Annual Report
April 1, 2023 – March 31, 2024

For submission to the Ministry of Innovation, Science and Economic Development
July 31, 2024

FROM THE EXECUTIVE DIRECTOR

For over 20 years, the Institute for Quantum Computing (IQC) has been leading the theoretical and experimental pursuit toward quantum information science (QIS) and technology. The intellectual cross-pollination at IQC has led to world-leading advancements in quantum communications, sensing, computing and materials. IQC is a home unlike others, with a diverse research-driven community that supports one another and represents a full-stack approach to the innovation continuum from foundational, curiosity driven research to the development of quantum applications that will enable technologies and spinoff companies focused on quantum devices.

Our researchers – the foundation of the institute – have demonstrated the ability to contribute to the solution of quantum problems across a range of intellectual domains. They are developing cross-platform communities within IQC, but also Canada wide, that work on specific problems as well as broader research topics. They also contribute to Canada's economic output through startups, patent generation and responding to industrial needs with cutting-edge technologies. IQC is a thriving community that continues to push the understanding of QIS through experimental, theoretical and collaborative research.

Powered by people, some highlights from the past year include:

- Propelling open-source platforms and interdisciplinary communities that share a common goal of uniting theoretical and experimental researchers to achieve strategic missions and serve the wider quantum community. Highlights include the Quantum Repeater Community and the IQC-AMO (atomic, molecular and optical) science group, who both aim to foster interaction among all researchers working in the defined areas at IQC, and the Linux Foundation's Post-Cryptography Open-Source Alliance, which will impact post-quantum technologies and data security for industries around the world.

- Hosting the inaugural Quantum Connections conference that brought together over 150 members of Canada's quantum community, including academic, government and industry, in an engaging environment to connect and network with each other and inspire new quantum innovations and partnerships.

- Using ultra-cold molecules to create a newly developed trapping design to measure inelastic collisions of the molecules and is now inspiring studies focused on a variety of different effects, such as studying how molecules respond to the introduction of light, studying the previously problematic light-induced chemical reactions in controlled ways, and seeing if the lifetime of these ultracold molecules can be prolonged with the different trapping method. These published results are just one example of the highest cited papers in Web of Science, published by IQC researchers in the past couple of year (Alan Jamison's group).

- Having over 50% women or non-binary attendees at our high school and undergraduate summer schools, ensuring that young women can see themselves attending STEM-related graduate schools and research institutes.

- Shaping other countries' quantum activities through invited talks and relationship building events. Michele Mosca is highly regarded as a world leading expert quantum security expert who regularly meets with economic and country leaders globally to aid them in understanding the coming risks and benefits of quantum cryptography. In the past year alone, he met with decision makers in the UK, Switzerland, Singapore, the USA and across Canada. His leadership is on example of the recognition of IQC and Canada as a trusted expert in quantum excellence.

Our researchers continue to push boundaries, routinely bringing advances in quantum theories to applications and commercialization. We've built a community driven by bold, forward-thinking talent. We are leaders meeting the rising demand for quantum technologies and opportunities. As the most established institute in Canada focused on quantum technology, IQC is uniquely positioned to produce highly qualified personnel that are demanded by industry and academia through the strength of its expertise, curriculum and ecosystem.

IQC has been the driving force behind QIS in Canada for the past two decades. It remains the hub of the Canadian Quantum community– it is the main centre in Canada that can produce world class students (our alumni include 40 faculty members now at universities world-wide), deliver world-class research results, and spin off successful startups to address the growing commercial interest in quantum technologies at this scale. IQC's strength allows it to support the quantum ecosystem outside and across Canada through open-source projects and deep-tech access to quantum computing platforms. It positions our nation for success as the Canada science community builds quantum research centres from coast to coast

Norbert Lütkenhaus
Executive Director, Institute for Quantum Computing
University of Waterloo

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EXECUTIVE SUMMARY

Established in 2002, the Institute for Quantum Computing (IQC) has emerged as a catalyst for discovery in Canada, delivering breakthroughs in quantum information science and quantum technologies. These discoveries have attracted engaging faculty, brilliant students, and investments from around world. Fundamental research paired with the entrepreneurial environment at Waterloo has created a culture where research leads to commercialization that benefits all Canadians.

In support of its important work, in 2022 IQC was awarded $10M in funding by the Government of Canada to be used over two years. This funding has supported five key objectives and the great strides IQC has made toward achieving each of them.

Highlights from the 2023-2024 year, include:

- IQC members have attracted just over $150,000,000 in funding in the last 5 years including almost $25M in funding in fiscal 2023-2024
- Recruited new faculty member; Bradley Hauer studying optomechanical systems and superconducting circuits.
- Supported 53 postdoctoral fellows working across 7 departments
- Published 178 papers in peer-reviewed journals and recorded over 97,000 cumulative citations
- Delivered 134 talks at conferences and colloquia across Canada and the globe informing the development of new standards, providing scope for novel legal interpretations and challenging leading researchers everywhere
- Developed and maintained an enormous networks of academic and entrepreneurial partnerships worldwide with more than 187 ongoing collaborations in Canada and abroad
- Attracted 310 applications from across Canada and the world to our quantum information graduate programs and several hundred more to traditional programs
- Hosted nine workshops, 63 seminars, 11 colloquia, and sponsored 15 external scientific programs to continuously expose leading graduate students to professional academics from leading institutions worldwide

IQC, in collaboration with the Government of Canada and our other partners, is actively constructing Canada's quantum information economy in the Waterloo-Ottawa corridor and across the country. In addition to having established the nation's leading market-oriented ecosystem for developing, constructing, and evaluating quantum information services and devices, IQC has supported the wider Canadian effort by educating and mentoring many of the faculty working at other major quantum research institutes across the country and by producing the highly qualified graduates that are in high demand in the growing private sector growing around the Canadian quantum future.

INSTITUTE FOR QUANTUM COMPUTING

IQC at the University of Waterloo was founded in 2002 to drive the development of quantum information science and technology within Canada. The founding vision for IQC was bold: **position Canada as a leader in research and provide the necessary infrastructure for Canada to emerge as a quantum research powerhouse.** Today, IQC stands among the top quantum information research institutes in the world. Experts in all fields of quantum information science and technology come to IQC to conduct research, share knowledge and encourage and support the next generation of scientists, mathematicians, and engineers.

IQC is leading the next great Canadian technological revolution. Quantum discoveries and applications developed in IQC labs are creating the foundation for next generation technologies, based on quantum information research conducted right here in Canada.

None of this would be possible without the visionary leadership and investments of Mike and Ophelia Lazaridis, the Government of Canada, and the University of Waterloo. This strategic private-public partnership has accelerated the advancement of quantum information research and discovery in Canada, and around the globe.

Vision & Mission

IQC's vision is to harness the power of quantum mechanics for transformational technologies that benefit society and become the new engine for economic growth in the 21st century and beyond.

IQC's mission is to develop and advance quantum information science and technology at the highest international level through the collaboration of computer scientists, engineers, mathematicians and physical scientists.

Strategic Objectives

IQC is guided by strategic objectives developed in partnership with the Government of Canada:

1. To establish Waterloo as a world-class centre for research in quantum technologies and their applications.
2. To become a magnet for highly qualified personnel in the field of quantum information.
3. To be a prime source of insight, analysis and commentary on quantum information.

FUNDING OBJECTIVES

2022-2024

In April 2022, IQC was awarded $10M over two years from the Government of Canada in support of the following five objectives:

A. Promote knowledge in quantum information science and technology.

B. Provide opportunities for students to learn and apply new knowledge.

C. Raise awareness and knowledge of quantum information science and technology in both the scientific community and amongst Canadians more generally.

D. Position Canada to take advantage of economic and social benefits of research by seizing opportunities and commercializing breakthrough research.

E. Brand Canada as a place to conduct research in quantum information science and technologies.

The activities planned and undertaken by IQC with the support of the Government of Canada over the past decade has positioned Canada to take full advantage of socioeconomic benefits of quantum research and technology. What follows is progress achieved by IQC in the 2023-2024 year.

Objective A

Promote knowledge in quantum information science and technology.

Expected Result: Increase knowledge in quantum information and technology.

Planned activities:

- Leveraging talent from across three University of Waterloo faculties — Engineering, Mathematics and Science — researchers will continue IQC's collaborative and interdisciplinary research agenda in quantum computing, quantum communication, quantum sensors and quantum materials.
- Publishing research results in globally recognized journals.
- Recruiting new faculty members, research assistant professors and research associates.
- Continuing to outfit and maintain the Quantum Nano Fabrication and Characterization Facility (QNFCF) to enable fabrication of quantum-enabled technologies.
- Updating and maintaining laboratory space in the Research Advancement Centre (RAC) buildings.
- Continuing effective and relevant relationships with current research partners.
- Seeking out new partnerships that will advance IQC's mission and strategic objectives.

Research Publications and Citations

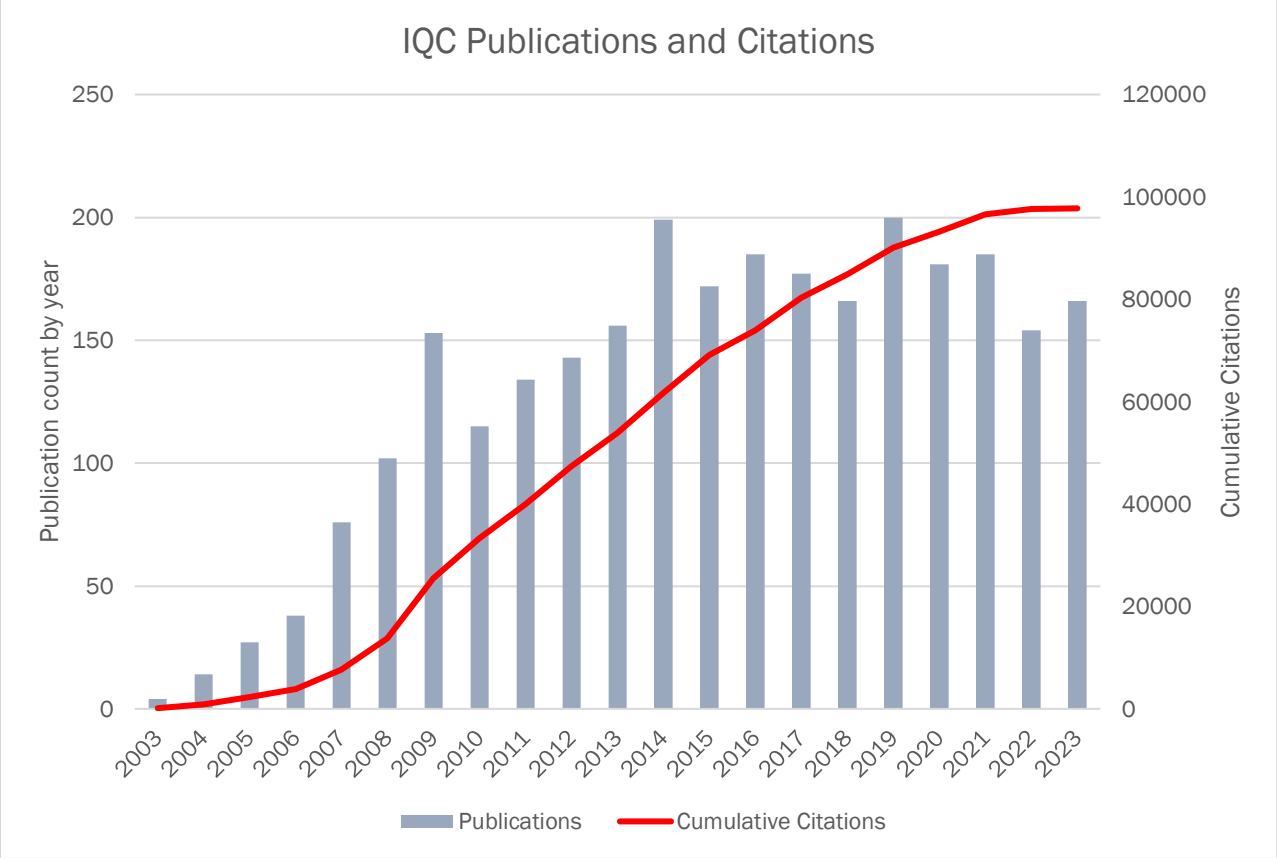
In 2023-2024, IQC researchers collectively published 178 papers in peer-reviewed journals, bringing the cumulative number of publications to 2943[1] since 2002. Several papers appear in prominent scientific publications including Science, the Nature family, the Journal of Mathematical Physics and Physical Review Letters. In addition to journals that are generally understood to be prestigious, IQC researchers also publish in journals like Quantum, NPJ Quantum Information, and PRX Quantum which are equally prestigious but much more focused on quantum science.

In addition to the number and general quality of articles published, it is also worth noting the impact of individual researchers on the field. Because impact accrues over time an article may not become highly cited in the year it is published but in the following year or two. Once such article, published in February 2023 by Dr. Alan Jamison in Nature, titled 'A Feshbach resonance in collisions between ground-state molecules' gained a 'Highly Cited' designation in 2024, with 14 citations in a year. The promise of further control of chemical reactions is being recognized by Dr. Jamison's peers as a promising result on which future research can be based. A cursory review of highly cited papers on Web of Science shows that IQC researchers have produced 12 such papers in the last 5 years.

Further analysis reveals that 64.3% of IQC papers (in 2023-2024) have been published with international collaborators from leading universities and institutes including Massachusetts Institute of Technology (MIT), University of Maryland, University of Oxford, as well as other prominent Canadian quantum institutions including Université de Sherbrooke, University of Ottawa and University of Toronto. IQC also collaborates with non-academic researchers including publications with IBM, NRC and the National Institute of Standards and Technology.

[1] Includes Web of Science as well as journals from Scopus that are not indexed in Web of Science.

Citations are also an important indicator of the influence of published research. As of March 31, 2023, the number of cumulative citations from IQC's published papers reached 97,772 – it is worth noting that the cumulative citations for IQC will surpass 100,000 in 2024. The following table highlights the large increases in IQC citations, highlighting the significant impact of IQC researchers on global quantum research.



Source: Web of Science; Search: AD= ((Inst Quant* Comp*) OR IQC) and ad = waterloo + Scopus Journals not indexed in WoS: Search: AFFIL(Inst* Quant* Comp*) AND AFFILCITY (waterloo); timespan 2015-2022. Is restricted to indexed articles between April 1 and the following March 31.*

Research Highlights: Advancing Quantum Knowledge and Understanding

The following stories highlight the research being done at IQC and the people doing the research. These stories serve to highlight the breadth and depth of the research produced at the Institute and the motivations that drive our researchers.

Designing new materials as platforms for robust quantum devices

Based on research published in Applied Physics Letters on January 4th, 2023
Field effect two-dimensional electron gases in modulation-doped InSb surface quantum wells

For researchers to successfully engineer future quantum computers, it will be important for them to use the right materials.

Dr. Jonathan Baugh, a professor at IQC and Waterloo's Department of Chemistry, is collaborating with researchers across campus to create new, high-quality materials with desirable properties for these future applications in quantum computing.

After several years of work, Baugh and his collaborators have found a method for growing crystalline structures using the semiconductor indium antimonide, which has been engineered with specific purposes in mind. This is an exciting first step towards building designer quantum devices.

The researchers have created an indium antimonide platform designed for a type of qubit known as a Majorana fermion. While still theoretical, these qubits are predicted to have better resilience to noise and decoherence compared with other types of qubits due to their unique physics. Majorana qubits are shielded from outside influences due to the way their information is encoded across highly non-local quantum states. This protection is an attractive property that could make future quantum computers less susceptible to errors. Indium antimonide has a unique combination of properties, including high electron mobility and strong spin-orbit coupling, that when combined with a superconductor, yield just the right conditions for Majorana fermions to appear.

"Theoretically, indium antimonide has the best set of ideal ingredients that are needed for Majorana qubits, from a semiconductor point of view," said E. Annelise Bergeron, the first author of the study and a PhD candidate at IQC and Waterloo's Department of Physics and Astronomy. "Our research is the first to overcome some of the difficulties that previous research did not achieve in terms of a platform to build these devices for Majorana qubits."

Their work was a true collaboration across the University of Waterloo community. Baugh and Bergeron collaborated closely with Dr. Zbigniew Wasilewski, a professor in Waterloo's Department of Electrical and Computer Engineering and an IQC Affiliate, and his Molecular Beam Epitaxy Group from the Waterloo Institute for Nanotechnology to grow the crystalline indium antimonide; devices were fabricated in

the Quantum-Nano Fabrication and Characterization Facility (QNFCF); and the team used specialized test facilities at the Transformative Quantum Technologies (TQT) program with IQC.

Yingiu (Peyton) Shi, a research associate, and Ahmed Elbaroudy, a PhD candidate in Waterloo's Department of Electrical and Computer Engineering and both members of Wasilewski's research lab, grew wafer structures using a technique called molecular beam epitaxy, which grows crystals one atomic layer at a time. These structures containing thin layers of indium antimonide called quantum wells, which confine electrons to motion in a 2D plane, a configuration known as a 2D electron gas.

Bergeron took these wafers and fabricated quantum devices known as gated Hall bars on the surface, which are used to measure the properties of the 2D electron gas. Bergeron and the team then characterized these devices using very low temperatures and strong magnetic fields – a regime in which the Hall resistance takes on quantized values, known as the quantum Hall effect regime. Their findings show that high quality 2D electron gases can be achieved in indium antimonide, with properties that are very promising for future Majorana qubit devices.

After many iterations of growing wafers, fabricating devices, and performing measurements, the team of collaborators has finally found a method that results in reproducible quantum well structures, reliable fabrication methods, and high-quality 2D electron gases.

"Indium antimonide has been plagued with difficulties in the past, which is why no one else has been successful with this material yet," says Bergeron. "So, the fact that we reported on two wafer growths and multiple devices from each of those growths indicates that we've achieved a successful method of crystal growth and fabrication reproducibility. All of that together is quite the accomplishment!"

Now that the team has successfully overcome the hurdles for growing and characterizing these 2D electron gases in indium antimonide, they are excited to use this platform as a starting point for future work.

"We're hoping that our research is setting the stage for a really unique new platform on which to build more interesting quantum devices and probe whether we can detect Majorana fermions," said Baugh. "We're at the dawn of working with this new material to see where we can take it."

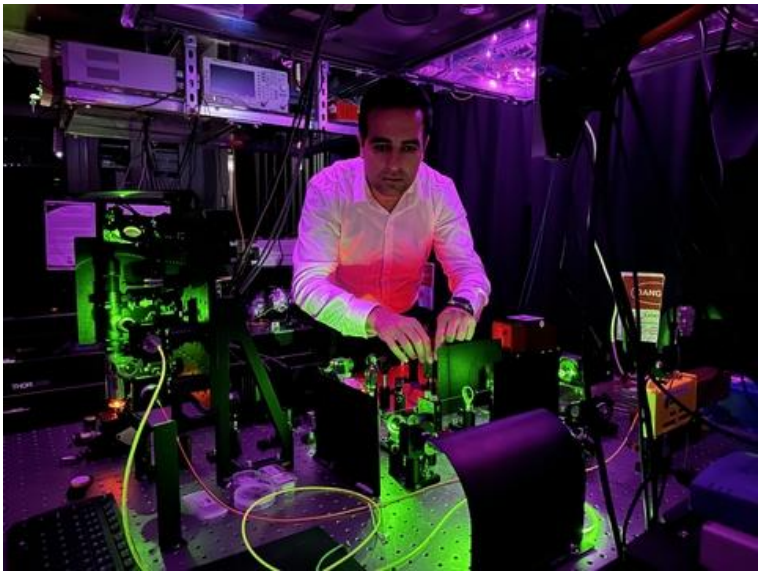
This research was supported in part by the Canada First Research Excellence Fund through the TQT program at IQC.

Researchers propose technique to detect microwave photons using point defects in diamond

Based on research published in the journal Materials on April 21st, 2023
Detecting Single Microwave Photons with NV Centers in Diamond

Many experiments in quantum information processing rely on our ability to transmit, manipulate, or detect photons. In these applications, the wavelength of photons being detected can range from the infrared and visible light used in optical communication systems, to the microwave photons that superconducting quantum devices respond to. While a wide range of detectors are available for optical photons, detecting microwave photons is significantly more challenging due to the much lower energies of individual photons compared to the level of noise, including background light, in the world around us.

The development of efficient microwave photon detectors will be useful for a wide variety of applications, including superconducting quantum devices, quantum computing, quantum sensing, and particle physics. Working toward the realization of these applications, researchers at IQC are investigating a new technique for detecting single microwave photons using diamonds.



Abdolreza Pasharavesh with the experimental setup the group is now developing to test their theories.

Olivia Woodman and Abdolreza Pasharavesh, graduate students at IQC, together with Dr. Michal Bajcsy and Dr. Christopher Wilson, faculty members at IQC and Waterloo's Department of Electrical and Computer Engineering, have developed a promising model to detect these photons by making use of the light-sensitive properties of a point defect found in the lattice structure of diamond. In its perfect form, diamond consists of only carbon atoms, however a defect called a nitrogen-vacancy (NV) center can occur if a nitrogen atom takes the place of a carbon atom within the diamond

crystal's structure while the neighboring site is left empty. NV centers, which can make a diamond appear pink in colour, are known for their unique interactions with both microwave photons and optical photons, making them attractive for various applications in quantum technology such as communications, sensing, and fundamental research.

For their proposal, the researchers envision a device in which microwave photons interacting with the defects in diamond change the properties of an optical resonator (cavity). "First we need to confine the photons in electromagnetic cavities," says Pasharavesh. "Because the level of light given off by a single photon is so low, we use the cavities as a mechanism to enhance the interaction between the photons and our quantum emitter." The NV center is coupled to an optical cavity and a coplanar waveguide (CPW), a structure that consists of a conductive material, like a strip of metal, on a ground plane that acts as a barrier on the sides and underneath. CPWs efficiently guide and transmit microwave signals along a specific path without them spreading out and dissipating.

