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NEWBIT

ISSUE 34

Bridging Perspectives

UNIVERSITY OF WATERLOO | IQC Institute for Quantum Computing

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IN this issue

ON THE COVER

CHRISTINE MUSCHIK discusses with students **RYAN FERGUSON, ANGUS KAN** and **DANNY PAULSON.**

Cover photo by: IQC

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IQC COMMUNICATIONS & STRATEGIC INITIATIVES

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FROM THE EDITOR

When Stephen Hawking visited the Institute for Quantum Computing (IQC) in September 2012 for the opening of the Mike and Ophelia Lazaridis Quantum-Nano Centre (QNC), the crowds that gathered outside the building greeted him with a rock-star welcome. Unlike anyone before, **STEPHEN HAWKING** brought science to the masses. He bridged the gap between science and pop culture, and prompted us to look deeper at the world around us. As IQC works to advance quantum information science and technology, Hawking's legacy will continue to inspire us to bridge perspectives, push boundaries and ask bold questions.

In this issue, you will see how **CHRISTINE MUSCHIK** is bridging perspectives to explore the origins of the universe (pg 6). Her work pulls from the fields of quantum and high energy physics to build quantum simulations of gauge theories, the theories that describe the way particles interact at the most fundamental level. You will also read about a new project that is bringing quantum technology into the realm of national defence (pg 4). This technology promises to cut through heavy background noise in the Canadian arctic and identify stealth aircraft with unparalleled accuracy.

This issue also highlights some notable research advances, including a new technique that brings magnetic resonance imaging to the nanometer scale with unprecedented resolution (pg 10) and a neutron interferometry technique that is more powerful and practical than existing techniques. (pg 11).

From the lab to the classroom and into the community, the work that we do at IQC is strengthened by our many partnerships and collaborations. As we build on our academic strengths and share quantum with the world, we are buoyed by Stephen Hawking's belief that: "What is happening here in Waterloo is truly special, from theory to experiment and beyond."

CHRISTINE BEZRUKI

Senior Manager, Communications
Institute for Quantum Computing

REMEMBERING STEPHEN HAWKING

A MESSAGE FROM RAYMOND LAFLAMME

The scientific community, and the world, was deeply saddened by the news of Professor Stephen Hawking's passing on March 14, 2018.

Professor Hawking was monumental in shaping our understanding of modern physics. He was known for his theories on black holes and relativity, and made significant contributions to cosmology and quantum gravity. He was also committed to communicating his findings to a broad audience. We are grateful for his support for IQC at the University of Waterloo and the Perimeter Institute for Theoretical Physics.

I was fortunate to study with Professor Hawking at the University of Cambridge. In the 1980s, when Professor Hawking was writing his best-selling book *A Brief History of Time*, it was my job to mathematically demonstrate his theory about what happens to time in a contracting universe. Instead, I found that the math just didn't add up, meaning that Hawking's suggestion – that time reverses direction – could not be true.

Afterwards, he gave me a copy of his book with a personalized inscription: *"To Raymond, who showed me that the arrow of time is not a boomerang. Thank you for all your help. Stephen."*

When Professor Hawking came to visit IQC in 2010, I gave him a boomerang. He immediately understood its significance. The boomerang was a fun inside joke, but it was more than that. It was a way of saying that, although time is indeed an arrow, it has a way of bringing our lives – and what is most important to us – full circle.

We thank Professor Hawking for his impactful contributions to theoretical physics. He was an incredible scientist who has changed the way we think about the universe. His work will continue to inspire scientists all over the world, and generations for years to come.

RAYMOND LAFLAMME
Founding Executive Director
Institute for Quantum Computing

"To Raymond, who showed me that the arrow of time is not a boomerang. Thank you for all your help."

IQC researchers **FRANCOIS SFIGAKIS, JONATHAN BAUGH** and **MICHAEL REIMER** look at a sample for the dilution refrigerator in the Coherent Spintronics Lab.

Quantum radar will **EXPOSE STEALTH AIRCRAFT**

New $2.7 million project funded by the Department of National Defence will develop technology for quantum radar.

Researchers at the University of Waterloo are developing new quantum radar technology that promises to help cut through heavy background noise in the Canadian arctic and isolate objects — including stealth aircraft and missiles — with unparalleled accuracy.

