, J. Chang. *Spatially inhomogeneous competition between superconductivity and the charge density wave in $YBa_2Cu_3O_{6.67}$*. Nat. Commun. **11**, 990 (2020).

F. D'Acierno, W.Y. Hamad, C.A. Michal, M.J. MacLachlan. *Thermal Degradation of Cellulose Filaments and Nanocrystals*. Biomacromolecules **21**, 3374 (2020).

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