In the group's detector designs, the diamond sits at the intersection of the CPW, which brings the microwave photons into the device, and the optical cavity which is probed by laser and monitored by an optical single photon detector. In their simulations, microwave photons hit the diamond's NV centers, interact with it, and change its electronic spin. Changes to the NV center's spin also change the optical cavity's resonance frequency, which provides the researchers with a way to measure the presence of microwave photons on the CPW by using visible photons.

Based on their simulations using the master equations for the NV center and fields in the cavities, the group determined that their design could achieve a microwave photon detection efficiency of about 90 percent, and a fidelity, or percentage of correctly recorded detections, of over 90 percent. The dynamics of the system were investigated using Monte Carlo techniques, which averages many simulated trajectories of a complex system to predict its real-world behaviour.

The relative simplicity, practicality, and effectiveness of this new design is promising for the development of microwave photon detection technology. Additionally, proposing the use of a solid material like diamond could mean that these detector designs would be more easily integrated into solid-state electronic systems, which have a higher scalability compared to other quantum information platforms.

This research is part of an ongoing collaboration that aims to convert microwave photons into optical photons, and is supported by the Transformative Quantum Technologies program. "Inside a quantum computer, working with superconducting circuits and microwave photons is great, but when you want to send that information to a second computer, you need to convert it to optical photons because they have lower loss when transmitted in fiberoptic cables," says Pasharavesh. "Moving forward, we will be concentrating on coherent interactions in order to convert microwave qubits into optical qubits."

The group is now preparing for the next step of their research by turning their theoretical system into experimental reality to test their new theories.

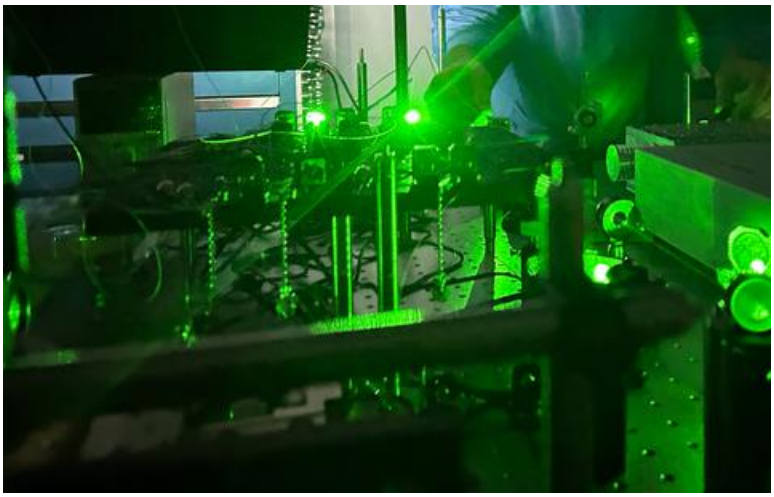
Waterloo researchers make a significant step towards reliably processing quantum information

Based on research published in the journal Quantum Science and Technology on July 27th, 2023
A guided light system for agile individual addressing of Ba+ qubits with 10^{-4} level intensity crosstalk

New optical system designed to target and control individual atoms

Using laser light, researchers have developed the most robust method currently known to control individual qubits made of the chemical element barium. The ability to reliably control a qubit is an important achievement for realizing future functional quantum computers.

This new method, developed at IQC, uses a small glass waveguide to separate laser beams and focus them four microns apart, about four-hundredths of the width of a single human hair. The precision and extent to which each focused laser beam on its target qubit can be controlled in parallel is unmatched by previous research.



Green laser light is the correct energy to manipulate the energy states of barium ions.

"Our design limits the amount of crosstalk–the amount of light falling on neighbouring ions–to the very small relative intensity of 0.01 per cent, which is among the best in the quantum community," said Dr. K. Rajibul Islam, a professor at IQC and Waterloo's Department of Physics and Astronomy. "Unlike previous methods to create agile controls over individual ions, the fibre-based modulators do not affect each other.

"This means we can talk to any ion without affecting its neighbours while also retaining the capability to control each individual ion to the maximum possible extent. This is the

most flexible ion qubit control system with this high precision that we know of anywhere, in both academia and industry."

The researchers targeted barium ions, which are becoming increasingly popular in the field of trapped ion quantum computation. Barium ions have convenient energy states that can be used as the zero and one levels of a qubit and be manipulated with visible green light, unlike the higher energy ultraviolet light needed for other atom types for the same manipulation. This allows the researchers to use commercially available optical technologies that are not available for ultraviolet wavelengths.

The researchers created a waveguide chip that divides a single laser beam into 16 different channels of light. Each channel is then directed into individual optical fibre-based modulators which independently provide agile control over each laser beam's intensity, frequency, and phase. The laser beams are then focused down to their small spacing using a series of optical lenses similar to a telescope. The researchers confirmed each laser beam's focus and control by measuring them with precise camera sensors.

"This work is part of our effort at the University of Waterloo to build barium ion quantum processors using atomic systems," said Dr. Crystal Senko, Islam's co-principal investigator and a faculty member at IQC and Waterloo's Department of Physics and Astronomy. "We use ions because they are identical, nature-made qubits, so we don't need to fabricate them. Our task is to find ways to control them."

The new waveguide method demonstrates a simple and precise method of control, showing promise for manipulating ions to encode and process quantum data and for implementation in quantum simulation and computing.

Older techniques inspire new discoveries for ultracold molecules

Based on research published in the journal Nature Physics on July 31, 2023
Magnetic trapping of ultracold molecules at high density

Sometimes, new scientific discoveries can be made from looking at well-known methods or experimental techniques in new ways. This is the basis for new research from Dr. Alan Jamison, a faculty member at IQC and Waterloo's Department of Physics and Astronomy, and his collaborators at the Massachusetts Institute of Technology (MIT).

Jamison researches ultra-cold molecules, which are made by cooling down atoms to nearly absolute zero in an atom trap. Once formed, these molecules can then be studied for applications including quantum-state-controlled chemistry, quantum simulations, and quantum information processing. One of the first great successes of cooling atoms to ultracold temperatures was the observation of the Bose-Einstein condensate. This was first achieved experimentally using magnetic atom traps in the mid 1990s by researchers including Jamison's collaborator, Dr. Wolfgang Ketterle, for which Ketterle was awarded the 2001 Nobel Prize in Physics.

Since this time, however, while magnetic traps are sometimes used during the process of cooling atoms, it has become more common for researchers to use optical lasers to trap atoms during experiments. The optical traps are faster and can trap a wider range of atoms and molecules than just those with the specific magnetic properties needed to use the magnetic traps.

“When people started making ultracold molecules, they had to be in an optical trap to hold the right atomic states to make the molecules, and so you just naturally did the experiments with the molecules also in an optical trap,” said Jamison. “But it turns out that some ultracold molecules which were expected to be chemically stable seem to be undergoing chemical reactions caused by the light from the optical traps.”

Jamison and his collaborators reasoned that if they could remove the requirement of light from their experiments by using magnetic traps, they could then study these light-induced chemical reactions in controlled environments and explore new and exciting results.

“We study one of the few ultracold molecules that can be magnetically trapped, which gave us the freedom to study these older techniques in new ways,” said Jamison. “It’s exciting looking at these reactions without having to worry about what the light is doing. On one hand, it constrains us to only work with states that are magnetically trappable, but on the other hand it removes the constraint that we always need to have light on in the background.”

To combine the best properties of magnetic and optical traps, their experiment used both trapping techniques in a new combined experimental design that removed the need for atoms to be moved between the different trap types. Atoms of sodium and lithium were cooled down to ultracold temperatures using a combination of magnetic and optical cooling techniques. To form the ultracold NaLi molecules, optical trapping was necessary, however, upon formation, the molecules can be trapped again by magnetism, so the laser light was removed.

The researchers used their newly developed trapping design to measure inelastic collisions of the molecules as a proof of concept. Their success is now inspiring studies focused on a variety of different effects, such as studying how molecules respond to the introduction of light, studying the previously problematic light-induced chemical reactions in controlled ways, or seeing if the lifetime of these ultracold molecules can be prolonged with the different trapping method.

“By looking at what's considered an older way of doing things, we're finding that we have new possibilities for the future and how we work with our molecules,” said Jamison. “It’s important to always be looking forward, but also not lose sight of what's been done in the past. People had different interests and different focus in the past, so a lot of times, they thought through things in a way you didn't, or they've done something that you forgot could be done.”

Quantum Q&A with Melissa Henderson

Based on research published in the journal Nature Physics on August 14, 2023
Three-dimensional neutron far-field tomography of a bulk skyrmion lattice

Dr. Melissa Henderson is a researcher at IQC and Waterloo's Department of Physics and Astronomy. Her research considers the scattering of neutral particles known as neutrons, and their relation to quantum materials.

Henderson's research, alongside her PhD supervisor Dr. Dmitry Pushin – a professor at IQC and the Department of Physics and Astronomy – was recently published in Nature Physics in the paper Three-dimensional neutron far-field tomography of a bulk skyrmion lattice. We reached out to her to learn about these latest findings.

Can you explain the topic you researched in this paper?

I study nanoscale magnetic structures known as skyrmions, which are present in some magnetic crystals. They are formed by the collective alignment of magnetic properties from individual atoms which twist into tornado-like vortexes significantly larger than atomic scales.

Magnetic skyrmions are primarily concerned with a concept known as topology. A simple way to visualize topology is to consider the deformations of a continuous object, such as a balloon. A balloon without any holes is said to have a topology of zero. We can stretch or compress it, but still maintain its spherical, continuous structure and therefore its topology. If we wished to alter the topology of the balloon, we could introduce a discontinuity, such as a hole. In doing this we provide energy to the system to pop the balloon.

Instead of holes in balloons, topology in skyrmions is a measure of how their magnetic properties, also known as electron spin, twist and wind in their orientations. This representation of topology can be visualized by imagining the electron spins in a cross-section of the skyrmion wrapping around a sphere. Typically, these spins cover the sphere once, pointing straight out from the centre, which corresponds to a topology of one. However, skyrmions can also have higher integer topologies where they wrap around this sphere multiple times.

What is something that excites you about your work?

I work at the cutting edge of both neutron and quantum materials physics, unifying the two fields to push the boundaries of what we know and what we can measure. It's exciting to develop new investigative/characterization tools which could provide unprecedented access to magnetic phenomena and uncover novel physics. I also like that we can develop our own instrumentation and new probes that push the frontiers of the fields – that's where the new science happens.

It is also exciting that our measurement/characterization techniques and results may transcend those of just neutron techniques and skyrmion systems, enabling the

examination of a broader set of topological phases and excitations across a diverse range of quantum materials, spanning a variety of length, scales, dimensions, and interactions.

Can you explain your new research findings?

Prior to our work, existing skyrmion probing methods primarily utilized electrons and x-rays, both of which have limited penetration depths in the materials they are measuring. Therefore, these measurement tools require thinned and geometrically confined systems which completely change the shapes, sizes, and transition pathways of skyrmions.

Our latest finding uses so a probing technique called Small Angle Neutron Scattering to circumvent this fundamental restriction of electron and x-ray techniques as neutrons are one of the few particles that can pass through a larger crystal, known as a bulk sample. One drawback, however, is that neutrons provide a 2D average of the magnetic moments that they interacted with in the sample. To counteract this and retain the depth information, we rotated the sample and measured it from a variety of different angles, in much the same way as a CT scan uses 2D x-rays to develop a 3D image. This allowed us to visualize the 3D nature and internal structures of skyrmions in large crystal samples, known as bulk samples, for the very first time.

This result is the first demonstration of how these skyrmion tubes form and interact in bulk systems through topological defects, providing novel insight into their stabilization mechanisms and nucleation and annihilation pathways.

What are the real-world implications of these findings?

An emerging field known as spintronics uses electron spin instead of current to hold digital information. Our findings may reimagine current skyrmion-based spintronic frameworks, motivating new designs which exploit the 3D nature of skyrmions, which offer new symmetries, degrees of freedom, and dynamical behaviors compared to those of thin and confined systems.

These results open the door to a new era in the characterization of bulk quantum materials and the three-dimensional engineering of skyrmion spintronic devices. Moreover, these results offer fundamental insights into topological defect and phase behaviors, which may be applied to understand a variety of physical systems spanning superconductors to liquid crystals.

Launching the future of secure communication

Based on research published in the University of Waterloo's 2024 Global Futures report, January 22, 2024
Launching the future of secure communication

Researchers at IQC are leading Canada's first quantum satellite to protect tomorrow's data

In our increasingly digital and interconnected world, graduate students like Kimia Mohammadi constantly innovate to stay ahead of emerging security risks. She is part of a national team creating Canada's first quantum satellite, currently scheduled for launch in 2025. The Quantum EncrYption and Science Satellite (QEYSSat) mission will be a demonstration of secure ground-to-space quantum communication.

"QEYSSat is a huge milestone for Canadian technology," says Mohammadi, a PhD student in Waterloo's Department of Physics and Astronomy, and IQC. "It's so satisfying to see my research play a role in the future of communication."

Leading QEYSSat's national science team is Mohammadi's graduate supervisor, Dr. Thomas Jennewein, a professor in Waterloo's Department of Physics and Astronomy and a faculty member at IQC. Jennewein's research aims to create a global quantum internet, developing the technologies to realize secure satellite-based quantum communications. His research also sheds light on fundamental questions in quantum physics as he explores quantum entanglement over large distances and speeds.

The key to quantum encryption

Jennewein, Mohammadi and the QEYSSat team use a technique called "quantum key distribution" to generate encrypted keys sent between the satellite and researchers on Earth. These cryptographic keys take advantage of a quantum mechanics property, asserting that a quantum state cannot be observed without changing it. Therefore, if the secret quantum key is observed or copied, a detectible trace is left, so the researchers know that the key has been compromised and is no longer secure.

"Quantum signals are secure because they cannot be copied. However, this also makes it difficult to transmit through fibreoptic cables over large distances, unlike classical signals which rely on signal repetition and amplification," Jennewein says. "So, to successfully transmit a QKD signal over large distances, we need methods such as satellites that don't rely on signal repetition."

With the science headquartered at IQC, Canada's anchor-point of the quantum ecosystem, QEYSSat will communicate with research ground stations at both the University of Waterloo and the Canadian Space Agency headquarters in Saint-Hubert, Quebec. These ground stations will generate quantum signals using photons of light and send them up to the satellite. Such quantum satellites could then be used as a trusted relay to send these signals between the ground stations.

One distinct advantage of this configuration is that since the photons are being sent from Earth to the satellite, the research teams will have the advantage of flexibility, being able to change the source of the photons or update the device as new technologies are developed.

Mohammadi is currently working to ensure that the Waterloo ground station can find and communicate with the satellite using their telescope transceiver, which she built during her previous master's degree, located on the roof of the Research Advancement Complex at the north end of Waterloo's Research and Technology Park.

"Most people wouldn't like to go to the telescope at 2 a.m. to do optical alignments via stars or track objects such as the International Space Station, but for me, it's fascinating to take each small step toward having a fully functional ground station once the satellite is launched," she says. "Thomas gave me the opportunity to design and build our own telescope, which will be used in our future free-space communication experiments."

Canadian satellites for quantum security

Launching a satellite like QEYSSat is an interdisciplinary undertaking. Experts in physics develop the scientific basis for the quantum communication efforts; engineering experts build the satellite components and ensure they will survive the launch and harsh conditions of outer space; and industry partners, including the Canadian Space Agency and Honeywell, are guiding the satellite launch and manufacturing.

Looking forward, Mohammadi and Jennewein have also explored realistic future satellite scenarios and identified current technological bottlenecks in the project QEYSSat 2.0 to demonstrate the technologies necessary for developing a quantum internet across Canada.

While the QEYSSat mission will be a demonstration of quantum key distribution and secure communication to a satellite, it is paving the way for Canada to be a leader in secure communication in the quantum age. As an entirely Canadian-owned project, it is focused on creating a future prioritizing national security and sovereignty.

"Governments around the world, including Canada, have recently announced national quantum strategies," Jennewein says. "Once quantum computers come online, our current encryption methods become potentially vulnerable, and world leaders are recognizing the importance of becoming quantum literate and quantum ready."

New technique to identify and control large numbers of atomic-scale defects aims to improve sensitivity of quantum sensing devices

Based on research published in PRX Quantum on February 7, 2024
Control of an Environmental Spin Defect beyond the Coherence Limit of a Central Spin

Researchers at IQC, MIT, and the University of Illinois at Urbana-Champaign have developed a technique that enables them to identify and control a greater number of microscopic defects in diamond. Outlined in a paper published by PRX Quantum this week, this new technique could help researchers build a larger system of qubits that can perform quantum sensing with greater sensitivity.

"I am thrilled to announce the latest milestone in our journey to advance quantum sensing with spin defects in diamond. Our research showcases groundbreaking insights into the characterization and control of a spin defect beyond the coherence limit of a central spin," said Alexandre Cooper-Roy, an IQC research associate and senior technical lead for Quantum Simulation and Transformative Quantum Technologies. "By pushing the boundaries of quantum sensing, our paper offers a pathway towards scaling up spin systems in solids and using the spin bath as a resource for quantum-enhanced sensing. This breakthrough holds immense potential for revolutionizing various industries and scientific fields."

This research was done in collaboration with researchers at MIT, and also covered in an MIT News story.

The world is one step closer to secure quantum communication on a global scale

Based on research published in the journal Communication Physics on February 24, 2024
Oscillating photonic Bell state from a semiconductor quantum dot for quantum key distribution

University of Waterloo researchers combine Nobel prize winning concepts to achieve scientific breakthrough

Researchers at IQC have brought together two Nobel prize winning research concepts to advance the field of quantum communication.

Scientists can now efficiently produce nearly perfect entangled photon pairs from quantum dot sources.

Entangled photons are particles of light that remain connected, even across large distances, and experiments on this topic were recognized by the 2022 Nobel Prize in Physics. Combining entanglement with quantum dots, a technology recognized with the Nobel Prize in Chemistry in 2023, the IQC research team aimed to optimize the process

for creating entangled photons, which have a wide variety of applications, including secure communications.

“The combination of a high degree of entanglement and high efficiency is needed for exciting applications such as quantum key distribution or quantum repeaters, which are envisioned to extend the distance of secure quantum communication to a global scale, or link remote quantum computers,” said Dr. Michael Reimer, professor at IQC and Waterloo’s Department of Electrical and Computer Engineering. “Previous experiments only measured either near-perfect entanglement or high efficiency, but we’re the first to achieve both requirements with a quantum dot.”

By embedding semiconductor quantum dots into a nanowire, the researchers created a source that creates near-perfect entangled photons 65 times more efficiently than previous work. This new source, developed in collaboration with the National Research Council of Canada in Ottawa, can be excited with lasers to generate entangled pairs on command. The researchers then used high resolution single photon detectors provided by Single Quantum in The Netherlands to boost the degree of entanglement.

“Historically, quantum dot systems were plagued with a problem called fine structure splitting, which causes an entangled state to oscillate over time. This meant that measurements taken with a slow detection system would prevent the entanglement from being measured,” said Matteo Pennacchietti, a PhD student at IQC and Waterloo’s Department of Electrical and Computer Engineering. “We overcame this by combining our quantum dots with a very fast and precise detection system. We can basically take a time stamp of what the entangled state looks like at each point during the oscillations, and that's where we have the perfect entanglement.”

To showcase future communications applications, Reimer and Pennacchietti worked with Dr. Norbert Lütkenhaus and Dr. Thomas Jennewein, both IQC faculty members and professors in Waterloo’s Department of Physics and Astronomy, and their teams. Using their new quantum dot entanglement source, the researchers simulated a secure communications method known as quantum key distribution, proving that the quantum dot source holds significant promise in the future of secure quantum communications.

Understanding the realistic limits of security for quantum key distribution

Based on research published in the journal PRX Quantum on October 10, 2023
Finite-size security for discrete-modulated continuous-variable quantum key distribution protocols

A commonly researched method of quantum cryptography is quantum key distribution (QKD). In this method, quantum states are used to generate secret keys which can then be used for secure communication between two users. Due to the fundamental principles of quantum mechanics, the QKD protocols produce keys that can be

guaranteed as secure from eavesdroppers, thus also ensuring the security of the subsequent communication using the secret keys.

QKD protocols use photon detectors which can be either single photon detectors that yield simple click/no-click outcomes (discrete variables) or measure continuous quantities of the quantum signals. The sub-field of QKD that uses pulses of weak laser light combined with continuous measurement, known as continuous variable QKD (CV-QKD), is an area currently being studied by Dr. Norbert Lütkenhaus, Executive Director of IQC and a professor in Waterloo's Department of Physics and Astronomy, and members of his research group.

"CV-QKD is worth pursuing because it offers the prospect of the cheaper option, as it doesn't require satellites or bulky single photon detectors that require cooling. Additionally, there are performance advantages particularly in the low to medium range," says Florian Kanitschar, who recently completed his master's degree at IQC under the supervision of Lütkenhaus. "The goal of my work was to find a security proof in the finite size regime, building on previous research from the group."

In CV-QKD, a continuous and infinite range of possible quantum states are available theoretically. However, to be used practically, the quantum states that are used to carry information represent only a small section of the available states. One process, known as discrete-modulated CV-QKD, limits the number of possible states which are used to generate the quantum key to a countable number. The security of this scheme has been proven, but only in the impractical scenario where the sender and receiver can repeat the protocol an infinite number of times, the so-called asymptotic regime.

In a recent project from Lütkenhaus' group, the researchers studied discrete-modulated CV-QKD in the so-called finite-size regime, when the sender and receiver exchange a finite number of quantum signals, and showed how to calculate a lower bound, or minimum, for the secret key rate. While each specific key rate is dependent on the experimental setup and individual case, the key rate can be considered both secure and useful in realistic scenarios if the rate calculated is higher than zero.