"In the Arctic, space weather such as geomagnetic storms and solar flares interfere with radar operation and make the effective identification of objects more challenging," said IQC faculty member **JONATHAN BAUGH.** Baugh is leading the project along with faculty member **MICHAEL REIMER**, research assistant professor **FRANCOIS SFIGAKIS** and in collaboration with the Waterloo Institute for Nanotechnology.

"By moving from traditional radar to quantum radar, we hope to not only cut through this noise, but also to identify objects that have been specifically designed to avoid detection."

Stealth aircraft rely on special paint and body design to absorb and deflect radio waves, making them invisible to traditional radar. They also use electronic jamming to swamp detectors with artificial noise. With quantum radar, in theory, these planes will not only be exposed, but also be unaware they have been detected.

Quantum radar uses a sensing technique called quantum illumination to detect and receive information about an object. At its core, it leverages the quantum principle of entanglement. In this case, two photons form a connected, or entangled, pair.

IQC research assistant professor FRANCOIS SFIGAKIS, associate professor JONATHAN BAUGH, assistant professor MICHAEL REIMER, the Honourable BARDISH CHAGGER, Leader of the Government in House of Commons, Deputy CJOC Comptroller, Department of National Defence PETER MASON, University of Waterloo President FERIDUN HAMDULLAHPUR, interim director KEVIN RESCH, Member of Parliament of Kitchener Centre RAJ SAINI, and Regional Chair KEN SEILING were among those gathered at IQC's Research Advancement Centre in April for the announcement.

To date, quantum illumination has only been explored in the laboratory. The challenge for researchers is realizing a fast, on-demand source of entangled photons. The Government of Canada, under the Department of National Defence's All Domain Situational Awareness (ADSA) Science & Technology program, is investing $2.7M to expedite its use in the field.

"This project will allow us to develop the technology to help move quantum radar from the lab to the field," said Baugh. "It could change the way we think about national security." ■

Bridging **Perspectives**

Christine Muschik, Emmy Noether Fellowship holder and assistant professor in the Department of Physics and Astronomy in the Faculty of Science, is taking a quantum perspective on high-energy physics to answer some of science's most elusive questions.

Sometimes breaking a leg — or a foot — really is good luck. At the age of 15 CHRISTINE MUSCHIK tripped and fell on her way out of a museum, shattering the bones in her left foot. She didn't know it at the time, but this accident would alter the course of her life. Unable to walk for more than a year, the aspiring dancer joined the science club at her high-school and found an entirely new passion: theoretical physics.

Today, Muschik is leading the field of quantum simulations for high-energy physics. Quantum simulators capitalize on the exotic properties of quantum systems for realizing computations that cannot be performed with conventional methods. The field holds the potential to answer questions that have eluded particle theorists for decades such as, what really happens inside a neutron star? What exactly happened during the Big Bang? Why is there more matter than anti-matter in nature and hence why do we exist?

"These questions belong to a subclass of very hard problems that cannot be solved with super computers," said Muschik.

"This is where quantum computing shows incredible promise."

Muschik and her team are working to build quantum simulations of gauge theories, the theories that describe the way particles interact at the most fundamental level. Starting first with simple theories, she hopes to develop practical simulation concepts that could be turned into special purpose simulators in the lab.

Research is a collaborative process. Here, **CHRISTINE MUSCHIK** leads a group discussion with IQC students **DANNY PAULSON, ANGUS KAN** and **RYAN FERGUSON.**

"The ultimate long-term vision is to tackle problems that cannot be addressed with numerical methods," she said, "including questions related to heavy ion collisions in particle accelerators, matter at extreme densities or the physics of the early universe."

ONE STEP AT A TIME

But just like relearning to walk after breaking her foot, Muschik believes a step-by-step approach is key to her work.

"The field is very young, it's just taking its first baby steps," she said. "Right now we are completely busy developing a new type of quantum simulator and not focused yet on answering the grand questions."

In 2016, Muschik and a team of researchers at the University of Innsbruck, including Peter Zoller and Rainer Blatt, successfully created the first quantum simulation of a simple gauge theory – one-dimensional quantum electrodynamics. Named a top 10 breakthrough of the year by Physics World, the project proved it is possible to use quantum techniques to study particle physics and fundamental forces.