Finding secure key rates in this so-called finite-size regime is important for practical applications of QKD. In addition to the infinite or finite-size regimes which describes the number of quantum signals exchanged, there is another variable of infinity which must also be considered, the dimension of the quantum state. While CV-QKD protocols require infinite-dimensional spaces to describe mathematically, in practice, the computers used to calculate secure key rates are limited to finite, low-dimensional spaces.

"The security promise of QKD, in particular, compared to classical cryptography is very strong, so when proving security, we have to be very careful. We cannot just say 'cut it off somewhere and that's good enough', so we need to find a way to bound the 'effective' dimension of the problem," says Kanitschar. "The idea we followed was to develop and use an energy test, which is kind of a statistical procedure that ensures that the space we're considering contains almost all information of the quantum states considered. The

remaining information can be accounted for using a dimension-reduction method technique previously developed by the Lütkenhaus group."

This is the first energy test proposed for discrete-modulated CV-QKD and allowed the problem to be reduced from an infinite-dimensional problem to a finite-dimensional one, solving one of the crucial steps for proving security in the finite-size regime and finally enabled us to prove security.

"We're now working with experimental groups in both Germany and Denmark to take our theoretical security proofs and use them in practical experimental setups," says Lütkenhaus. "Our work helps to explore how far we can push the CV-QKD approach. It will be interesting to see whether the promise of simpler QKD schemes that use more standard optical telecommunication equipment can be demonstrated in practical implementations, thus helping to have QKD more widely deployed."

Research Forecasts: Building the future of Quantum Technology

It is worth celebrating the recent research achievements and breakthroughs at IQC but it's equally important to demonstrate how the future of Canadian Quantum Science runs through Waterloo and IQC. In 2023-2024, IQC researchers drove research agendas that are nationally and internationally recognized as being academically, socially and economically critical to Canada.

In March 2024, four University of Waterloo researchers, including Dr. Michael Reimer, a faculty member at IQC were awarded funding from the Ontario government for innovative research with implications ranging from cleaning up arsenic-laden mine to using artificial intelligence to protect valuable financial data.

The funding is provided through the Ontario Research Fund, which focuses on advancing the development of innovative new products and technologies. The money will broadly support the Waterloo researchers to attract top talent, cover the cost of operations, and help build, renovate, or equip research facilities with the latest technologies.

Reimer was awarded $1.7 million for work developing a special camera that will help take more efficient images of the human eye.

"This grant allows us to build efficient single photon detectors and cameras that are portable, which will be able to detect single photons over an unprecedented wavelength range, including the wavelength range of interest for eye imaging where other detector technology has limited efficiency," says Reimer. "This new technology could aid ophthalmologists in seeing key things in eye tissue and may help them detect diseases earlier."

The National Killam Program administered by the National Research Council of Canada (NRC) announced Dr. Adam Wei Tsen as the recipient of the 2024 Dorothy Killam Fellowship. This prestigious honour provides $80,000 for up to two years in support for dedicated research time to scholars "whose superior, ground-breaking, best-in-class research stands to have significant impact on a national or global scale."

Tsen, a professor at IQC focuses on the study of various two-dimensional (2D) quantum materials and making new magnetically active molecules for quantum material applications, including quantum computing and quantum information.

As one of the emerging leaders in the study of 2D materials, Tsen's ambitious goal is to electrically generate, detect, and control coherent magnons, where the magnon condensates in a 2D magnet for the first time. This is an important step towards the development and integration of 2D quantum magnonics for on-chip hybrid quantum systems.

In his research, 2D magnets are used as a powerful platform in the development of quantum magnonics. Currently, this research is hampered by the lack of available magnetic materials. The recently discovered class of 2D magnets provides tremendous new opportunities.

Dr. Jonathan Baugh, a faculty member at IQC, has been awarded $1,481,200 to lead the project *Next-generation photonic source to enable quantum remote sensing and communications*. This project will use cutting-edge semiconductor device engineering to develop novel, on-demand sources of single photons that have unique capabilities, such as tunability between one- and two-photon emission and can be scaled to on-chip arrays.

"We are thrilled to work with our partners in government, industry and academia to develop next-generation, solid-state photonic sources with applications in quantum metrology and sensing," says Baugh.

Dr. Adrian Lupascu, a faculty member at IQC, has been awarded $1,137,724 for the project *Development of a scalable superconducting quantum computing platform based on fluxonium qubits*. The project aims to establish key hardware research programs for quantum computing systems. It will focus on identifying improvements in device design and materials quality that support increasingly coherent superconducting quantum processors.

"The collaboration with D-Wave Quantum will provide a unique opportunity to explore fundamental aspects of the physics of a new generation of superconducting qubits, which have the potential to enable new quantum computing architectures," says Lupascu.

Dr. David Cory, a faculty member at IQC, has been awarded $2,980,789 for the project *Quantum Enhanced Navigation, QuNav*. This project aims to develop and deploy advanced navigational tools for GPS denied environments. It uses quantum engineering to achieve greater precision and reliability leading to compact tools for dead reckoning. The project is dual use with potential applications to aircraft and submarine navigation and may even advance robotic surgery and logistics.

Dr. Chris Wilson's project, *Microwave Quantum Radar*, has received $3,000,000. Alongside Qubic Inc., Zero Point Cryogenics Inc., and Carleton University, the team is focused on advancing quantum sensing.

"The IDEaS program is a very unique opportunity to bring together academia and industry into joint projects where we can work collaboratively for an important goal," said Wilson, also a professor in Waterloo's Department of Electrical and Computer Engineering. "We are very excited to be part of this opportunity and also very excited about the team we will be working with to develop real world applications of quantum sensing."

Several IQC faculty members have received funding this year from the NSERC Discovery Grants Program and the Research Tools and Instruments grants program. The discovery grants allow our researchers to focus on long-term research goals, as well as train graduate students and support postdoctoral fellows. The following list includes faculty members and a brief description of their projects:

Dr. Raffi Budakian: Atomic-scale nanoMRI studies of the structure and dynamics of solid-state spin systems;

Dr. Thomas Jennewein: Quantum Optical Ground-Station for QEYSSAT;

Dr. Norbert Lütkenhaus: Robust Quantum Key Distribution;

Dr. Ashwin Nayak: Efficient Quantum Algorithms and Protocols;

Dr. Kevin Resch: Experimental optical quantum technologies for ultrafast entanglement, photonic simulation, and quantum causality.

In 2022, the Natural Sciences and Engineering Research Council of Canada (NSERC) put out a call for proposals that would strengthen Canada's quantum research and innovation capacity in alignment with the National Quantum Strategy. This new funding opportunity, the NSERC Alliance Quantum Grant, was established to pair academic researchers with partner organizations in the public, private or not-for-profit sectors.

Dr. Na Young Kim, IQC faculty member and professor in Waterloo's Department of Electrical and Computer Engineering, is leading a project which has been awarded over $1 million in the Alliance Quantum Grants program.

These examples funding for the ongoing work at IQC are not exhaustive and many of the highlighted faculty members received multiple funding awards throughout the year. The funds are sourced from various levels of government and represent various agencies within government as well as collaboration with a number of private sector partners across Canada. It is worth emphasizing that various federal agencies, provincial governments, private sector partners and universities across Canada have evaluated the Canadian Quantum landscape and determined the most appropriate place to invest for the future of Canadian Quantum is at IQC. In addition to the leading research happening at IQC many of the awards are a recognition of the fact that only IQC, amongst all Canadian institutions, can produce the increasing number of academics and professionals that will be required to capitalize on the groundbreaking discoveries taking place in Waterloo.

Recruitment – Faculty

Alongside research and training, each year IQC prioritizes recruitment activities to continue to attract world-class theoretical and experimental researchers across a range of disciplines. With a talented cohort of 30 faculty members collaborating on some of the most complex problems in the history of science, IQC is dedicated to maintaining its strong research team.

IQC is actively engaging in faculty recruitment and is selective in bringing the best and the brightest through faculty and research associate hiring. Recruited in 2023, IQC hired Dr. Bradley Hauer, who arrived at IQC in April 2024 and is a faculty member in Waterloo's department of Electrical and Computer Engineering. Hauer's research areas include cavity optomechanical systems and superconducting circuits. He comes to IQC from the Advanced Microwave Photonics group at NIST Boulder, Colorado, USA.

Recruitment – Associate members

In addition to dedicated faculty members IQC encourages cross-pollination of quantum focused research across our partner departments through funding the time-limited recruitment of a wide variety of experts enabling them to focus on their research programs where they intersect with quantum research.

Beginning in May 2024, Dr. Sam Jaques, an associate professor in the department of Combinatorics and Optimization at the University of Waterloo, will be an associate member at IQC for a five-year term. Jaques' research interests center on cryptography and its implications for privacy and anonymity. Cryptographic implications surrounding quantum computing highlight the time-sensitive need for Dr. Jaques' work investigating how large-scale quantum computers might endanger current cryptographic methods. This career step is a homecoming for Dr. Jaques as he was a member at IQC for his MMath, which was supervised by Alfred Menezes and Michele Mosca prior to his doctorate at Oxford.

Recruitment – Institutions recruit faculty from IQC trainees

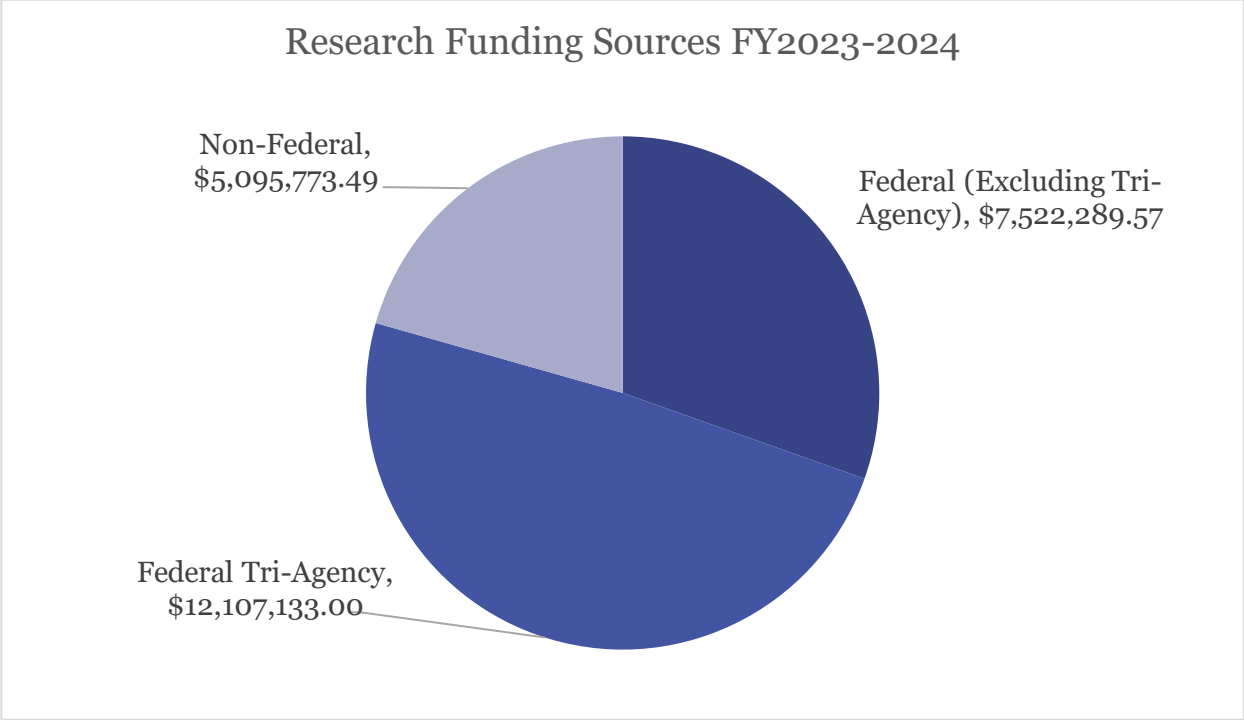
The Canadian and Global demand for highly qualified personnel is significant – McKinsey estimates that approximately 50% of jobs remained unfilled in 2023. IQC is one of the few institutes that produces highly qualified personnel at a sizable scale. Our alum members are in high demand. In the last year IQC has celebrated the success of a number of former IQC members.

Former Research Associate Dusan Sarenac is now an Assistant Professor at the University of Buffalo. Dr. Sarenac still has strong ties to IQC, publishing with recently with David Cory and Dmitry Pushin as well as building a startup with Dmitry Pushin and Connor Kaphahi. Dr. Erika Janitz, a former student at IQC was successfully recruited by the University of Calgary (Department of Electrical and Software Engineering). Dr. Matt Amy, an assistant professor of Computer Science at Simon Fraser University and a Canada Research Chair holder in Quantum Computing, joined the Quantum Algorithms Institute as an Affiliate Fellow. Dr. Amy achieved both his advanced degrees as a member at IQC.

These are not the only recent success stories, but they illustrate how IQC shapes the local and Canadian Quantum future not only in Waterloo but across the country. IQC continues to train and mentor the next generation of quantum researchers nationally and internationally.

Awards & Research Chairs

IQC researchers have collectively been awarded $24,725,196 in research funding during the period of April 1, 2023 to March 31, 2024. Funding sources are diverse and include research chair awards, funding from the Government of Canada, the Canada Foundation for Innovation (CFI), industry partners and others. It is worth noting that private sector funding reached almost $620,000 in 2023-2024, nearly double the private sector investment from 2022-2023.



The research by IQC faculty members has a significant global impact, indicated by numerous prestigious awards and acknowledgements. These accolades reinforce IQC and Canada's exceptional standing in quantum information science. Here are some notable awards received by faculty members in 2023-2024:

Faculty Member	Award Sponsor
Adam Wei Tsen	CFREF (Canada First Research Excellence Fund)
	NSERC (Natural Sciences and Engineering Research Council of Canada)
	University of Ottawa
	US Army Research Office
Adrian Lupascu	CFREF (Canada First Research Excellence Fund)
	DRDC (Defence Research and Development Canada)
	Fermilab (Fermi National Accelerator Laboratory)
	NRCan (Natural Resources Canada)
	NSERC (Natural Sciences and Engineering Research Council of Canada)
Alan Jamison	NSERC (Natural Sciences and Engineering Research Council of Canada)
Ashwin Nayak	MITACS (Mathematics of Information Technology and Complex Systems)
	NSERC (Natural Sciences and Engineering Research Council of Canada)
	University of Ottawa (NSERC Alliance Quantum Consortia)
Bradley Hauer	NSERC (Natural Sciences and Engineering Research Council of Canada)
Christine Muschik	CIFAR (Canadian Institute for Advanced Research)
	Ministry of Colleges & Universities (MCU)

	NSERC (Natural Sciences and Engineering Research Council of Canada)
	UW (University of Waterloo)
Christopher Wilson	CFI (Canada Foundation for Innovation)
	DND (Department of National Defence)
	DRDC (Defence Research and Development Canada)
	Laurentian University
	MITACS (Mathematics of Information Technology and Complex Systems)
	NSERC (Natural Sciences and Engineering Research Council of Canada)
Crystal Senko	CFI (Canada Foundation for Innovation)
	CRC (Canada Research Chair)
	Ministry of Colleges & Universities (MCU)
	NSERC (Natural Sciences and Engineering Research Council of Canada)
	Various Sponsors (CFI In-kind)
David Cory	CFREF (Canada First Research Excellence Fund)
	DND (Department of National Defence)
David Gosset	CIFAR (Canadian Institute for Advanced Research)
	IBM US
	NSERC (Natural Sciences and Engineering Research Council of Canada)
Debbie Leung	University of Ottawa (NSERC Alliance Quantum Consortia)
Dmitry Pushin	Indiana University
	NSERC (Natural Sciences and Engineering Research Council of Canada)
Guo-Xing Miao	CFREF (Canada First Research Excellence Fund)
	NSERC (Natural Sciences and Engineering Research Council of Canada)
Jon Yard	NSERC (Natural Sciences and Engineering Research Council of Canada)
Jonathan Baugh	MITACS (Mathematics of Information Technology and Complex Systems)
	NSERC (Natural Sciences and Engineering Research Council of Canada)
	University of British Columbia (NSERC Alliance Quantum Consortia)
Kazi Rajibul Islam	Ministry of Colleges & Universities (MCU)
	NSERC (Natural Sciences and Engineering Research Council of Canada)
Kevin Resch	NRC (National Research Council)
	NSERC (Natural Sciences and Engineering Research Council of Canada)
Matteo Mariantoni	CFREF (Canada First Research Excellence Fund)
	NSERC (Natural Sciences and Engineering Research Council of Canada)
Michael Reimer	CFREF (Canada First Research Excellence Fund)
	Ministry of Colleges & Universities (MCU)
	MITACS (Mathematics of Information Technology and Complex Systems)
	NSERC (Natural Sciences and Engineering Research Council of Canada)
Michal Bajcsy	NSERC (Natural Sciences and Engineering Research Council of Canada)
Michele Mosca	Massachusetts Institute of Technology
	NRC (National Research Council)

	NSERC (Natural Sciences and Engineering Research Council of Canada)
Na Young Kim	CFREF (Canada First Research Excellence Fund)
	NSERC (Natural Sciences and Engineering Research Council of Canada)
Norbert Lütkenhaus	DND (Department of National Defence)
	NSERC (Natural Sciences and Engineering Research Council of Canada)
	University of Alberta (NSERC Alliance Quantum Consortia)
Raffi Budakian	NSERC (Natural Sciences and Engineering Research Council of Canada)
Raymond Laflamme	MITACS (Mathematics of Information Technology and Complex Systems)
	NSERC (Natural Sciences and Engineering Research Council of Canada)
Richard Cleve	University of Ottawa (NSERC Alliance Quantum Consortia)
Shalev Ben-David	NSERC (Natural Sciences and Engineering Research Council of Canada)
Thomas Jennewein	Canadian Space Agency
	DND (Department of National Defence)
	INRS University
	NRC (National Research Council)
	NSERC (Natural Sciences and Engineering Research Council of Canada)
	University of Alberta (NSERC Alliance Quantum Consortia)
William Slofstra	NSERC (Natural Sciences and Engineering Research Council of Canada)

IQC is also home to the following Research Chairs:

- Raymond Laflamme, Mike and Ophelia Lazaridis Chair (2017-2027)
- Christine Muschik, University Research Chair (2022-2027)
- William Slofstra, University Research Chair (2022-2027)
- Crystal Senko, Canada Research Chair (2020-2025)
- David Cory, Canada Excellence Research Chair Laureate (2017)
- Raffi Budakian, University of Waterloo Endowed Chair in Nanotechnology (2014-ongoing)
- Pierre-Nicholas Roy, IQC Affiliate, Canada Research Chair (2017-2027)

And the following past Research Chair holders:

- Debbie Leung, University Research Chair (2015-2022)
- Michele Mosca, University Research Chair (2012-2022)
- Raymond Laflamme, Canada Research Chair (2002-2022)
- Kevin Resch, Canada Research Chair (2013-2023)
- Roger Melko, IQC Affiliate, Canada Research Chair (2018-2023)

Infrastructure–Mike & Ophelia Lazaridis Quantum-Nano Centre (QNC)

As of March 2024, there are 16 operational research labs in QNC.

Selected labs are listed below:

- Quantum Photonics Laboratory
- Satellite Quantum Key Distribution Laboratory
- Quantum Verification Laboratory
- Laboratory for Digital Quantum Matter
- Nano-Photonics and Quantum Optics Lab
- Trapped Ion Quantum Control
- Engineered Quantum Systems Laboratory
- Integrated Nano Electronics
- Laboratory of Ultracold Quantum Matter and Light
- Quantum Optics and Quantum Information Group Laboratory
- Quantum Information with Trapped Ions

IQC continues to improve the quality of our existing infrastructure. For example, Chris Wilson's lab added a major piece of shared infrastructure that will help advance the work of several faculty members on quantum sensing. The ultralow temperature cryostat, called a dilution refrigerator, was provided by the Canadian startup, Zero Point Cryogenics, based in Edmonton.

Additionally, David Cory, Jonathan Baugh, and Chris Wilson added a significant amount of qubit control electronics, financing this purchase with several partners including TQT and CFI. It was delivered January 2023, but we are still working to bring it online.

Infrastructure–Quantum-Nano Fabrication and Characterization Facility (QNFCF)

QNFCF is responsible for three labs in the Quantum-Nano Centre's Metrology area: TEM lab, FIB lab and Dry Sample Prep lab. Open to researchers in government, industry and academia, over the past year the QNFCF reported a total of 42,481 hours of independent lab equipment use logged by registered lab users. This is the highest usage rate the lab has reported to date. Academic and industrial demand for lab time continues to draw significant interest from groups across Ontario and Canada.

- With a record 42,481 hours of usage the lab saw a near record in total users with 215 (a slight decrease from 232 in 2022-2023), including 39 industrial users.
- It is noteworthy that the 'Staff Fee for Service time' increased from 150 hours in 2022-2023 to 276 hours in 2023-2024. This increase points to the fact that IQC students develop specialized lab skills that are in high demand across industry.

- There is a growing demand for advanced laboratory facilities in Canada, as 85 research groups used QNFCF facilities (68 academic, 17 industry).
- 24 total institutions (7 academic and 17 industry) use the facilities at QNFCF. This includes users from the University of Toronto, University of Alberta and the University of British Columbia.
- QNFCF staff provided 960 hours of hands-on equipment user training.
- Examples of growing private companies that use the facilities at QNFCF include Opalux Inc. (Mississauga) and Omniply Technologies (Montreal) in addition to Photonic Inc. (founded out of UBC) which consumed more than 4,600 hours of time at QNFCF.

The QNFCF continues to work closely with various research projects at IQC in addition to the growing portfolio of private companies and external university research projects.