Now Muschik and her group are focused on building more complex simulations, with an eye on quantum chromodynamics, which describes the interactions between quarks.

FROM WHITEBOARD TO LAB

Although still in its infancy, quantum simulations of high-energy physics are by nature a collaborative, interdisciplinary endeavour.

"The idea is really to come up with something that doesn't just work on the whiteboard or paper, but which at the end of the day will lead to something that comes to life in the lab," said Muschik, who is already collaborating with experimentalists to test algorithms.

Industry is also taking note, with Google, IBM and Rigetti Computing showing interest in the projects.

"The best way to describe the field is a bridging of perspectives," said Muschik. "You've got theory and experiment, quantum and high-energy physics, and industry and academia all coming together. It's really quite exciting."

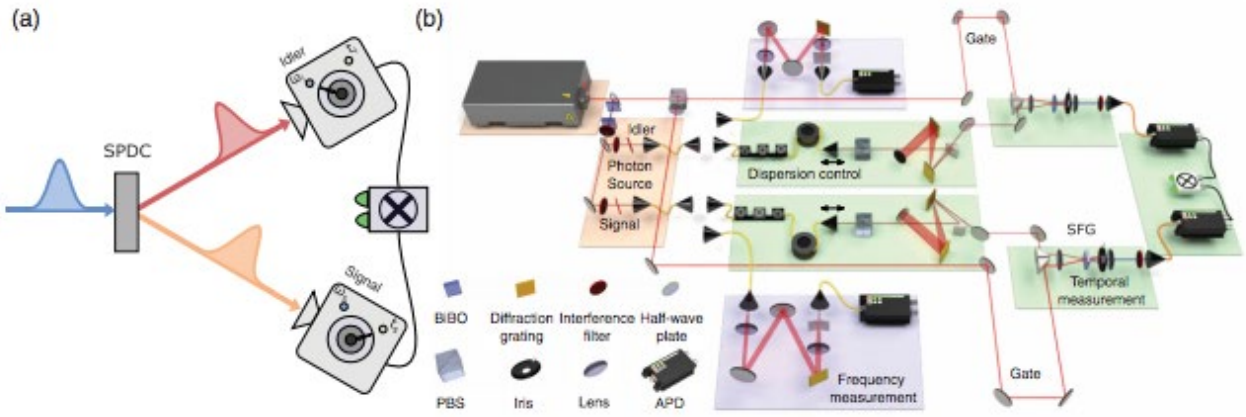
"This line of research has the potential to dramatically advance our understanding of some of the most challenging questions in modern physics. Further down the road, the quantum simulation tools developed in this context will be widely applicable and could even revolutionize simulations in such diverse fields as chemistry, biology, material science and medicine." ■

SCIENCE HIGHLIGHTS

IQC faculty, postdoctoral fellows and students continue to conduct internationally recognized quantum information science research. Here is a sampling of their research published in academic journals.

Capturing images of ultrafast energy-time entangled photon pairs

Phys. Rev. Lett. 120, 053601



Experimental setup for ultrafast energy-time entangled photon pairs.

IQC scientists have captured the first images of ultrafast photons that are energy-time entangled. To capture one of the shortest quantum events possible, the researchers used a technique known as optical gating. This technique acts like a high-speed strobe light, using short pulses of light to image the photons in time. This surpasses the speed limitations of current detectors and effectively imaging the entangled photon pairs with a resolution below one trillionth of a second.

Scientists have been interested in exploiting energy-time entanglement for quantum information, but until now, they lacked the resolution in both energy and time to directly observe it. The new apparatus brings a tool frequently relied upon in classical optics research to the quantum world.