In 2023-2024 a working partnership between the Quantum Photonic Device Research group (Reimer) and several QNFCF scientists (Electron Beam Lithography Scientist & Senior Facility Microscopist among others) resulted in a novel technique for manipulation of nanowires (NW) which promises to advance the production of quantum light sources with quantum dot technologies. Indium phosphide NW quantum dots generate on-demand single/entangled photon pairs. Traditionally, half of the photons are emitted while the other half are lost to substrate.

This QNFCF developed method addresses this loss by using the FIB-SEM to move the InP NWs (with embedded InAsP quantum dots) from the substrate on which it is grown to a metallic mirrored substrate. Moving the NWs to a mirrored substrate more than doubles the production of the required photons. There are several challenges that have been overcome in this novel method including the manipulation of NWs that are 6 microns tall and 200 nm in diameter, vibrations due to gas injection system valve movements which affect placement and a lack of depth perception due to electron beam imaging to support manipulation.

Nonetheless, a high-yield process has been developed for the transplantation of NWs, producing an exciting new technique to develop high photon emission quantum light sources with applications in quantum computing, quantum cryptography and quantum optics.

The IQC and CFREF-TQT (Transformative Quantum Technologies) programs support the QNFCF operations and in 2023-2024 contributed over $1.1M to cover staff salaries, equipment acquisitions, equipment service contracts and other miscellaneous costs associated with cutting edge labs.

Infrastructure – Research Advancement Centres (RAC)

As of March 31, 2022, there are seven operational research labs in RAC, six of which are led by a principal investigator:

- Quantum Materials and Devices (QMAD) lab
- Quantum Photonic Devices Lab
- Quantum Innovation (QuIN) Lab
- Quantum Photonics Lab
- Coherent Spintronics Lab
- Nanoscale Magnetic Resonance Imaging Lab
- Quantum Exploration Space

While the Quantum Exploration Space does not have a principal investigator, this is an impressive lab space that supports students enrolled in the IQC's MSc Physics (Quantum Technology) program, offered at Waterloo in partnership with IQC and TQT. Two of the three lab-based courses required to complete the Quantum Technology degree are held in this lab and all three lab requirements are hosted there. Additionally, this lab is used to give students and IQC visitors access to real, research-grade quantum systems for laboratory experiments and knowledge building, such as during industry-IQC workshops that explore ways these companies can use quantum in their ventures. High school and undergraduate students in outreach programs such as Quantum School for Young Students (QSYS) and Undergraduate School on Experimental Quantum Information Processing (USEQIP) also benefit from detailed, hands-on experience with the real systems in the Quantum Exploration Space.

To ensure that this unique space continues to be able to fulfill its mission, 2 new benchtop NMR spectrometers were added to expand the Quantum Technology program operations and support larger groups for outreach activities. These systems have a 1.5T magnetic field that is used to explore up to 3-qubit quantum dynamics. We use the systems as a testbed for exploring experimental quantum information processing.

The Quantum Exploration Space also added an additional nitrogen vacancy (NV) setup into the space again for expanding Quantum Technology program operations and for outreach. These systems support training activities in quantum sensing (in partnership with Velocity) and were integrated in the fall term into the Quantum Technology course.

The lab was also upgraded with helium recovery infrastructure to enable operation of a liquid helium flow cryostat. A new cryostat was purchased last year and arrived in the fall term, and we have been working to get that system online. As of now, we have a working cryogenic system enabling the characterization and teaching of a variety of low temperature quantum devices (thin films, Josephson Junctions, superconducting microwave resonators). This system will be used for the Quantum Technology low temperature course running this spring.

Collaborations & Seeking New Partnerships

The IQC research community values opportunities for collaboration, both with other research groups and universities as well as with government, non-profits and private organizations. In 2023-2024, IQC faculty members collectively reported 187 active collaborations with at least 150 unique organizations that span the globe. The following list of organizations are an example, including universities, research institutes, private corporations, and government. A full list of collaborations can be found in Appendix D on page 86.

- Qubic
- Google Quantum AI
- National Research Council of Canada
- IBM
- PASQal
- National Institute of Optics, Canada
- University College London
- 1Qbit
- SERENE-RISC
- University of British Columbia
- Georgetown University
- Simon Fraser University
- University of Western Ontario
- ETH Zurich
- University of Chicago
- PINQ2
- Cornell University
- Jet Propulsion Laboratory
- TRIUMF
- Institute for Quantum Optics and Quantum Information (IQOQI)
- Quantum Algorithm Institute (BC)
- Institut Quantique
- Massachusetts Institute of Technology
- National University of Singapore
- University of Texas at Austin
- Xanadu Quantum Technologies
- D-Wave Systems

In addition to maintaining and growing established relationships, IQC's researchers and stakeholder groups continuously seek new partnerships to further strategic research objectives. This year, IQC engaged in relationship and partnership discussions with the following groups:

- **Government of Canada**: The leadership team at IQC meets regularly with representatives of the Government of Canada. As the leading quantum information institute in Canada, IQC is funded by the government and works collaboratively to advise the government on both progress and implications of quantum information science and technology research. In addition to direct communication between leadership at IQC and various ministries, IQC faculty

members also provide direct technical guidance to various ministries. Examples include faculty (Pushin, Lupascu, Cooper-Roy) producing a white paper to NRCan examining how quantum technology might benefit geophysical science and natural resources explorations and monitoring. Faculty (Bajcsy, Muschik, Pushin) also produced a proposal, supported by ongoing discussions, about how new neutron facilities in Canada would support studies in quantum materials, quantum sensing and quantum computing.

- **Foreign International Government**: Canada is among the world leaders in quantum information science and technology. As a result of IQC's world-class standing, we regularly receive visitors from other nations with advanced quantum institutes and facilities interested in continued collaboration. In 2023-2024 representatives from the Singaporean Ministry of defense, the deputy director for the Future Systems and Technology Directorate and technical staff from their Physical Sciences Laboratory visited IQC. IQC has a longstanding relationship with the National University of Singapore and their Centre for Quantum Technologies. Similarly, IQC has a longstanding relationship with TU Delft and QuTech; representatives of the Netherlands also visited IQC this year, specifically the Consul General and the Director at the Netherlands Foreign Investment Agency. IQC also hosted a delegation from Korea, including their Director for Artificial Intelligence Software and various team heads. IQC is a plank in the bridge between Canada and these partner nations; all of which have direct ties to the work going on at IQC via trade, academic collaboration or scientific outreach.
- **Large Multi-national Companies**: While IQC is a draw for start-ups and QNFCF pulls in growing commercial partners from across the country, IQC is also a magnet for the largest and most quantum-focused companies in the world. In 2023-2024, IQC hosted visitors from IBM, Apple and Google Quantum AI. IQC also hosts visitors from large multi-nationals that are not quantum focused but have an interest in the quantum future. In 2023-2024 IQC hosted visitors from NTT Research, Ernst & Young and Sandia National Laboratories demonstrate the wide swath of industries that are recognizing the economic implications of quantum technologies in the near future. These relationships result in the flow of information, and sometimes personnel, between these companies and IQC. These companies can supplement the funding of the Canadian Government, and in some cases, they may provide valuable resources, such as access to working quantum computers, which benefits our researchers enormously.
- **Quantum Focused Emerging Companies**: In addition to the largest companies in the world, IQC also advises and engages in projects funded by emerging companies from across the world. Examples of companies in this size range include Canadian companies such as Xanadu Computing Technologies, 1QBit, Anyon Systems Inc., Photonic Inc. and Crypto4A, and emerging international companies like Zapata Computing and KETS Quantum Security Ltd. Many of these companies and their founders have strong ties with IQC,

having previously worked or studied in Waterloo. Beyond informal community ties that form at IQC there are also formal arrangements with Canadian companies to the benefit of both IQC and the companies themselves. For example, Xanadu and IQC recently signed an MOU where Xanadu will work with IQC researchers to develop blitz quantum computing modules using Xanadu hardware and software. This led naturally to the formal development of internship opportunities for IQC graduate students, both from our QI programs and from our Quantum Technology specialization. Similarly, IQC and Quantum Valley Investment Labs (QVIL) are also developing an MOU to support internships in the Waterloo Region.

- **Start-ups**: IQC start-ups and the environment that enables their creation and success will be discussed later in this report.
- **Canadian Academic Groups**: As the oldest and most prestigious quantum information institute in Canada, IQC is visited by representatives of other Canadian institutes with some regularity. Visitors in 2023-2024 include researchers from McGill University, University of Toronto, Carleton University, University of Calgary and the University of British Columbia. In 2023-2024, IQC hosted visitors from every major centre of quantum research in Canada. IQC also has faculty members that are collaborating with PINQ2, which is hosted by the Université de Sherbrooke. IQC acts as a hub, connecting all quantum research in Canada.
- **International Academic Groups**: The list of international researchers that visited IQC in 2023-2024 is extensive and demonstrates not only the academic and research excellence taking place here but also the long-standing cultivation of relationships and the building of communities across the world. A brief list of highly distinguished academic visitors includes visitors from MIT, Harvard, University of Maryland, Oxford, TU Delft, Technical University of Munich, Yongsei University, University of Tokyo, Indian Institute of Technology (Delhi, Roorkee, and Bombay), Korean Advanced Institute of Science and Technology, and Griffiths University. Cultivating these relationships re-enforces IQC's standing among the world leaders in quantum science and reflects well on the Canadian scientific ecosystem.

These examples of collaborations taking place at IQC reflect only visitors that represent opportunities for strategic growth, resource sharing and pooling of academic and technical expertise; later in this report, examples of visitors from the Canadian public and future quantum scientists will demonstrate the full scope of the action taking place at IQC.

Objective B

Provide opportunities for students to learn and apply new knowledge.

Expected Results: Support and create opportunities for students to learn and apply knowledge.

Planned Activities:

- Continuing to grow and attract the best talent to IQC's graduate program.
- Fielding at least 400 applications to the University of Waterloo/IQC graduate studies program.
- Expanding connections made with undergraduate programs at Ontario and Canadian universities.
- Continuing to host timely, focused conferences, workshops, seminars and courses as pandemic-related logistical restrictions are reduced.
- Hosting up to 100 workshops, seminars and colloquia.
- Jointly sponsor or host up to 10 workshops and conferences with national and international partner organizations.

Attracting Talent – Postdoctoral Fellows

Postdoctoral fellowship positions provide early career researchers with invaluable opportunities for additional mentoring, publishing, researching and teaching. In 2023-24, IQC recruited at least 20 new postdoctoral; postdoctoral members come to IQC from prestigious institutions worldwide including Oxford, Brookhaven National Laboratory, Universidade de Sao Paulo, Queen's University and the University of Waterloo.

Over the last fiscal year, IQC employed a total of 53 unique postdoctoral fellows, at least 16 of whom were women (30%). As outlined in the table below, newly recruited fellows came from prominent institutions in Canada and around the world.

Canadian	International
Simon Fraser University, CA	Oxford University, United Kingdom
University of Waterloo, CA	Harvard, USA
Queen's University	Universidade de Sao Paulo, Brazil
Cienna Inc.	Univerita degli Studi Roma, Italy

A full list of current postdoctoral fellows can be found in Appendix E on page 91.

Since 2021, 18 IQC PhD alumni have been awarded postdoctoral fellowships, furthering the academic careers of talent developed in-house at IQC. These alumni represent a group of early researchers dedicated to advancing their work in quantum information at IQC. In addition to attracting highly qualified young researchers, IQC postdoctoral fellowships are a proven method to seed further quantum research across Canada with former IQC postdocs holding faculty positions at Mount Allison University, Université de Sherbrooke, McGill University, University of Ottawa, Carleton University, Toronto Metropolitan University and University of Waterloo, to name a few examples.

Attracting Talent – Graduate Students

IQC welcomed 51 new graduate students this past year from more than 400 applications, bringing the total current number of master's and PhD students to 205 (81 and 124, respectively). IQC receives applications from some of the most prestigious schools across Canada and around the world. In 2023-2024, IQC received applications from 33 countries and all 6 inhabited continents on Earth; the reputation and reach of IQC is truly global. The table below illustrates the range of institutions our applicants come from, including applicants from eight of the 10 Canadian provinces (Prince Edward Island and Newfoundland and Labrador are not represented among our applicants).

Canada	International	United States
Université de Montreal	National University of Singapore	Columbia University
University of Calgary	ETH Zurich	Cornell University
University of Saskatchewan	Indian Institute of Technology (many)	Massachusetts Institute of Technology
Saint Mary's University	Imperial College London	California Institute of Technology
University of British Columbia	Federal University of Sao Carlos	Princeton University

A full list of current graduate students studying at IQC can be found in Appendix F on page 92.

Attracting Talent – Undergraduate Students

IQC offers many opportunities to expose undergraduate students to research.

USEQIP

Students can apply in tandem with applications to the annual Undergraduate School on Experimental Quantum Information Processing (USEQIP) with the opportunity to stay for a research term following the program, or they can apply for a research associate position outright. With both opportunities, undergraduate students are provided an in-depth introduction to the knowledge skills necessary to succeed in a quantum information science graduate level program. In 2023, 27 out of 32 USEQIP participants stayed for the term as an Undergraduate Research Assistant (URA) gaining valuable work experience in addition to a unique learning opportunity

CO-OPERATIVE EDUCATION

While USEQIP is an excellent opportunity to attract talent from across the globe, it is worth noting that IQC also takes advantage of the largest co-operative education system in Canada here at the University of Waterloo. Many of the labs at IQC expose various

undergraduate students to the day-to-day operations of advanced labs. For example, Dr. Crystal Senko's lab hired eight co-op students per term in 2023-2024, while all faculty members hired 47 co-op students over the course of the year. These students are exposed to advanced lab procedures and are occasionally named in publications with their principal investigators. Similarly, Dr. John Donohue, Senior Manager Scientific Outreach, employed three students over that time as well – these students are exposed to advanced science communication and educational outreach opportunities. Many of Donohue's co-ops also complete ensuing co-op terms in the labs of various faculty they meet through their work with him.

UNDERGRADUATE RESEARCH ASSISTANTS

Many of the participants in USEQIP follow the course with an opportunity to work in a lab for the remainder of the spring term (in spring 2023, 27 out of 32 USEQIP participants stayed in Waterloo and worked with IQC faculty members for the remainder of the term). However, undergraduate students do not need to attend USEQIP to become a URA. Many apply directly to the labs; Dr. Thomas Jennewein employed two USEQIP URA's and five independent URAs, for example.

For 2023-2024 IQC employed 107 URA's and co-op students in various roles in our labs.

Graduate Student Awards

The best and brightest minds are studying and researching at IQC, earning awards and scholarships in recognition of their work. These awards provide students with the funding needed to devote themselves to their studies and demonstrate their research excellence. In the last year, all full-time IQC graduate students received some financial support to pursue their studies.

The list below highlights some of these top awards, scholarships and fellowships our master's and PhD students received:

- Eight Mike & Ophelia Lazaridis Fellowships
- Two IQC Entrance Awards
- 39 International Doctoral Student Awards
- 13 International Master's Awards of Excellence
- 63 Marie Curie Graduate Student Awards
- One NSERC Alexander Graham Bell Canada Graduate Scholarships - Doctoral
- Three NSERC Alexander Graham Bell Canada Graduate Scholarships - Master's
- Six NSERC Postgraduate Scholarships - Doctoral
- Three NSERC Vanier Canada Graduate Scholarships
- 17 President's Graduate Scholarships

- One Provost Doctoral Entrance Award for Women
- Five Ontario Graduate Scholarships
- One Queen Elizabeth II Graduate Scholarship in Science and Technology
- One Amit and Meena Chakma Award for Exceptional Teaching by a Student

Career Building

IQC has an enviable academic reputation. It also has an excellent reputation as an institution that fosters the development of its students and postdoctoral fellows. In 2023-2024 doctoral candidates and postdoctoral fellows published at least 31 peer-reviewed articles with no faculty member (including affiliates and associates) as co-author (17.5% of all publications), in some cases these students and fellows worked together and in some cases PhD students are the sole authors. For example, Erickson Tjoa published an article in Physical Review D in August 2023 which currently has 1 citation. Tjoa also has a number of papers where he is the sole author and H-index of 10 (before being granted his PhD). Tjoa has graduated and moved on to the Max Planck Institute for Quantum Optics and is quickly building a reputation as a world class researcher. Similarly, Lane Gunderman published in Physical Review A (2 citations) in June 2023 as a sole author and is currently named in 7 publications. Gunderman has left academia (though he still publishes) and is now a Research Scientist at HRL Laboratories, LLC. Note that the theme of assisted career development and opportunities to build professional networks appears in many of the profiles that follow. Additionally, IQC students and postdoctoral fellows (over a dozen former or current non-faculty members) are involved with commercialization of their research, either in partnership with faculty members or alone.

IQC leverages its academic reputation to draw in excellent students and postdoctoral fellows and provides those community members with opportunities to excel in their chosen careers, either in academia or in industry. Academic reputation and international reach continue to draw the best and brightest to Waterloo. For example, as former members become faculty across the globe, they recommend IQC to their students. For example, several students of Rahul Jain (postdoctoral fellow at IQC 2006-08) have attended IQC in recent years.

IQC Alumni: Building the Quantum Workforce

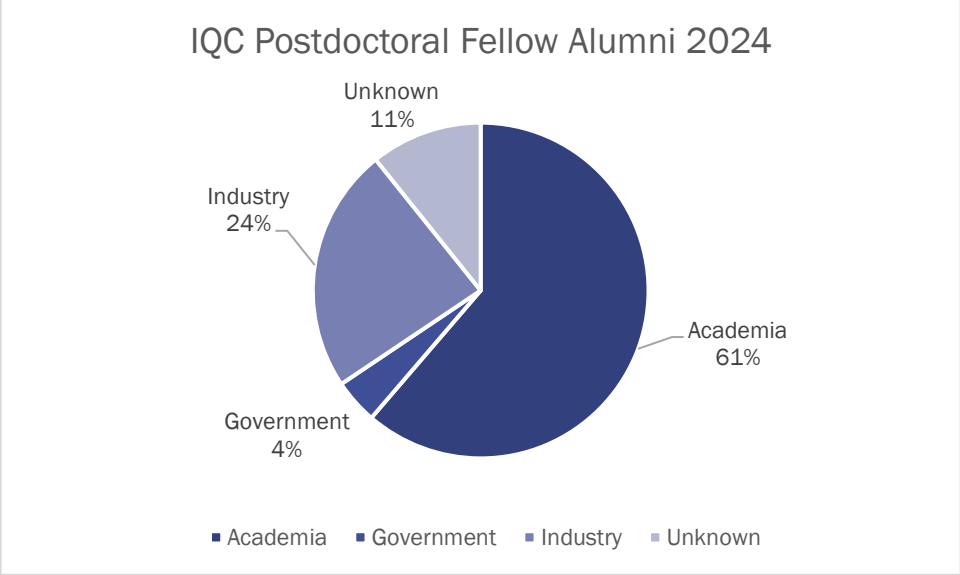
IQC students and postdoctoral alumni leave to become global citizens who have a profound impact on academic, industry and government sectors. They help shape quantum advancements across industrial sectors including banking, communications, and technology and inspire future generations of innovators with their passion, purpose and ingenuity.

Selected alumni careers:

- Associate Professor
- Research Engineer
- Vice-president, Quantum Computing
- Senior Scientist
- Director of Quantum Computing

Postdoctoral Fellows Alumni Overview

After leaving academia, postdoctoral fellow alumni are regarded as role models, visionaries and leaders of the quantum industry by their peers. Our alumni leave campus and become global citizens who impact academic, industry and government sectors. Below is a representation of where IQC postdoctoral fellows have gone, as of March 31, 2024:



Postdoctoral Fellow Alumni Profiles

A postdoctoral fellowship at IQC provides the basis for an entire career; while we often focus on recent departures it is also worth noting potential career trajectories of postdocs who left IQC a decade ago to begin careers. As the following profiles demonstrate, experiences at IQC can reverberate through careers for decades.

Daryoush Shiri – Postdoctoral Fellow 2013-2015

As a PhD student and postdoctoral fellow at IQC, Dr. Daryoush Shiri was given the freedom to learn and explore, reinvigorating his passion for problem solving and research. He also had the opportunity to teach two graduate mini-courses. Combined, these experiences all led him to his chosen career path as a combination of research and teaching, and Shiri is now a research scientist at Chalmers University of Technology in Sweden. There, his research focuses on the design and simulation of microwave superconducting circuits for quantum computing applications, he supervises graduate students, guest lectures, and has also co-authored the textbook "*Quantum Mechanics for Engineers and Material Scientists*", published in March 2024.

"I try my best to transfer the lessons I learned from my great mentors at Waterloo, in both Electrical and Computer Engineering and IQC, to my students, but I always see myself as a curious student. Research surprises you, it's like walking into an unknown territory. Keep your eyes open for moments when an idea or a solution comes to you from a totally unexpected resource."

Shiri remembers IQC as an open and friendly environment, where he could ask questions and discuss science with anyone. He appreciated the interdisciplinary nature and culture of respect and diversity at IQC, which make IQC a unique role model for other research centres. "IQC staff were always available for help and support, like family members. I miss them all."

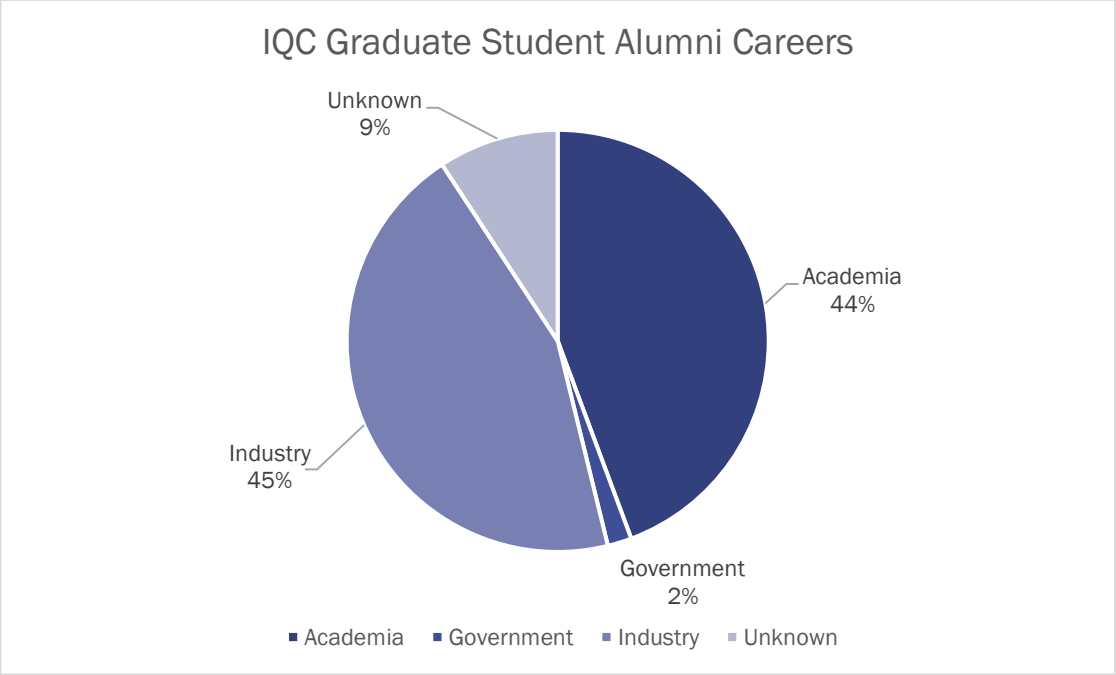
Audrey Dot – Postdoctoral Fellow 2014

During her time as a Postdoctoral Fellow at IQC, Dr. Audrey Dot was using four-wave mixing in optical fibre to convert a single photon into a pair of photons. Dot, along with her supervisor Thomas Jennewein, PhD student Evan Meyer-Scott and colleagues at McGill University, Montreal, sent a single photon through the optical fibre with a strong pump beam to produce a pair of photons with increased efficiency compared to previous methods. Dot then brought her knowledge and research skills to the smart thermostat company Qivivo, where she worked on machine learning algorithms as a Physicist Engineer.

Now she is at Thales Research and Technology in France. She is working as an Applied Scientist in the field of Quantum Communications; specifically, on deploying QKD networks in the Paris area. This work is directly related to her postdoctoral work with Thomas Jennewein, a world-wide leader in QKD communications.

Graduate Students Alumni Overview

This year, IQC proudly granted degrees to 13 master's students and 14 PhD students, bringing the total number of degrees to 432 cumulatively. These graduates are employed in a diverse range of positions, from academia to industry and government, both within Canada and around the world. As of March 31, 2024, 127 (30%) IQC graduates are working in the Quantum Information (QI) field in Canada, of which 27 are women. At least nine IQC graduates are employed as postdoctoral fellows at Canadian Universities. The chart below indicates the sectors where IQC graduate students have moved on to after leaving IQC, where known.



Student Alumni Profiles

Chris Ferrie - (MMath Applied Mathematics, PhD Applied Mathematics)

Dr. Chris Ferrie began his quantum journey at IQC as a graduate student with Professor Joseph Emerson. During this time, he published his first academic paper and learned the research skills he continues to use in his day-to-day work. He remembers growing his network of friends and colleagues within quantum in a collaborative atmosphere full of the world's experts; something he considers equally as important as the technical skills he developed.

Ferrie is now a professor at the University of Technology, Sydney, where he researches applications in characterizing, controlling, and improving quantum technology through

the design of automated and intelligent learning protocols. He also has a passion for communicating science and has written sixty books for children and adults, including *Quantum Physics for Babies*. “I started writing children’s books for my own children because I could not find any books about science for young kids. I write about complex topics because it’s fun and interesting, but also because I believe anyone can understand them when phrased in an engaging and welcoming way.”

Looking forward, Ferrie hopes his research will lead to enabling scalable methodologies to access critical information needed for building practical quantum technology.

Agnes Ferenczi – (PhD Physics)

When faced with a challenge, Dr. Agnes Ferenczi sees an opportunity for discovery. Currently, Ferenczi is working with the German Aerospace Center as a Research Project Lead, working in the field of Quantum Communication Systems (satellite quantum key distribution (QKD)). Previously, she investigated a variety of areas including machine learning, software development, user experience and search algorithm implementations at Cliqz, a search engine and browser company focused on privacy. She's used the research tools and skills she developed during her PhD research on quantum cryptography with IQC researcher Norbert Lütkenhaus.

With an emphasis on security proofs for quantum cryptography systems, Ferenczi adapted quantum theories to match current experimental capabilities, bridging the gap between theory and experimental reality. Her PhD research included a revision to the phase encoded BB84 protocol where quantum information is transmitted using photon polarization. In this scenario, one party sends out two laser pulses. One laser pulse stays the same and the other weakens, a result that was not initially accounted for in the theoretical proof. “We adapt the proof to allow for imperfections in the experimental environment,” said Ferenczi. Simplifying the proof for experimental implementation often improves accessibility for experimentalists.

Seminars & Colloquia

With frequent events, IQC’s schedule of seminars and colloquia consistently keep the research community and their respective visitors engaged. This past year, IQC hosted 9 workshops, 63 seminars and 11 colloquia. The student seminar series introduced in FY 2019-2020 (27 hosted in 2023-2024) continues to connect IQC members, allowing students to share results of their ongoing research, to be exposed to research outside of their core research area, and to serve as a platform to develop presentation skills. IQC also supports quantum science by hosting meetings for groups of likeminded researchers; for example, in November 2023 an Atomic, Molecular and Optical group launched with a Community Meeting which included facilitated discussions and a Q&A following a lead presentation on Flat Optics.

Sponsored Conferences & Workshops

IQC commits to supporting external conferences and workshops to encourage opportunity for collaboration among a domestic and global network of researchers. In 2023-2024, IQC sponsored the following external partner events and remains committed to supporting relevant events as opportunity increases:

Date	Conference	Location
May	Ontario Association of Physics Teachers (OAPT)	Perimeter Institute,
May	IQC Student Conference	IQC
June	JAM Hacks 7	Waterloo
June	Canadian Association of Physicists (CAP) Congress	University of New Brunswick
July	Summer School on the Foundations of Quantum Computational Advantage	Bilkent University, Ankara
July	Women in Physics Canada	University of Manitoba
July	50th EATCS International Colloquium on Automata, Languages and Programming (ICALP 2023)	Paderborn University
July	Theory Canada 15	Mount Allison University
August	QCrypt	NIST
September	QPV 2023: Advances in Quantum Position Verification	Perimeter Institute
September	Q-Site Conference - A Canadian Student Quantum Conference	University of British Columbia
September	Q-SITE 2023	Toronto and Vancouver
October	Canadian Undergraduate Physics Conference (CUPC)	Waterloo
October	IQC – WIN Workshop	Waterloo
January	Canadian Conference for Undergraduate Women in Physics (CCUWiP)	McGill and U. de Montreal

Supporting these conferences builds the IQC brand for recruiting future students (JAM Hacks 6 is a high school conference, Canadian Undergraduate Physics Conference) and future postdoctoral fellows or faculty building their careers.

Organize conferences with multidisciplinary participants

IQC hosted many multidisciplinary meetings and conferences in 2023-2024, among the highlights are the following:

Security Proof Workshop 2023 is designed to bring together experts in the security analysis of QKD for candid and informal discussions. The fifth iteration of this workshop was intended to focus on Practical-Device independent QKD, Optimal use of statistics and classical processing in QKD and non-id security proofs. This workshop was hosted by IQC on September 11-13, 2023, and was a well-received event, likely to lead to greater national and international collaborations. Participants included internationally renowned researcher such as Renato Renner (ETH Zurich), Frederic

Dupuis (UMontreal), Masato (University of Tokyo), Peter Brown (Telecom Paris), Hoi Kwong Lo (University of Toronto), and Rotem Arnon-Friedman (Weizmann Institute).

In October, IQC hosted the annual Waterloo Institute for Nanotechnology (WIN)-IQC workshop. This annual workshop is designed to bring together two institutes that share a building at Waterloo and allow faculty member of each institute to engage with peers across the hallway. In addition, both faculty groups benefit from a keynote presentation delivered by an external researcher. In 2023, the external researcher was Jiwoong Park from the University of Chicago and the topic was large-scale processes for generating two-dimensional crystalline semiconductor films and superlattices to fabricate atomically thing integrated circuits.

Quantum Innovators (QI) is a weeklong workshop that brings the most promising young postdoctoral fellows to Waterloo to present their network with peers and present their research to an audience of experts to refine their skills and presentation styles. In 2023, QI was offered in two streams, the first stream recruited fellows from theoretical fields and was held on November 6-8, 2023. Fourteen postdoctoral fellows from the world's most prestigious universities (MIT, NRC Canada, ETC Zurich and University College London, among others) came to Waterloo and discussed their work with IQC faculty and students. Later, from November 8-10 an experimental stream saw 9 postdoctoral fellows arrive to discuss their research with the IQC community. Attendees were from Harvard, University of Maryland-Joint Quantum Institute, Cornell and MIT among others.

These conferences expose IQC students to research from across the world and bring young experts to Waterloo to participate in the world leading quantum hub that exists here.

Objective C

Raise awareness and knowledge of quantum information science and technology in both the scientific community and amongst Canadians more generally.

Expected Results: Increase awareness and knowledge of quantum information science and technology and the Institute in both the scientific community and amongst Canadians more generally.

Planned Activities:

- Hosting USEQIP (undergraduate) and QSYS (high school) summer schools
- Hosting the annual high school teacher's workshop (Quantum for Educators, formerly known as Schrödinger's Class)
- Hosting outreach events including public lectures to increase the knowledge of event participants on quantum information and IQC
- Presenting dedicated STEM programming for women and girls
- Establishing relationships with key strategic partners to further share IQC's research discoveries
- Continuing to share IQC's research through publications, new stories/press releases, web and social media platforms
- Leveraging online resources and content to drive new visitors to IQC's website

Increase Awareness

The IQC outreach team, through 202 virtual and in-person events, exposed more than 41,000 people to quantum information science ideas this year. More than 13,000 of those people were deeply engaged by our outreach team led by Dr. John Donohue. The vast majority (10K+) of these highly engaging talks are oriented towards Canadian elementary or high school students or the general public, providing context and education for the broad enthusiasm surrounding the quest of a quantum computer in popular press and fiction. Many of these outreach activities take place on an intimate level, where IQC goes into the classrooms in person and engages with students, for example. By engaging small groups of students our outreach team has a significant advantage in their ability to answer individual questions and raise the level of understanding of QIS themes among all Canadians.

Outreach at IQC demonstrates pedagogical and scientific leadership, unique among Canadian quantum institutes. In the past three years Dr. Donohue has helped to shape American outreach programs (the American university system is the second leading source of graduate students at IQC). At the undergraduate level, especially in conjunction with the University of Texas system Donohue has provided guidance based on his experience with the IQC USEQIP program; at the high school level, in conjunction with the National Q-12 Education Partnership, Donohue has contributed to program development based on his extensive experience with the IQC QSYS program. IQC programming is so integrated into the National Science Foundation (NSF) quantum programming through UT-Austin that Donohue's demonstrations were recently used in the Quantum Research Showcases in Washington DC by Sethuraman Panchananathan, Director of the NSF.

Additionally, Donohue has presented on quantum outreach strategies at the APS March meetings (2022), the IEEE Quantum Week in 2022 and CAP Congress in 2023. Lastly, and notably among quantum outreach managers, Donohue published in Nature Photonics in September 2023. Dr. Donohue is uniquely qualified among Canadian quantum institutes to lead quantum science discussions with outstanding high school and university students as well as the general public because he is experienced in translating and teaching advanced materials at a more accessible level and is a highly qualified professional quantum scientist.

In addition to the strategic development tours mentioned earlier, IQC also engages wider audiences with a guided tour through various labs located in the QNC building. Some tours in the past year include the International Women's Forum, Next Generation Manufacturing Canada, a delegation from the U.S. Consulate, EinsteinPlus (teachers' workshop), the University of Ottawa Certificate program in Public Sector Leadership and Governance, and various members of the local community.

Faculty members at IQC are also actively engaged with non-academic outreach. Dr. Michele Mosca has been advocating for the use of quantum safe cryptography for a number of years, having realized that some data holds its value for decades. These efforts have resulted in Dr. Mosca's membership in the *World Economic Forum's Global*

Future Council on the Future of the Quantum Economy and his talk titled "*Quantum Computing for National Security Leaders*" delivered to the G7 Cyber Expert Group conference in Ottawa hosted by the Department of Finance in June 2023

Another example is Dr. Rajibul Islam's engagement on 'Quirks & Quarks' in June 2023. Dr. Islam's success as a teacher (President's Excellence in Teaching Award, 2021 and the Excellence in Science Teaching Award, 2024) is on full display as he embeds his highly developed experimental knowledge in everyday language and clear examples for a general-purpose audience.

IQC members are involved in setting the rules that will govern the use of quantum technologies including examining the potential economic and legal impacts and these technologies become more accessible.

For example, Dr. Raymond Laflamme chaired an expert panel (including leading faculty from across Canada, like Dr. Barry Sanders from the University of Calgary) on how to stimulate adoptions of quantum technologies for the Canadian Council of Academies. The report, titled 'Quantum Potential' is a direct response to a request from the National Research Council of Canada (NRC) and Innovation, Science and Economic Development Canada (ISED). The purpose of the report is to identify and assess opportunities and challenges attached to the adoption of quantum technologies in Canada. This report considers not only the technical challenges that may be involved in adopting new technologies but the ethical, economic, legal and policy implications that such fundamental technologies may have on Canadian society. Dr. Laflamme may be uniquely qualified for this task, having been executive director at IQC for more than 15 years and the current co-chair of the National Quantum Strategy in Canada.

In addition to public outreach and engagement with the wider social implications of research into Quantum Information Science, IQC also has longstanding and successful programs to engage target audiences.

Quantum Information Science Engagement Programs

Undergraduate School on Experimental Quantum Information Processing (USEQIP)

The impact of programs like USEQIP has inspired past participants to further their academic studies at their home institution, and then return to IQC for graduate school. Since the program's inception in 2009, dozens of past USEQIP participants have returned to IQC to pursue graduate studies, proving it to be a useful recruitment tool for top talent. USEQIP participants note that the openness and engagement with lecturers establishes a very inviting atmosphere:

> *"If someone is even curious about QIC or already works in the field, I believe this is probably one of the best programs in the world to be in. We get an opportunity to meet people at the forefront of research in QIC and also acquire hands-on experience with state-of-the-art equipment in the*

labs. It gives a deep insight into the research at IQC and is. Overall, it is an amazing experience where you get to think, learn, apply, and explore several fields in Quantum Information with like-minded peers."

"USEQIP provides you with so much raw information as well as opportunities to apply that information many engaging labs. I felt as though I learned more about the world of quantum information during USEQIP than I had during the past four years of my undergrad."

"Everyone is super friendly and you can learn so much just by asking questions because everyone is open. The lectures often clarified my knowledge about particular experimental platforms and algorithms. The program was well-structured and we didn't miss a beat as we went through our scheduled activities. Overall, a wonderful and well-executed program!"

In 2023, IQC hosted its annual USEQIP program from May 29 to June 9. USEQIP returned to being an in-person experience in 2022. Talented students from across North America and Asia with representation from the IIT Bombay, Yale and the University of Maryland – College Park attended in 2023. Many Canadians also attended from McGill University, University of Toronto, Université de Sherbrooke, Dalhousie University, and the University of Waterloo. 32 students were selected to come to Waterloo for the intense program. Of those students, 27 stayed for the term working as a URA with various faculty members and gained invaluable experience working with leading researchers.

Quantum School for Young Students (QSYS)

IQC hosted its annual QSYS summer school from August 9 to 17 2023 with students from Canada, the United States of America, the Czech Republic, India, Pakistan and Cambodia.

QSYS returned to being a fully in-person event in 2023; from more than 720 applicants 42 students were hosted in Waterloo with more than 20 world-class researchers taking part in the event. The researchers are as enthusiastic about meeting the students as the students are about being exposed to cutting edge research:

> *"It's a real treat to meet high school students with such enthusiasm for science, particularly quantum science. I'm amazed by the depth of thought that comes out in their questions."*
>
> - *Dr. Alan Jamison, Ultracold Quantum Chemistry*

QSYS's enormous applicant pool indicates an extraordinary appetite in quantum topics for high school-aged students, and it also highlights IQC's reputation as a world-class institute for quantum information science research. In addition to an excellent

curriculum QSYS in also an inclusive environment for young people with 23 of 42 (55%) participants being young women.

In a follow-up survey to students once the summer school had concluded, 98% of respondents rated their overall experience at QCSYS as excellent (83%) or good (15%). 100% of respondents said that they would actively encourage people to apply (93%) or if asked, they would encourage people to apply (7%). 95% of respondents strongly agreed with the statement, "QSYS exposed me to ideas not available in my high school classes."

> *"Please do repeat the final challenge, it was so engaging. We could put our newly acquired skills to the test in unfamiliar contexts, while also collaborating with other people."*
>
> *"This is a phenomenal program and I can't thank everyone enough for how amazing it was!"*
>
> *"I loved the program!"*

Quantum for Educators (formerly Schrödinger's Class)

IQC hosted its 9th annual high school teacher workshop, Quantum for Educators, from December 1 to 3 2023.

As the second quantum revolution permeates society it's important to ensure that accurate and up-to-date information is available to learners early in their lives to generate interest and promote participation. IQC is committed to making it easier for high school teachers to stay current about quantum science and to provide details of how quantum-based technologies are utilized across a wide variety of sectors in society.

The event not only facilitated individual growth for participants, but also established connections between a new community of educators committed to transforming science education.

The workshop opened possibilities for science educators, encouraging them to explore new dimensions in their teaching and inspiring their students to become the next generation of quantum researchers.

In the post-workshop survey, 100% of respondents replied that they would "actively refer colleagues to the program" (88%) or "refer if asked about the program" (12%). When asked "How many teachers would you share Schrödinger's Class material with?" on average each participant answered that they would share this material with an additional 15 teachers.

> *"As a computer science teacher, I would love all of my science colleagues to attend so that we could work together on interdisciplinary teachings. I would recommend it to every STEM teacher because it is so confidence boosting as a teacher to "pull the curtain back" on some of the quantum*

concepts that I understood previously at a very superficial level. It is also so fulfilling to learn new things with like-minded colleagues!"

"This is the kind of information that is incredibly difficult to self-instruct. The deeper understanding necessary to teach is enhanced by the live discussion with the instructor as well as with the other educators. You simply can't replicate that level of experience. It is really neat to see the labs as well and hear from students and professors, bringing back personally relatable stories to your students."

"I think that this conference was a great way to learn more about quantum physics and how to learn incorporate into our classrooms. I believe that colleagues would benefit from this as well. Also, it is a great opportunity to network with other science teachers"

Outreach-Public Lectures

IQC continued a series titled 'Quantum Today' that addressed the overall need for more scientific content designed to keep the scientific public aware of the current problems and potential solutions in quantum information science being developed and researched at IQC.

'Quantum Today' switched to an in-person format and featured the work of two groups at IQC and drew more than 100 attendees focusing on:

- University of Waterloo professor Eduardo Martín-Martínez and IQC alumnus Hemant Katiyar discuss taking ideas from quantum thermodynamics and designing an experiment to test the foundations of quantum mechanics. This discussion is based on their publication, titled "*Experimental activation of strong local passive states with quantum information*" in Physical Review Letters.
- Joan Arrow and Özge Gülsayin of the Quantum Ethics Project, a team of researchers exploring the intersection of quantum and society discussed how to advocate for the responsible and inclusive development of quantum technologies through education and research, and why an ethics lens is important in even the early stages of technological innovation.

IQC faculty and graduate students also participated in several "IBM Seminar Series" webinars hosted by IBM and intended for a specialized audience. Topics included:

- Dr. Christine Muschik - Simulating One-Dimensional Quantum Chromodynamics on a Quantum Computing

- Dr. David Gosset - How to Simulate Quantum Measurement Without Computing Marginals
- Shayan Majidy, IQC PhD candidate - Monitored Quantum Circuits with Noncommuting Conserved Quantities

Dr. Thomas Jennewein also delivered a public lecture (in conjunction with a scientific lecture at Brock University titled, 'Beyond the Imitation Game: From Dieppe and James Bond to Blackberry and Quantum Encryption'. This talk capitalizes on Dr. Jennewein's work to ensure perfect knowledge about eavesdropping on electronic communication via Quantum Key Distribution.

Dr. John Donohue, Senior Manager, Scientific Outreach also held dynamic presentations designed to reach the public in a more visceral way. Examples include open houses, alumni events and coding boot camps. Additionally, Donohue participated in the TED^{x} Columbia Lake Youth event in Waterloo which focused on reinventing education and participated in the Lumen Festival in Waterloo with a public demonstration. Donohue also gave a public lecture at the Quantum Algorithms Institute in BC discussing Quantum and pop-culture. John returned to international outreach and recruiting with a trip to the Netherlands this year. Hosted by Leiden University, John set up the IQC travelling pop-up exhibit for a public demonstration of all things quantum at the 'Gala van Quantum en Samenleving'.

Public outreach at IQC takes advantage of a wide variety of channels and is designed to provide accurate information about quantum science and draw people into the realization that quantum science already affects their lives, and they can participate in the future.

Outreach-High School Visits

Outreach is intended to promote the work going on at IQC, but recruitment is also a result of outreach at IQC. Every year IQC personnel visit hundreds of classrooms in Canada to demonstrate the power of quantum science and to promote IQC among students with an interest in STEM topics. In these visits, quantum experts join a class and share a presentation about quantum science and quantum information, taking questions from students about the field and pathways into research careers. With exactly 100 visits across Canadian classrooms this year, IQC engaged with more than 3000 students. IQC is also an internationally renowned research institute, so we do receive and honour international requests for virtual high school visits when possible. In 2023-2024, IQC virtually visited classrooms in Poland, Romania, Ghana and the United States, engaging with over 200 students internationally.

In-person community events also present IQC with an opportunity to engage kids in learning about Quantum Science. The Canada-Wide Science Fair, the LUMEN Festival and the Launch/IQC Family STEAM Day were opportunities for IQC to get in front of thousands of Canadians with a special interest in technical topics. The Canada-Wide

Science Fair was held in Edmonton in 2023 and IQC had 2 people at the fair to provide demonstrations, answer questions and generally promote IQC to the high performing high school students in attendance.

Promoting Science for Women & Girls

As part of IQC's commitment to equity and diversity, we strive to open doors for girls and women before they can apply to graduate school so that young women can see themselves attending STEM-related graduate schools and research institutes. To drive gender parity, QSYS (high school students) had 55% women or non-binary attendees, USEQIP had 50% women attendees. IQC also partners with other organizations so that we can extend a warm invitation to women and girls across Canada.

In 2023-2024, IQC had several events that focused on promoting gender equity in STEM fields spanning various audiences. IQC co-organized 2 events with the Canadian Association for Girls in Science (CAGIS), one in Vancouver (CAGIS Vancouver Workshop) and one in Ontario (CAGIS Workshop & Filming). Both events are intended for an elementary school audience and are designed to help girls see themselves as scientists. IQC has a decade long relationship with CAGIS and is committed to including women in the quantum future.

IQC had representation at PhysiX: Girls Matter workshop at the University of Waterloo which is designed to bring middle school-aged girls and non-binary students to the University of Waterloo to connect with like-minded students in exciting workshops, meet role models, and hear mentors share their experiences.

An IQC graduate student was also part of a panel at the Centre for Education in Mathematics and Computing. The Seeing Possibilities and Rewards in Computer Science (SPARCS) workshop is designed to spark interest in computer science among selected young secondary school students who have little or no previous exposure to computer science. IQC grad students can be very inspiring for high school students that many not have had previous interest in advanced computer science topics.

Dr. Donohue also attended the Canadian Conference for Undergraduate Women in Physics (CCUWiP) held at the Université de Montreal in January 2024. Donohue was accompanied by master's student Fiona Thompson and Dr. Sara Zafar Jafarzadeh. This event was part recruiting trip, part modeling women in graduate studies.

As a world-class research institute, IQC is committed to promoting a diversity of research interests and viewpoints. To meet that objective, IQC makes an effort to reach out to other groups of students who may not see themselves in graduate school. In 2023-2024, IQC participated in two events designed to draw in Black students from across Ontario. IQC hosted a STEM-Powered Workshop in SuperConductivity in partnership with Engineering and Science Quest in March of 2024. In August of 2023, Donohue led a Developing Young Leader of Tomorrow Today (DYLOTT) workshop on Polarization and Quantum Cryptography.

Strategic Outreach Partnerships

IQC has partnered with organizations including the Hamilton Public Library, SHAD and LUMEN to bring quantum ideas and associations into public spaces. IQC also has existing relationships with the Canadian Association for Girls in Science (CAGIS), Perimeter Institute and PhysiX, and remains committed to engaging with corporate and non-profit partners to promote quantum science. We are focused on building new partnerships in FY 2024-2025 to expand our ability to lead the quantum future in a Canadian context.

IQC also engages with several Strategic Science Fund recipients in a Community of Practice to ensure an awareness best practices across all recipients. In the next year, IQC will engage directly with Actua and Let's Talk Science to look for ways to build our outreach efforts, especially among Canadian youth. We are also working together with other quantum hubs in Canada, most recently with Quantum City at the University of Calgary on efforts to promote commercialization of quantum technologies in Canada.

Communications

IQC ensures that researchers and their work are recognized worldwide through news stories, media releases, print and online platforms. Communications are tailored to ensure that stories are accessible to a broad range of audiences, from the general public to international members of the quantum community.

News Stories and Earned Media

With IQC members reporting research results each year, IQC strives to promote its community's work to the mainstream media. Between April 1st, 2023, and March 31st, 2024, over 900 media mentions of IQC were recorded, translating to a potential reach of just over 1 billion impressions – the number of times that a post has been viewed on a feed.

Media outlets include but are not limited to:

- Forbes
- Yahoo! Finance
- The Globe and Mail
- Associated Press
- MIT Technology Review
- Science Business
- CBC
- Popular Mechanics

These outlets and more mentioned or cited IQC or IQC researchers in the last year, demonstrating IQC's global presence as a trusted expert in the international quantum industry.

Social Media

IQC continued to post informative and engaging content on social media for its followers throughout April 1, 2023, to March 31, 2024. On average, approximately 1.5 pieces of content each day were posted across Twitter, LinkedIn, Facebook, and Instagram generating 943,891 impressions, 12,531 interactions, and 42,218 engagements. The number of engagements is over 34% higher than in FY 22/23.

During the same period, the IQC YouTube channel garnered over 128,000 views and 10,000 hours of watch time.

Throughout last year, IQC enjoyed steady growth across all its social media platforms. Below are some highlights of social platform growth from April 1, 2023, to March 31, 2024.

	New Followers	Total Current Followers	Increase in Total Followers
LinkedIn	7,055	17,987	64.5%
Twitter	2,647	21,516	14.0%
Instagram	213	1,972	12.1%
YouTube	1,842	28,767	6.3%
Facebook	38	5,918	0.7%
TOTAL	**11,795**	**76,160**	

Consistent online growth is a positive sign that points toward IQC's established position of being an authoritative voice in its field.

In FY 23/24, LinkedIn has become our primary social media platform of focus, due to the growing audience of quantum professionals in academia, industry, and government that we are targeting with our content, and their presence and engagement on this

specific platform. IQC chose to target these groups to increase our relationships with quantum stakeholders and has been prioritizing fostering quality engagements with our content over the quantity of posts across all of our social media platforms. Over the past year, our overall engagement increased by 34% across all platforms, despite our number of posts decreasing, meaning that our targeted approach is reaching an audience who is more engaged with our content.

IQC continues to plan and implement new strategies to generate high quality, quantum-related content that is valuable for IQC's social media audiences and experiment more with targeted campaigns and evergreen content.

IQC continues to position itself as a quantum authority, Canada as a global quantum leader, and quantum information science and technology itself as an endeavour worth understanding, supporting and developing further.

Objective D

Position Canada to take advantage of economic and social benefits of research by seizing opportunities and commercializing breakthrough research.

Expected Results: Canada is positioned to take advantage of economic and social benefits of quantum information science through seizing opportunities to commercialize breakthrough research.

Planned Activities:

- Supporting the building of a new quantum industry
- Promoting opportunities for IQC researchers to connect with Waterloo's entrepreneurial ecosystem through networking opportunities and formal events in partnership with the broader startup networks in Waterloo Region

Supporting Quantum Industry and Ecosystem Connections

IQC is at the centre of the emerging quantum industry in Canada. Companies, like Photonic Inc., or Anyon, despite being based in other provinces, make operational pilgrimages to Waterloo to make use of the facilities located which has resulted in fulltime employees being located in the region. The environment of entrepreneurship at IQC, combined with specialized knowledge emerging from an intensive research centre, has created the necessary conditions for aggressive commercialization of emerging technologies.

2023-2024 was an exceptional year for entrepreneurial activity at IQC. In its Quantum Technology Monitor for April 2024 McKinsey & Company notes a 44% decrease in the number of startups created in 2023, compared to 2022. IQC pushed back against this trend with the formation of 2 startups, granted patents and, at least 2 patent applications.

Dr. Christine Muschik has had research success over the last 3-4 years at IQC and formed a company, Quantum Creative Minds Inc. to commercialize some of the work coming out of her lab.

Alex Maierean (IQC Graduate Student) and Dr. Thomas Jennewein, along with Dr. Shihan Sajeed (IQC Affiliate and Visiting Researcher) have formed Phantom Photonics to capitalize on the unparalleled sensing capabilities emerging from research on quantum sensing.

IQC's research and innovative technologies are influencing the development of new companies and creating a significant marketplace impact. To date, the below 22 currently active startups have emerged from IQC research.

IQC quantum spinoff companies:

- evolutionQ
- Neutron Optics
- QuantumLaf Inc.
- Universal Quantum Devices
- SoftwareQ Inc.
- SpinQ
- Aquabits
- Northern Quantum Lights
- Phantom Photonics
- UpScale Quantum Solutions
- Qubo Consulting Corp.
- High Q Technologies LP
- BioGraph Sense Inc.
- Qubic Inc.
- Single Quantum Systems
- QEYnet
- Foqus
- Q-Block Computing Inc.
- Aegis Quantum
- Incoherent Vision
- Chiral Quantum Inc.
- Quantum Creative Minds Inc.

NB: In the past, researchers were not required to report on patents or commercialization activities. The actual number of patents and/or licenses is not known and may be higher.

While nearly 42% (12/31) of IQC principal investigators have commercialized their expertise and research through spinoff companies and patents, startups are also emerging from the labs and minds of research associates, postdoctoral fellows and graduate students. Additionally, the active mentorship of IQC faculty members also takes the form of advising quantum companies (both quantum and non-quantum firms), coaching early alum focused on careers in industry, and collaborating with accelerator and business development hubs in and beyond Waterloo's quantum ecosystem.

IQC is aware that quantum startups have unique challenges to move from idea to prototype to a viable business. After researching what support would be most useful to our startup community, IQC has begun building partnerships with startup incubators with a proven track record including the University of Waterloo's Velocity program and Creative Destruction Lab. How these incubators and accelerators can help quantum startups is described later in this report.

Transforming quantum ideas into impactful technologies

In addition to the 22 startups listed above, there are dozens of startups that have been launched by IQC members after they left IQC (KETS Quantum Security Ltd, Photonic Inc. and more) many of the founders describe the origin of their businesses with something like 'we were in the lab investigating….'. How is it that IQC is the common denominator for so many startups? The foundational idea for IQC was to investigate fundamental scientific questions to produce a revolutionary tool – a quantum computer. In order to investigate questions of fundamental science, world-class researchers were enticed to Waterloo. These researchers arrived with a long list of questions to be answered, each of which represents an opportunity for highly motivated graduate students. Unique resources were built, such as the Quantum Exploration Space and QNFCF; the former director of QNFCF, Vito Loguidice, described the lab as a sandbox that didn't depend on long production runs but could test out many different designs – a unique asset in Canada. UWaterloo also assigns all IP to investigators, which creates an advantageous environment for cash strapped startups. What IQC does better than any research institution in Canada is to provide opportunities. Opportunities to investigate leading-edge ideas, opportunities to experiment widely, and opportunities to interact with the broadest group of quantum-focused scientists in Canada. These opportunities drawn in highly motivated and successful students. IQC also provides tangible means to capitalize on opportunities by providing dual purpose (research & startup) space, equipment and expert support. Motivated students surrounded by opportunity produce economic and academic success, in many cases simultaneously.

At IQC, research excellence and innovation go together. Its rich entrepreneurial culture attracts and supports quantum experts that choose to go beyond aspiration to develop impactful technologies. The most striking successes that have emerged from IQC post-pandemic are as follows:

- Keysight Technologies keeping Quantum Benchmark in Waterloo Region after acquiring it in Y2022 so that the company continued to thrive from the unique environment Waterloo's Quantum Ecosystem offers. The valuable technology at Quantum Benchmark was commercial tools for characterizing and validating quantum processors which will be integral to a working quantum computer.
- Startup evolutionQ raised $7M in series A funding in FY 2022-2023 (May). evolutionQ attracted the attention of SandboxAQ (an Alphabet spinoff) as well the venture capital firms The Group Ventures and Quantonation. evolutionQ ensures safety using Quantum Key Distribution, which fulfills the promise of privacy emerging from fundamental physical processes.
- HighQ Technologies secured $3.75 million in funding from the Federal Government in February of 2024 for the development of quantum-enabled scientific instruments. This adds to the $6.5 million in funding that High Q received in 2019. HighQ was spun out of Dr. David Cory's lab in 2014 and

celebrates its first decade of success with more than 10 employees and a bright future.

Promoting Entrepreneurial Ecosystems Opportunities

In addition to the two new startups mentioned above and the three companies have reached operational maturity, IQC has direct ties to 18 additional startups in various phases of development. For example:

- Foqus, a startup we reported on in 2021-2022 is taking full advantage of the entrepreneurial support that is available to founders, both in Waterloo and in Toronto. Foqus graduated from the Quantum Stream of the Creative Destruction Lab (CDL) program in 2021. Since that time, Foqus has entered a very sharp growth stage. In 2023 Foqus had at least 6 employees (non-founder, non-partner) and is currently hiring for at least 2 roles – both posted roles prefer a master's degree and at least some exposure to quantum information science. Given the preferred qualifications for the role it seems likely that Foqus may be recruiting at IQC.
- Qubo Consulting Corp., a startup run by IQC Research Associate Katanya Kuntz, is based on Kuntz's demonstrated expertise in quantum communications and helps to integrate quantum science into existing industries like RF and Microwave engineering. In 2023-2024, Qubo delivered its first micro-credential course in partnership with Mitacs focusing on Quantum Skills & Entrepreneurship. Since then, Qubo has begun work with Alberta Catalyzer, an Alberta based incubator that supports tech-based businesses across Alberta.
- Single Quantum Systems Inc., where associate professor Michael Reimer is Chief Science Officer and Co-Founder (along with J.P Bourgoin – IQC alum, CEO and co-founder) won the 2023 Photons Canada/Photonics North Pitch Competition. With several contracts with the federal government and a well-developed pitch, SQS has a steady cash flow and bright future.

In addition to the number of startups directly associated IQC, it is noteworthy that there are startups in early stages of development, growth stages and late stages of development.

It is worth noting that most of these startups are centred around IQC on a single city bus route. A grad student could get on a bus at IQC and get off that same bus for an internship at QVIL, a job at HighQ or open a startup at the Accelerator Centre without changing buses.

IQC also has connections to startups in Toronto (Foqus), Sherbrooke (Qubic), Montreal (Anyon), Calgary (Qubo) and Vancouver (1Qbit & Photonic). IQC also has strong ties to more mature operations in Toronto (Xanadu) and Vancouver (D-Wave).

Without IQC acting as a central hub for the entire Canadian quantum information effort it is unlikely that Canada would be seen as a world leader in quantum.

Thanks to Federal investment and private philanthropy over the last decade, IQC has become a quantum information hub for Canada with the talent, capacity and scale that enable it to connect academics, entrepreneurs, industry across Canada. This early investment and IQC's rapid progress is at the root of Canada's leadership in quantum information, science and technology. We see the ripple effect with the development of other quantum centres across Canada and the publication of the National Quantum Strategy which strengthens Canada's position.

Promoting opportunities for IQC researchers to connect with Waterloo's entrepreneurial ecosystem through networking opportunities and formal events in partnership with the broader start-up networks in Waterloo Region

With more than 40% of current IQC faculty involved in the commercialization of technology emerging from their labs, including both directly linked and indirectly linked startups, IQC is helping to create the conditions for startup success. IQC members also hold nearly 100 patents and have had patents granted in fiscal 2023-2024 and well as provisional patents granted pending review.

This economic success does not emerge from a vacuum. As mentioned, the Quantum Connections Conference is a unique event where leading academics, venture capitalists, IP lawyers, successful executives and potential entrepreneurs can sit in the same space and have focused conversations that lead to tangible outcomes.

IQC also hosts Creative Destruction Labs seminars quarterly to ensure that members have access to the largest incubator in Canada. Dr. Michele Mosca (CEO evolutionQ, professor Combinatorics and Optimization, IQC co-Founder) is a CDL Mentor. Mosca's proximity to Waterloo means that, not only have he and IQC Executive Director Nobert Lütkenhaus already built their own successful company, Mosca has also been available to provide invaluable guidance to SoftwareQ and Foqus. Similarly, Dr.'s Jennewein and Pushin are involved with companies where student members at IQC are co-Founders (Phantom Photonics and Incoherent Vision respectively).

IQC also hosts tours of potential funders, including government funding bodies, large multi-national corporations, and other potential investors. Where time and interests align, IQC will actively broker meetings between investors and founders to ensure that economic success accrues to the Waterloo region.

In 2022, IQC launched IQC Canada Inc., a not-for-profit arm of IQC with the goal of providing strategic commercial and market support to push quantum research beyond the boundaries of academic institutions. IQC and IQC Canada Inc. will embrace this new model and mobilize its expertise and resources to strengthen Canada's science, technology and innovation excellence and global leadership.

In 2023, IQC inaugurated the Quantum Connections Conference to bring together many diverse partners in the Canadian technology development space. Partners include venture capitalists, government partners, researchers, entrepreneurs and commercial groups with well-established use cases for emerging quantum technologies.

IQC is proactively creating an environment where members have access to entrepreneurial opportunities as well as monitoring the environment across the country and the world to ensure that our researchers can best promote their work. This activity has resulted in demonstrated success of startups emerging from IQC and businesses locating operations in the Waterloo region to take advantage of the HQP emerging from IQC.

Objective E

Brand Canada as a place to conduct research in quantum information science and technologies.

Expected Results: Brand Canada as a place to conduct research in quantum information technologies.

Planned Activities:

- Promoting Canada internationally as a place to conduct research in quantum technologies by participating in global quantum initiatives (including conferences, talks, seminars and other events)
- Being a catalyst for collaborations of quantum information scientists across Canada and around the world
- Contributing to the national and global quantum information science and technology community through organizing and participating in conferences both in Canada and abroad.
- Organizing three conferences that involve multidisciplinary participants
- Continuing to host visits to IQC by international scientists and academics
- Inviting participants from industry and foreign government agencies to promote Canada as a reliable, advanced partner in quantum information science.

Promote Canada as international place for quantum technology research through participation in global quantum initiatives

Quantum information research and technology remain a cutting-edge science. As one of the most comprehensive quantum research institutes in the world, as well as one of the oldest quantum institutes, IQC has thrived by creating a community of academically like-minded people. Cross-appointed faculty members at IQC (Cory, Mosca, Wilson, Laflamme, among others) supervise students from outside their home departments which means that students gain broad exposure to ideas that they may not access in more traditional programs. Demonstrably excellent teachers like Rajibul Islam (President's Excellence in Teaching – 2021 and Excellence in Science Teaching – 2024) and Adam Wei Tsen (Excellence in Science Research – 2023) means that students and their careers are a significant focus for our faculty.

In addition to renowned faculty members and post-docs, students arrive at IQC for a sense of community as well as academic focus.

For example, Dr. Sara Zafar Jararzadeh has been deeply involved with the quantum community at IQC for almost a decade. Sara first came to Waterloo to develop professional cryptographic skills through CryptoWorks21 in 2016 while completing her PhD with Dr. Gilles Brassard and Louis Savail at Université de Montreal. While Brassard is a towering figure in Canadian quantum, he recommended IQC to Sara as a place where there was a larger community of like-minded researchers. Through her work in CryptoWorks21, Sara arranged for an internship at ISARA, an internship at RBC, finished her PhD, worked at IQC as a long-term research visitor, then as a postdoctoral fellow and began a career at RBC followed by a move to Synopsys. During this time Sara was connected to IQC through research and met many of the cryptographic experts that have come through IQC through their shared interests. Recently, in addition to her career, Sara has returned to Cryptoworks21 to guide the program through the next phase of cryptographic standards. As NIST, ETSI, ISO and PSI work through the certification of new protocols for post-quantum cryptography, Sara will leverage her academic and professional connections to ensure that the next generation of IQC students will be exposed to the wide range of skills that are needed to implement these standards across the public and private sector industries. Sara came to Waterloo to find a community and, a decade later, is helping to build that community.

IQC also has an entrepreneurial community. J.P. Bourgoin (mentioned above as CEO and co-Founder of Single Quantum Systems) knew that he was interested in developing emergent technologies into a vibrant company. Bourgoin arrived at IQC in 2010 and completed his doctorate in 2014. Since then, J.P. has worked with Michael Reimer to push technology into industry through several startups, including QEYNet and SQS. A decade later, in 2020, Alex Maierean arrived from the University of Toronto as an Undergraduate Research Assistant (URA). Alex had started her undergraduate degree focused on finance and ended with a degree in Mathematics. Attracted to Waterloo for

the ideas percolating at IQC but also by the 100% inventor owned IP rights, Alex began a master's degree in Applied Math in 2021 under the supervision of Nobert Lütkenhaus (IQC Executive Director and evolutionQ CTO) and Thomas Jennewein (UQDevices, CEO). Within 2 years, Alex has found herself pushing advanced sensing technologies based on quantum coherence into industrial applications as CEO and co-Founder of Phantom Photonics. Low-power, high resolution, robust Lidar systems have applications in transportation (including self-driving), mining, precision agriculture, satellite navigation and defense. As one of the first master's students to be involved with creating a startup at IQC, Alex is expanding the entrepreneurial community here in Waterloo.

These IQC members are actively participating in global quantum initiatives; Sara's work will ensure that future IQC members are well prepared to transition from academia to industry by rebuilding the Cryptoworks21 curriculum to account for newly updated cryptographic standards published by ETSI, ISO, NIST and Psi. While this work may sound obscure, it will affect every person that uses the internet for decades to come.

Similarly, improvements in quantum sensing are likely one of the next impactful technologies that will emerge from the global quest to build a quantum computer. Pushing the adoption of that technology will not only improve the lives of people everywhere will also push forward the entire project of quantum information science.

Be a catalyst for collaborations of quantum information scientists

We have a strong international reputation, excellent talent, and critical infrastructure. With IQC and the Waterloo Quantum ecosystem partners, we are working on the scale needed to develop and commercialize quantum opportunities. Collaborations occur at IQC because there is a large enough community here where you can discuss cutting edge cryptography or quantum coherence-based Lidar or ultra-cold quantum chemistry at the coffee maker. If a student arrives at IQC and wants to start a business, they will find help to do that here. If a student arrives at IQC and would like to hold a Canada Research Chair in quantum science one day, they can find chairholders among our current faculty and among our former graduate students to model their career on. If a student arrives and would like a faculty position in one of 15 countries where former IQC students hold faculty positions, there are examples here. Civil servants, legal scholars, faculty members, founders and researchers have all emerged from IQC and many of them remain in communication with IQC for many years. For example, Rahul Jain accepted a postdoctoral fellowship at IQC from 2006-2008 with Dr. Richard Cleve. More than 15 years later and half a world away (CQT, Singapore) he still has an ongoing collaboration with IQC faculty member Ashwin Nayak and recommends his students to IQC (most recently Srijita Kundu, current IQC postdoctoral fellow).

Long-term Academic & Scientific Visitors

IQC hosts leading academic visitors from organizations around the world. These colleagues and collaborators come to Waterloo to engage with leading scholars, participate in cutting-edge research and collaborate with a varied group of experts at a world-class centre for quantum science. Having fully recovered from the pandemic, IQC hosted 95 visitors from major research centres around the globe, leading quantum corporations, government advisors and startups interested in collaborating with like-minded experts:

Global Research centres	Major Corporations	Startups and Government
Harvard	Google Quantum AI	Craft Prospect Ltd
University of Toronto	Ernst and Young	National Research Council Canada
Yale University	NTT Research	German Aerospace Center
TU Delft	Apple	National Institute of Standards and Technology
QuSoft, Research Centre for Quantum Software, The Netherlands	IBM Research	Bluefores Inc.
Massachusetts Institute of Technology	Sandia National Laboratories	Xanadu Quantum Technologies

Over the last year, IQC has built new and strengthened existing relationships with other Canadian universities and organizations in quantum research and technology.

A strong indicator of Canada and IQC's leadership in quantum excellence around the world is the prestigious visitors who come and spend time at the Institute for research, collaboration and knowledge dissemination. IQC continually attracts top-ranking visitors from global research centres and corporations.

A full list of academic and scientific visitors can be found in in Appendix H on page 103.

Promote collaborations through participation in national and international conferences

In addition to bringing leading scholars to Waterloo for cross collaboration IQC faculty were collectively asked to speak at over 100 conferences with organizers from around the world. The below list highlights selected scientific conferences IQC members were invited to speak at and/or attended. A complete list of conference participation is listed in Appendix G on page 95.

- Assorted experiments with atoms in hollow-core fibers, SPIE Photonics West

- Next-generation photonic source based on lateral GaAs/AlGaAs heterostructure devices, Canadian Semiconductor Science and Technology Conference
- How to simulate quantum measurement without computing marginals, IBM Qiskit quantum information science seminar series
- Quantum information processing with trapped ions, 10th international Petra School of Physics, Amman
- Feshbach Resonances and Ultracold Chemistry Workshop on Ultracold Molecules 2023, University of Warsaw
- Canada's first quantum communication satellite, Photonics for Quantum Conference, Rochester, New York
- Introduction to Quantum Approximate Algorithms, Special seminar, The Korea Electrotechnology Research Institute, Changwon, Korea
- Deep Neural Network Models for Random Telegraph Signals, Workshop on Quantum and Artificial Intelligence, Massachusetts Institute of Technology
- Quantum Potential, Council of Canadian Academies for ISED/NRC, Ottawa
- The quantum internet and why satellites will be needed, QIT46 Symposium
- Rate-Distortion Theory for Mixed States, International Centre for Mathematical Sciences (ICMS), Edinburgh
- Investigation of coherence of niobium-based resonators enabled by a fast-sealing microwave cavity, D-Wave, Vancouver
- Quantum Communication beyond QKD, ARAQNE Collaboration Meeting, Calgary, Alberta
- Developing iontronics for quantum materials and neuromorphic applications, IEEE ICEICT 2023, Qingdao, China
- On hiding quantum factoring inside simulation algorithms, QIT Consortium, NTT Research
- Hardware efficient quantum computing using qudits, Quantum Days 2024, Calgary, Alberta
- Bounds on Sample Complexity via Information Theory, Session on Quantum Information Theory, CMS Summer Meeting, Ottawa
- Neutron Interferometry and structured waves of matter and light, 6th Joint Meeting of the APS Division of Nuclear Physics and the Physical Society of Japan, Hawaii
- Quantum Information Processing with Barium Ions, Gordon Research Conference in Atomic Physics, Newport, Rhode Island
- Gordon Research Conference in Atomic Physics, Quantum Information, Les Diablerets, Switzerland

Tours and Meetings at IQC

In addition to long term academic visitors and faculty talks at more than 130 opportunities for various audiences IQC also brings in tour groups where the interests of the groups may align with promoting quantum science among new academic groups or among strategic audiences. In 2023-2024, IQC hosted more than 35 delegations consisting of more than 450 people. Government tours included ministers from France, Singapore, Korea, the Netherlands, Austria and Canada. Industry groups included representatives from life sciences, automotive, accounting and investment, scientific labs, cryptography and advanced manufacturing. Academic groups included representatives from artificial intelligence institutes, research and technology parks, deep tech groups, incubators and various professors and researchers that were unable to stay for a longer period of time.

Brand Canada as a place to conduct research in quantum information technologies

Branding Canada as a place to conduct research in quantum information technologies is an ongoing effort by many people at IQC. In addition to the internal community, long term visitors, faculty outreach and tours hosted at IQC outlined above there are additional ongoing initiatives taking place at IQC. Over time researchers have worked with our Communications and Strategic Initiatives team to build a coherent vision of a quantum future and to invite the world to Waterloo to see that message. Many different tools have been used at IQC to promote Canada and Waterloo as an inclusive home to QIS. As described above researchers have attended conferences worldwide to promote research and IQC has invited leading researchers from across the world to come to Waterloo and collaborate with our people. IQC also provides tours to foreign government officials, science and leadership-based NGO's and partner organizations from across Canada to promote Canada and Waterloo as a home of quantum research. The most recent link in this chain of events is developing a major cross-industry conference that brings together many different aspects of the technology development ecosystem for a conference that examines the state of quantum in Canada and discusses what is needed for a strong future from experts in academia, government, industry and startups.

Quantum Connections

Starting and running a business is a time intensive undertaking. Starting a business at the cutting edge of a research field after having spent a decade honing a very particular skill set is an even more daunting task. The Quantum Connections Conference is designed to put leading researchers (from many institutions across Canada) in the same room as investors, managers and people with entrepreneurial experience. The inaugural Quantum Connections Conference, held in May 2023, featured startups from the University of Toronto, Université de Sherbrooke, University of Calgary and University of British Columbia alongside researchers from IQC. It also included representatives from law firms, venture capitalists, incubators and government. Several connections between

startups were facilitated, for example Qubo and Qubic found an opportunity to work together to outline technical details for non-technical audiences. This conference focused on providing attendees with many networking opportunities, with an aim to foster new collaborations and creating connections between the academic, industrial and government sectors. A mix of panel discussions and keynote presentations critically examined the challenges that Canada is facing as the global quantum ecosystem expands, and offered suggestions and proactive steps that quantum professionals can take to ensure that Canada continues to have an enduring continued momentum within the global quantum landscape.

Quantum Connections was an incredible success, attracting over 150 quantum professionals to engage in the two-day conference, and the feedback from speakers, panelists, attendees and participants has been overwhelmingly positive. IQC will be hosting this conference again in May of 2024 and we expect that the impact on business formation, job creation and wealth creation will be measured in millions of dollars for Canadian society.

In addition to Quantum Connections, IQC also hosted the previously mentioned Security Proof Workshop 2023, the WIN-IQC workshop and the Quantum Innovators weeklong workshop. While Quantum Connections emphasizes the entrepreneurial and industrial applications that require quantum solutions these academic conferences brand Canada as a highly inclusive, leading research community to both Canadians and international scholars. IQC is central to advancing quantum technologies in Canada, both from a corporate and a research perspective.

Canada recognized the importance of quantum early, and thanks to crucial support from federal and provincial governments, the university sector, and philanthropy, we are a leader in quantum technologies. IQC has reached a critical capacity for talent, expertise, and specialized infrastructure required for advancing quantum applications. This has been a magnet attracting scientists to IQC and Canada to work and study. While we are a large country geographically, the quantum ecosystem is tightly connected — most quantum researchers worldwide have come through IQC's doors in one capacity or another. Conducting research at the highest international levels is a driving force, but beyond this, we as a country are focused on collaborating for the betterment of the community and nation. IQC hires the brightest minds who will be the glue to keep our community together, engage in information sharing, and grow the next generation of scientists. IQC opens its doors to long-term researchers to facilitate collaboration and draw others from across the world to Canada. This expertise and culture, combined with a deeply rooted entrepreneurial ecosystem, has meant there is there are opportunities along the innovation continuum for all—study what it means to have a quantum advantage (pure mathematics), work on quantum satellite or move innovations out of the university to the marketplace. The opportunities are endless here.

APPENDICES

A. Risk Assessment & Mitigation

		LIKELIHOOD		
	HIGH	LOW 6	MED 8	HIGH 9
IMPACT	MED	3	5	7
	LOW	1	2	4

Risk Factor	Impact Score	Likelihood Score	Risk Rating	Explanation of Score	Mitigation Measures
Turnover in faculty negatively affects research output and reputation	High	Medium	8	IQC has a significant research output which contributes to ongoing reputational excellence. IQC faculty also have a very strong entrepreneurial bent and the private sector demand for quantum talent is very high. The very high demand for high level quantum talent creates an environment where faculty may be mobile.	Continue to identify and implement new approaches to virtual collaborations. More aggressive recruiting in the face of increasing national and international competition for high performance individuals.
Transformational Technologies may render current research less relevant	Med	Low	3	If IQC research is rendered less relevant, highly qualified personnel (HQP) and investment will go elsewhere.	Continued focus on relevant sub-fields in quantum information science and engineering. Engage quantum authorities outside IQC through our Scientific Advisory Committee to provide objective commentary on IQC research focus/ progress. Ongoing collaboration with partners to ensure research aligns with societal priorities and economic drivers.

Difficulty recruiting the best and brightest HQPs	High	Med	8	McKinsey estimates that 50% of jobs in quantum remain unfilled. To address this need for qualified personnel the number of quantum programs in North America has jumped by more than 50 in the last year. IQC is competing with both an increased private sector demand and increased competition for graduate students in quantum science.	Diversify markets/ countries from which students are recruited. Promote IQC sufficiently. Ensure excellent research, a world-class research environment with offering HQP unique opportunities and an inclusive community for HQP to success.
Reduced Funding	High	Med	8	Reduced funding will result in reduced and streamlined operations. Activities will be curtailed and progress on outreach, communications and support will slow progress.	Diversify funding sources as much as possible, increase partnerships with other SSF recipients and other quantum ecosystem hubs to maintain research and communication baseline performance.

B. Publications

April 1, 2023-March 31, 2024 (Indexed)

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April 1, 2023 – March 31, 2024

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	Fraunhofer Institut, Germany
	Politecnico di Milano, Italy
	University of Padova, Italy
	National University of Singapore, Singapore
	University of Bristol, UK
	Craft Prospect Ltd., UK
	University of Illinois, USA
	Jet Propulsion Laboratory, USA
Na Young Kim	Adam Wei Tsen, University of Waterloo, Canada
	Bhashyam Balaji, Defense Research and Development Canada (DRDC)
	Anthony Damini, Defense Research and Development Canada (DRDC)
Raymond Laflamme	Quantum Valley Investments, Canada
	Perimeter Institute, Canada
	Canadian Institute for Advanced Research, Canada
	Keysight technologies, Canada
	Institut Quantique (Sherbrooke), Canada
	Quantum Algorithm Institute (BC), Canada
	University of Guelph, Canada

	1Qbit, Vancouver, BC
	Xanadu Quantum Technologies, Toronto, ON
	Technion, Israel
	University College London, UK
	Phasecraft, UK
	Imperial College, UK
	University of California at Berkeley, USA
	University of Tennessee, USA
	Dept of Homeland Security, USA
Debbie Leung	Technical University of Munich, Germany
	Centrum Wiskunde & Informatica, Netherlands
	Massachusetts Institute of Technology, USA
	University of Maryland, USA
Adrian Lupascu	Canada Microfabrication Corporation (CMC), Canada
	Department of Energy, FermiLab, Jefferson Lab, USA
	Defense Research and Development Canada (DRDC)
	D-Wave Systems (partners in Alliance grant)
	Felix Motzoi, Theoretical Physics Center Juelich
	Eduardo Martin Martinez, Applied Math, University of Waterloo
	Sahel Ashhab, National Institute of Information and Communications, Japan
Norbert Lütkenhaus	Thomas Jennewein, University of Waterloo, Canada
	Michele Mosca, University of Waterloo, Canada
	Christoph Marquardt, Max Planck institute for the Science of light, Germany
	Renato Renner, ETH Zurich, Switzerland
	Daniel Gauthier, Ohio, USA
	Michael Reimer, University of Waterloo (IQC)
	Daniel Oi, University of Strathclyde, UK
	Harald Weinfurter, LMU Munich, Germany
	Bruno Huttner, ID Quantique, Switzerland
Matteo Mariantoni	Multiverse Computing, Toronto, Canada
	PasQal, France, the Netherlands, Canada
	CMC, Microsystems, Canada
	Zero Point Cryogenics Inc., Canada
	BEIT Canada Inc., Canada
	Angstrom Engineering, Canada
Guo-Xing Miao	Jagadeesh Moodera, MIT
	Hao Zeng, SUNY Buffalo
	Sergey Zhdanovich, Andrea Damascelli, CLS/UBC
	Jing Fu, Tongji U
	Qiang Li, Shandong Li, Qingdao U

	Saeid Taherion, CNL
Michele Mosca	SERENE-RISC, Canada
	Global Risk Institute, Toronto, Canada
	QEYnet, Canada
	Crypto4a, Canada
	Creative Destruction Lab, Canada
	Rhea Canada Inc, Canada
	NIT Research Lab, Japan
	Centre for Quantum Technologies (CQT), NUS, Singapore
	CERN, Switzerland
	Transumtex, Switzerland
	University of Bristol, UK
	KETS Quantum Security, UK
	National Institute of Standards and Technology (NIST), USA
	CERN, Switzerland
Christine Muschik	Peter Zoller, Rainer Blatt and Martin Ringbauer, Institute for Quantum Optics and Quantum Information (IQOQI), Austria
	Wolfgang Dür, University of Innsbruck, Austria
	Robert Meyers, Perimeter Institute (Qfun), Canada
	Randy Lewis, York University, Canada
	Alessio Celi, Universitat Autònoma de Barcelona, Spain
	Mentoring Mattias Troyer, Microsoft, USA
	Oakridge National Labs, USA
	Member of the German Physical Society
	IBM
	Jad Halimeh, Ludwig Maximilians University Munich
	Zohreh Davoudi, University of Maryland
	Norbert Linke, University of Maryland and Duke University
	Ashok Ajoy, University of California, Berkeley
	CIFAR (member of the Program on Quantum Information Science)
	PINQ2, Canada
Ashwin Nayak	Dave Touchette, University of Sherbrooke, Canada
	Frederic Magniez, CNRS and University of Paris, France
	Rahul Jain, CQT and National University of Singapore, Singapore
	Henry Yuen, Columbia University, USA
Dmitry Pushin	PROSPECT (Yale), USA
	NIST (Neutron Interferometry), USA
	CEVR, Hong Kong
Michael Reimer	Single Quantum Systems, Canada
	National Research Council of Canada, Canada
	Delft University of Technology, Netherlands

	Royal Institute of Technology (KTH), Sweden
	Perimeter Institute, Canada
	Northern Quantum Lights, Canada
	CMC Microsystems, Canada
Kevin Resch	National Research Council, Canada
	Perimeter Institute, Canada
Crystal Senko	Sandia National Labs, USA
	Quantum Systems for Fundamental Science, USA
	Kazi Rajibul Islam, University of Waterloo
	NSERC (CRC Trapped Ion Quantum Computing)
	TRIUMF, Vancouver, Canada
William Slofsta	NSERC, Canada
	Alfred P. Sloan Foundation, USA
Graeme Smith	United States Department of Energy
	National Science Foundation (USA)
	United States Army
Adam Wei Tsen	McMaster University, Canada
	Renmin University of China, China
	Chinese Academy of Sciences, China
	University of Freiburg, Germany
	Goethe-Universität Frankfurt, Germany
	Weizmann Institute of Science, Israel
	Cornell University, USA
	University of Michigan, USA
	Texas Tech University, USA
	University of Texas at Austin, USA
	Wake Forest University, USA
	U.S. Army Research Office, USA
Christopher Wilson	Professor Ivette Fuentes, University of Austria, Austria
	Qubic, Canada
	Professor Enrique Solano, University of Basque Country, Spain
	Professor Ozgur Mustecaplioglu, Koc University in Istanbul, Turkey
	Dr. Jose Aumentado, NIST-Colorado, USA
	SNOLAB, Sudbury Canada
	Army Research Office, USA
	Per Delsing, Chalmers University of Technology, Sweden

E. Postdoctoral Fellows

Pratik Adhikary	Katie McDonnell
Rubayet Al Maruf	Alexander Meiberg
Paul Anderson	Sainath Motlakunta
Jeremy Bejanin	Tarun Patel
Paula Belzig	Pei Jiang Low
Adam Bene Watts	Roksana Rashid
Jamal Busnaina	Rodolfo Reis-Soldati
Ningping Cao	Pardis Sahafi
Anirban Ch Narayan Chowdhury	Zheng Shi
Mohammad Soltani	Fangchu Chen
Bowen Yang	Sasan Vosoogh-Grayli
Fatemeh Fani Sani	Ernest Tan
Xi Dai	Abhijit Chakraborty
Yonas Assefa Eshete	Daniel Tay
Alexander Frei	Lin Tian
Richard Germond	Yu-Ting Chen
Nafiseh Ghoroghchian	Simon Vallieres
Labanya Ghosh	Akbar Jahangiri Jozani
Brad Van Kasteren	Sam Jaques
Michael Jaroszewicz	Gaili Wang
Reza Kohandani	Yunkai Wang
Hlér Kristjánsson	Peixue Wu
Meenu Kumari	Ali Assem Abdelkader Mahmoud
Srijita Kundu	Rui Yang
Xiaoyang Liu	Sara Zafar Jafarzadeh
Meixin Cheng	Yujie Zhang
Chris Wyenberg	

F. Graduate Students

PhD Students

Abdolreza Pasharavesh	Junan Lin
Adam Teixido-Bonfill	Kelly Wurtz
Adina Goldberg	Kent Ueno
Aditya Jain	Kieran Mastel
Albie Chan	Kimia Mohammadi
Alec Gow	Kohdai Kuroiwa
Amir Arqand	Lars Kamin
Amit Anand	Luke Neal
Amolak Kalra	Maria Ciudad Alanon
Anastasiia Mashko	Maria Papageorgiou
Andrew Cameron	Maria Preciado Rivas
Andrew Jena	Matheus Zambianco
Annie Ray	Matteo Pennacchietti
Anthony Vogliano	Matthew Duschenes
Anya Houk	Melissa Henderson
Archishna Bhattacharyya	Nachiket Sherlekar
Arsalan Motamedi	Nicholas Zutt
Avantika Agarwal	Nikhil Kotibhaskar
Benjamin Maclellan	Nikolay Videnov
Bharat Kuchhal	Noah Gorgichuk
Bohdan Khromets	Noah Greenberg
Brad Van Kasteren	Noah Janzen
Brady Cunard	Omar Hussein
Brendan Bramman	Pablo Jaime Palacios Avila
Bruno De Souza Leao Torres	Padraig Daly
Caroline De Lima Vargas Simoes	Paul Anderson
Cheng (Auda) Zhu	Paul Rev (Sung Eun) Oh
Chi Zhang	Pei Jiang Low
Christopher (Xicheng) Xu	Pritam Priyadarsi
Chung-You (Gilbert) Shih	Rabiul Islam
Cindy (Xinci) Yang	Ramy Tannous
Collin Epstein	Reza Asadi
Connor Kapahi	Rory Soiffer
Connor Paul-Paddock	Rubaya Absar
Cristina Rodriguez	Sahand (Seyed) Tabatabaei

Daniel Centeno Diaz	Sai Sreesh Venuturumilli
Devashish Jayant Tupkary	Sainath Motlakunta
Einar Gabbassov	Salehi Iman
Ejaaz Merali	Samuel Winnick
Emma (Annelise) Bergeron	Sanchit Srivastava
Eric Culf	Sayan Gangopadhyay
Erickson Tjoa	Shayan Majidy
Esha Swaroop	Shlok Nahar
Estevao De Oliveira	Sonell Malik
Evan Peters	Songmin Xu
Everett Patterson	Sriram Gopalakrishnan
Forouzan Forouharmanesh	Stefanie Beale
Gabriel Vinicius De Oliveira Silva	Stephane Vinet
Guangyu Peng	Stephen Harrigan
Guillaume Verdon-Akzam	Sukanya Ghosal
Hawking (XingHe) Tan	Tales Rick Perche
He (Ricky) Ren	TC Fraser
HeeBong Yang	Tiasa Mondol
Henri Morin	Vahid Reza Asadi
Jack Davis	Wilson Wu
Jamal Busnaina	Xi Dai
Jennifer Zhu	Yawen Peng
Jesse Allister Kasian Elliott	Yi Hong Teoh
Jiahui Chen	Yinchen (Calvin) Liu
Jingwen Zhu	Yu (Jerry) Shi
Joan Etude Arrow	Yuming Zhao
Jose Polo Gomez	Zachary Merino

Master's Students

Abrar Kazi	Mohammad Ayyash
Adam Winick	Muhammad Shaeer Moeed
Akimasa Ihara	Namanish Singh
Alev Orfi	Nicholas Allen
Alexander Kazachek	Nithin Aaron
Alexandra Kirillova	Owen Lailey
Ali Khatai	Parth Padia
Anastasiia Bershanska	Paul Del Franco

Andres Schang	Pulkit Sinha
Andrew Lagno	Richard (Lewis) Hahn
Andrija Paurevic	Sarah Odinotski
Aosheng (Michael) Gu	Sarah (Meng) Li
Artem Zhutov	Satchel Jeanne Armena
Benjamin Jarvis-Frain	Sathursan Kokilathasan
Brinda Venkataramani	Scott Johnstun
Camille Lacroix	Sepehr Rashidi
Cheng Zheng	Severyn Balaniuk
Croix Gyurek	Shilpa Mahato
Danny (Xiangzhou) Kong	Shreyas Natarajan
Debankan Sannamoth	Soroush Khoubyarian
Dhruv Gopalakrishnan	Tanmay Joshi
Emiliia Dyrenkova	Tejas Naik
Fabien Lefebvre	Tony (Anthony) Lau
Fiona Thompson	Tristan Lismer
Gaurav Ashish Tathed	Victor Marton
Grant Brassem	Vyom Patel
Guofei (Phillip) Long	Wenxue Zhang
Ilyas Sharif	William Losin
Jack DeGooyer	Xianfan Nie
Jack (John) Burniston	Xiao Yang
Joshua McPherson	Xingyu Zhou
Justin Schrier	Xinning Wang
Kosar Shirinzadeh Dastgiri	YiDan Zheng
Liuhe Wang	Yifan Li
Lucas Hak	Zachary Mann
Lucas Roy	Zachary (Zach) St Pierre
Maeve Wentland	Ze Yuan (Michael) Li
Manar Naeem	Zeyi Liu
Matthew Piatt	Zhiying Yu
Megan Byres	Zhuoyang He
Megan Dawson	

G. Invited Talks & Conference Participation

Faculty Member	Title/Subject	Institution/Conference
Michal Bajcsy	Assorted experiments with atoms in hollow-core fibers	SPIE Photonics West, San Francisco, January 2024
	Building blocks for a hybrid quantum repeater	SPIE Photonics for Quantum, Rochester, United States of America, July 2023
Jonathan Baugh	Semiconductor quantum devices	Ray Laflamme 60th Birthday Conference, Waterloo, July 2023
	Next-generation photonic source based on lateral GaAs/AlGaAs heterostructure devices	Canadian Semiconductor Science and Technology Conference, Montreal, August 2023
	InSb surface quantum wells for proximity superconductivity	IQC-WIN workshop, Waterloo, October 2023
	Network architecture for a scalable spin qubit processor	Workshop on Quantum Computing: Devices, Cryogenic Electronics and Packaging (IEEE Circuits & Systems Society), Santa Clara, United States of America (virtual), October 2023
Shalev Ben-David		
Raffi Budakian	Novel Approaches in NanoMRI for Probing Atomic-Scale Material Structure	University of Konstanz, Germany, October 2023
	NanoMRI Measurements of Dynamic Nuclear Polarization Using Trityl Radicals	ETH Zurich, Switzerland, October 2023
	Nuclear Magnetic Resonance Diffraction (NMRd): A Probe of Structure and Dynamics of Spins at the Atomic Scale	University of California, Berkeley, United States of America, October 2023
	Novel Approaches in NanoMRI for Probing Atomic-Scale Material Structure	University of Basel, Switzerland, November 2023
	Novel Approaches in NanoMRI for Probing Atomic-Scale Material Structure	ETH Zurich, Switzerland, November 2023
	Novel Approaches in NanoMRI for Probing Atomic-Scale Material Structure	University of California-Davis, United States of America, February 2024
Richard Cleve	Infinite stabilizer states	Perimeter Institute, Waterloo, Canada, March 2024
David Gosset	How to simulate quantum measurement without computing marginals	Harvard University, United States of America, April 2023
	How to simulate quantum measurement without computing marginals	IBM Qiskit quantum information science seminar series (virtual), June 2023

	Classical simulation algorithms versus quantum computers	Q-site conference, Toronto, Canada, September 2023
	Classical simulation of peaked shallow quantum circuits	Google quantum AI computer science seminar, virtual, November 2023
	Stabilizer rank simulators	Quantum resources workshop, Singapore, December 2023
	Classical simulation of peaked shallow quantum circuits	Fundamental limitations to quantum computation workshop, BIRS, Banff, Canada, March 2024
Kazi Rajibul Islam	Quantum information processing with trapped ions	10th international Petra School of Physics, Amman, Jordan, October 2023
Alan Jamison	Coherent Chemistry with Ultracold Atoms and Molecules	Physics and Astronomy Colloquium, University of Waterloo, Ontario, Canada, February 2024
	Coherent Chemistry with Ultracold Atoms and Molecules	Physics Colloquium, McMaster University Ontario, Canada, November 2023
	Coherent Chemistry with Ultracold Atoms and Molecules	Physics and Astronomy Colloquium, University of New Brunswick, New Brunswick, Canada, October 2023
	Feshbach Resonances and Ultracold Chemistry	Workshop on Ultracold Molecules 2023, University of Warsaw, Warsaw, Poland, September 2023
	FrAg for Fundamental Physics	Science Week, TRIUMF, Vancouver, Canada, August 2023
	Laser Cooling to Quantum Chemistry	Quantum for Educators, Institute for Quantum Computing, University of Waterloo, Ontario, Canada, December 2023
	Laser Cooling to Quantum Chemistry	Quantum School for Young Scientists, Institute for Quantum Computing, University of Waterloo, Canada, August 2023
Thomas Jennewein	Long distance quantum communications – how fundamental science tests lead to satellite based quantum networks	Colloquium at Hyperspace, Rome, Italy, February 2024
	The future: Quantum Encryption	Quantum Enigma public event, St. Catherines, ON, Canada, January 2024
	Long distance quantum communications – how fundamental science tests lead to satellite based quantum networks	Colloquium, Brock University, St. Catherines, ON, Canada, January 2024
	Utilization of Optical Ground Station Testbed aiming for the international collaboration	SPIF workshop, Ithaca, New York, United States of America, December 2023
	QEYSSAT – THE CANADIAN QUANTUM SATELLITE MISSION	2023 Quantum Information Science Workshop, Rome, New York, United States of America, June 2023
	QEYSSAT – Canadas first quantum communication satellite	INSQT Workshop 2.1, Jena, Germany, May 2023

	QEYSSat – the Canadian quantum satellite mission	Colloquium at University of Innsbruck, Innsbruck, Austria, July 2023
	Canada's first quantum communication satellite	Photonics for Quantum Conference, Rochester, United States of America, June 2023
	QEYSSAT – a testbed for ground and space quantum networks	Quantum 2.0 conference – Panel on Quantum Internet Testbeds Across the World, Denver, United States of America, June 2023
	Hong-Ou-Mandel interference of unconventional temporal modes	Quantum 2.0 - Quantum-Enhanced Telescopy Workshop, Denver, United States of America, June 2023
	QEYSSat – the Canadian quantum satellite mission	Internal Seminar, Oberpfaffenhofen, Germany, July 2023
	Time-bin Encoded Photons over Multi-mode Channels: Advances on Quantum Communications and Sensing Over Free-space Channels	Quantum 2.0 Conference, Denver, United States of America, June 2023
	Networked quantum technologies and fundamental physics	INSQT Workshop 3, Berlin, Germany, August 2023
	Time-bin Encoded Photons over Multi-mode Channels: Advances on Quantum Communications and Sensing Over Free-space Channels	Photonics North 2023, Montreal, Canada, June 2023
Na Young Kim	Quantum Innovation Laboratory	Canadian Semiconductor Researcher Summit, University of Texas at Dallas, October, 2023
	Quantum Innovation Laboratory	Canadian Semiconductor Researcher Summit, University of Texas at Austin, October 2023
	Quantum Revolution 2.0	Yonsei School of Integrated Technology Seminar, Yonsei University, Songdo, Korea, September 2023
	Quantum Research Activities at the Institute for Quantum Computing & Quantum Innovation Laboratory	Quantum Computing Seminar, Yonsei University, Songdo, Korea, September 2023
	Introduction to Quantum Approximate Algorithms	Special seminar, The Korea Electrotechnology Research Institute, Changwon, Korea, August 2023
	Future Perspectives of Quantum Information Processing Science and Technology	National Information society Agency Workshop for Korea Quantum Industry Center Training Program, Seoul Korea, August 2023
	Quantum Research Activities at the Institute for Quantum Computing	2023 Canada-Korea Conference on Science and Technology, Ottawa, Canada, July 2023
	Quantum Revolution 2.0	2023 Canada-Korea Conference on Science and Technology, Ottawa, Canada, July 2023
	Deep Neural Network Models for Random Telegraph Signals	Worship on Quantum and Artificial Intelligence, Massachusetts Institute of Technology, Boston, May 2023
	The Second Quantum Revolution	The Korean-American Scientists and Engineers Association Distinguished Guest Series, Virtual, United States of America, April 2023

Raymond Laflamme	Quantum Potential	NRCan, Ottawa, Canada (virtual), March 2024
	Quantum Potential	NRC, Ottawa, Canada (virtual), February 2024
	Panel Discussion on the National Quantum Strategy	qConnect, University of Calgary, Canada, November 2023
	Quantum Potential	Invited talk; Council of Canadian Academies for ISED/NRC, Ottawa, Canada, November 2023
Debbie Leung	Purifying arbitrarily noisy quantum states	Banff International Research Station, Alberta, Canada, March 2024
	Quantum state purification	SwissMAP Research Station, Les Diablerets, Switzerland, February/March 2024
	The platypus of the quantum channel zoo and their generic nonadditivity	Southwest Quantum Information and Technology, 25th Annual SQuInT Workshop, University of New Mexico, Albuquerque, New Mexico, October 2023
	Rate-Distortion Theory for Mixed States	International Centre for Mathematical Sciences (ICMS), Edinburgh, United Kingdom, July 2023
	Rate-Distortion Theory for Mixed States	CMS 2023 Summer Meeting, Ottawa, June 2023
Adrian Lupascu	Investigation of coherence of niobium-based resonators enabled by a fast-sealing microwave cavity	D-Wave, Vancouver, Canada, March 2024
	Quantum sensing with superconducting devices	TRIUMF, Vancouver, Canada, March 2024
	Diamagnetic levitation – a platform for quantum sensing	QMUL - SNOLAB Workshop, Sudbury, Canada, January 2024
	Quantum sensing with superconducting devices	Northwestern Condensed Matter Physics Seminar, Evanston, United States of America, January 2024
	Capacitively shunted flux qubits with high anharmonicity: quantum control and decoherence	Technology Innovation Institute (virtual), United Arab Emirates, October 2023
Norbert Lütkenhaus	Security Statements for Practical QKD	Heraeus Seminar -Physics and Security, Bad Honnef, Germany, March 2024
	Quantum advantage for RNG? Round Table	Heraeus Seminar -Physics and Security, Bad Honnef, Germany, March 2024
	Quantum Communication beyond QKD	ARAQNE Collaboration Meeting, Calgary, Alberta, Canada, February 2024
	Quantum Key Distribution	International Summer School in Quantum Technologies, University of Birmingham, August 2023
	Quantum Key Distribution	Quantum cryptography tools workshop 2023, Waterloo, Ontario, July 2023
Guo-Xing Miao	Developing iontronics for quantum materials and neuromorphic applications	Zhengzhou University summer school on basic physics, Zhengzhou, China, July 2023

	Developing iontronics for quantum materials and neuromorphic applications	IEEE ICEICT 2023, Qingdao, China, July 2023
	Iontronics for information processing	13th Shandong Physical Society meeting, Dezhou, China, July 2023
	Applications of Spiontronics	Tongji University, Shanghai, China, December 2023
	Spiontronics Development and Application	Zhengzhou University, Zhengzhou ,China, January 2024
Michele Mosca	On hiding quantum factoring inside simulation algorithms	QIT Consortium, NTT Research, virtual, December 2023
	Introduction to Quantum Computing & Quantum Cryptography - Key Research	Cyberwal in Galaxia Program, CYBERSCHOOL – QUANTUM DAY, Redu, Belgium, December 2023
	Beyond Encryption: Strategies for a Post-Quantum Era	Annual Meeting on Cybersecurity 2023 and Quantum Economy Meeting 2023 of the World Economic Forum, Geneva, Switzerland, November 2023
	What is your quantum readiness plan?	SecTor2023, Toronto, Ontario, Canada, October 2023
	Your Technology Radar: Are you Quantum Ready?	Tech Horizons| Executives Webinar Series, WatSPEED, University of Waterloo, Ontario, Canada, October 2023
	The Rapidly Approaching Quantum Computing Tsunami - Are We Ready?	National Insurance Conference of Canada (NICC), Montreal, Quebec, Canada, September 2023
	Post Quantum Crypto-Controversy and Trends	ICMC Panel, PQC Q20, Ottawa, Ontario, Canada, September 2023
	Post Quantum Crypto-Implementations	Moderator - ICMC Panel, PQC Q20, Ottawa, Ontario, Canada, September 2023
	The Quantum Threat: How to navigate new cybersecurity challenges	Toronto, Ontario, Canada, September 2023
	Enabling Quantum-safe Network	Nokia Wavelengths 2023, New Orleans, United States of America, September 2023
	Quantum communications in academia vs. industry	QYRA X IMDA, Career in Quantum Communication Field, Singapore, virtual, July 2023
	Quantum Education for Shaping Regulation	World Economic Forum, a discussion series to help shape quantum security regulation, virtual, July 2023
	Prosperity, and Resilience in the Quantum Era	The Canadian Telecommunication Cyber Protection (CTCP)meeting, Innovation, Science and Economic Development Canada (ISED), virtual, June 2023
	Quantum Computing for National Security Leaders	G7 Cyber Expert Group conference in Ottawa, Department of Finance, Canada, June 2023
	Overview of Canadian Ecosystem	Inside Quantum Technology, Montreal, Quebec, Canada, June 2023

	Preparing for the Quantum Era	UOttawa program delegation, Institute for Quantum Computing, University of Waterloo, Ontario, Canada, June 2023
	Quantum computer for Business and Policy leaders	The Conference Board of Canada's meeting, Toronto, Ontario, Canada, May 2023
	Network Security Post Quantum	Quantum Marketplace event, Belmont, California, United States of America, virtual, May 2023
	Canada's Quantum Story: Leading the Future of Quantum	Quantum Connections 2023, Institute for Quantum Computing, University of Waterloo, Ontario, Canada, May 2023
	Cybersecurity and Privacy	Math and Computing Research Discovery Days, University of Waterloo, Ontario, Canada, April 2023
Christine Muschik	Hardware efficient quantum computing using qudits	Quantum Days 2024, Calgary, Alberta, February 2024
	Using a qudit quantum computer to simulate models from particle physics and beyond	UVIC Colloquium, Victoria, British Columbia, February 2024
	Hardware efficient quantum information processing with qudits	Quantum and AI Workshop 2023, Waterloo, Ontario, November 2023
	Simulating 2D lattice gauge theories on a qudit quantum computer	European Quantum Technology Conference 2023, Hannover, Germany, October 2023
	Simulating 2D lattice gauge theories on a qudit quantum computer	Quantum Information Science Program Meeting, Banff, Alberta, October 2023
	Simulating 2D lattice gauge theories on a qudit quantum computer	Atomic & Laser Physics (ALP) seminar series, Oxford University, Oxford, England, October 2023
	Simulating one-dimensional quantum chromodynamics on a quantum computer: Real-time evolutions of tetra- and pentaquarks	QSim, Telluride, Colorado, United States of America, August 2023
	Simulating one-dimensional quantum chromodynamics on a quantum computer: Real-time evolutions of tetra- and pentaquarks	IBM QISKIT, United States of America, Virtual, July 2023
	Simulating one-dimensional quantum chromodynamics on a quantum computer: Real-time evolutions of tetra- and pentaquarks	Quantum Simulators of Fundamental Physics, Waterloo, Ontario, June 2023
	Fresh approaches for scientific computing	Singapore MinDef Visit, Waterloo, Ontario, June 2023
	Status and prospect of quantum simulating quantum fields: digital approaches	Toward Quantum Advantage in High Energy Physics, Munich, Germany, April 2023
Ashwin Nayak	Bounds on Sample Complexity via Information Theory	Session on Quantum Information Theory, CMS Summer Meeting, Ottawa, Ontario, June 2023
Dmitry Pushin	54th Winter Colloquium on the Physics of Quantum Electronics (PQE)	Snowbird, Utah, United States of America, January 2024

	Neutron Interferometry and structured waves of matter and light	6th Joint Meeting of the APS Division of Nuclear Physics and the Physical Society of Japan, Hawaii, United States of America, November 2023
	Production of neutron beams with OAM and spin-orbit coupling	Twisted Light in Quantum and Sub-Atomic Systems conference, MITP-Mainz, Germany, 2023
	Neutron Interferometry and structured waves of matter and light	CQIQC Seminars, Toronto, Canada, May 2023
	Precision measurements in neutron optics	APS April meeting, Minneapolis, United States of America, April 2023
Michael Reimer	Quantum networks and sensing	National Research Council of Canada, Ottawa, Canada, December 2023
	Technology overview of quantum photonics	Photonics in Defence and Security Symposium, Ottawa, Canada, October 2023
	Nanophotonic devices for quantum networks and sensing	Summer school entitled “Quantum technology from fundamental science to real world applications”, Erice, Italy, October 2023
	On-demand generation of bright entangled photon pairs with near-unity fidelity	Photonics North 2023, Montreal, Canada, May 2023
Crystal Senko	Quantum Computing Hardware	APS March Meeting Minneapolis, United States of America, March 2024
	Quantum Information Processing with Barium Ions	Gordon Research Conference in Atomic Physics, Newport, Rhode Island, June 2023
William Slofstra	LCS games, non-hyperlinear groups, and Schaefer dichotomy theorems	Hot Topics: MIP*=RE and the Connes' embedding problem, SLMath, Berkeley, United States of America, October 2023
	Positivity is undecidable in product algebras	Special Session on Recent Developments in Operator Algebras and Quantum Information Theory, III, AMS Fall Eastern Sectional Meeting, University at Buffalo (SUNY), September 2023
	Positivity is undecidable in product algebras	Workshop on Operator Algebras and Applications: Connections with Logic, Fields Institute, Toronto, August 2023
	Positivity is undecidable in product algebras	Workshop on Analytical and Combinatorial Methods in Quantum Information Theory II, ICMS, Edinburgh, Scotland, July 2023
	Self-testing and stability of group relations	Workshop on Noncommutative Harmonic Analysis and Quantum Information, Mittag-Leffler Institute, June 2023
	Open problems in graph minors and contextuality over Zp	Session on DiscreteMathematics in Quantum Information Processing, CanaDAM 2023, University of Manitoba, June 2023
Graeme Smith	Additivity and Nonadditivity of Quantum Capacity	Quantum Information, Les Diablerets, Switzerland, February 2024
	Mathematical challenges in quantum information theory	Perimeter Institute Colloquium, Waterloo, Canada, January 2024

	Additivity and Nonadditivity of Quantum Capacity	BIRS Workshop: Fundamental Limitations to Quantum Computation, Banff, Canada, January 2024
	Mathematical challenges in quantum information theory	Mathematical Picture Language Seminar, Department of Physics Harvard University, Cambridge, Massachusetts, United States of America, September 2023
Adam Wei Tsen	Tunneling Probe of 2D Moiré Magnetism	Department of Physics Condensed Matter Seminar, University of Toronto, Toronto, Canada, September 2023
	Tunneling Probe of 2D Moiré Magnetism	Canada Chemistry Conference and Exhibition 2023, Vancouver, British Columbia, June 2023
Christopher Wilson	Microwave Quantum Radar	Pursuing Quantum Sensing for Reliable Roadmaps, Rome, Italy, December 2023
	Advanced characterization and mitigation of qubit decoherence in a deep underground environment	Quantum Computing Program Reviews, San Diego, United States of America, September 2023
	Giant Artificial Atoms and Programmable Topological Waveguides	Workshop on Giant Atoms, ETH Zurich, Switzerland, September 2024
	Advanced characterization and mitigation of qubit decoherence in a deep underground environment	GUINEAPIG 2023 Workshop on Light Dark Matter, Montreal, Canada, July 2023

H. Scientific Visitors & Tours

Visitor Name	Affiliation
Ashutosh Marwah	University of Montreal
Mikka Stusiak	McGill University
Rohin Verma	UCLA
Yeqing Zhou	University of Toronto
Yihui Quek	MIT
Daniel Carney	Berkeley Lab
Raj Shaw	Apple
David Luong	Carleton University
Sreeraman Rajan	Carleton University
John Kaullagher	Sandia National Laboratories
Sean Dougherty	Northwestern University, Illinois
Zhi Li	Perimeter Institute
Nolon Coble	University of Maryland, College Park
Anna Kis	University of Waterloo/Computer Science
Aziza Suleymanzade	Harvard
Luke Schaefer	University of Waterloo/Computer Science
Zohreh Davoudi	University of Maryland
Matthijis Vernooij	TU Delft
Christophe Couteau	University of Technology of Troyes
Zahra Khanian	Technical University of Munich
Sisi Zhou	Perimeter Institute
Ewan Murphy	University of Oxford
Ziheng Chang	University of Calgary
Yunhong Gong	University of Calgary
Matthew Yastremski	University of Calgary
Senrui Chen	University of Chicago
Tom Hapke	Technical University, Munich
Adrian She	University of Toronto
Thomas Hanh	Weizmann Institute of Science
Jong-Souk Yeo	Yongsei University
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