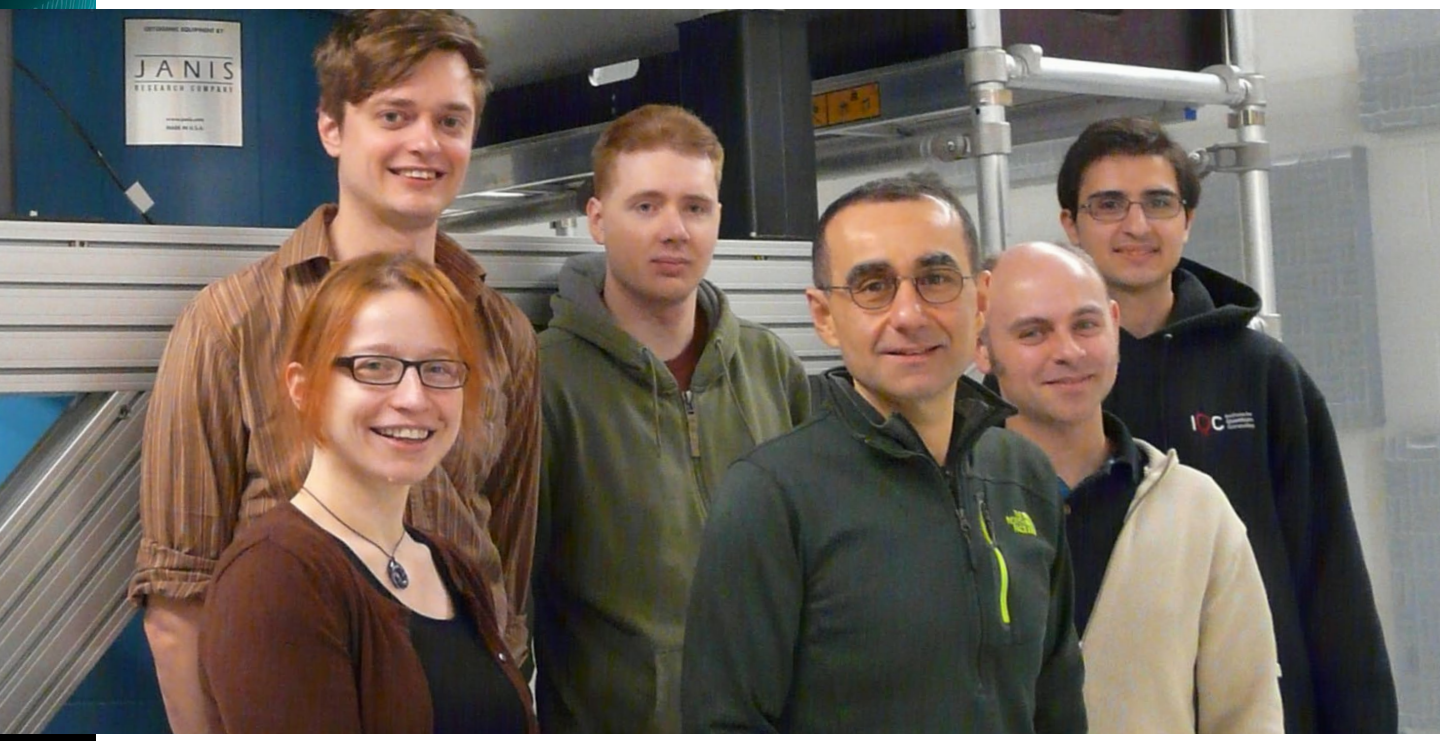
The technique has direct applications for quantum cryptography and communication protocols, including the possibility for establishing highly secure communication channels over long distances. The paper *Direct Characterization of Ultrafast Energy-Time Entangled Photon Pairs* by PhD students **JEAN-PHILIPPE MacLEAN**, **JOHN DONOHUE** and faculty member **KEVIN RESCH** was published in *Physical Review Letters* on January 30.

WEB **bit.ly/ultrafast-et-entangled** ■

SCIENCE HIGHLIGHTS

Bringing high res magnetic resonance imaging to nanometer scale

Phys. Rev. X, 8, 011030



From left to right: MICHELE PISCITELLI, HOLGER HAAS, ANDREW JORDAN, RAFFI BUDAKIAN, BEN YAGER, SAHAND TABATABAEI.

Researchers at IQC, led by faculty member **RAFFI BUDAKIAN**, developed a new technique that brings magnetic resonance imaging to the nanometer scale with unprecedented resolution. Using a new type of hardware and numerical algorithms to implement high-precision spin control, they were able to image proton spins with a resolution below 2nm.

The current work extends the capabilities of Magnetic Resonance Force Microscopy (MRFM) — an ultra-sensitive technique for nanometer scale MRI — by combining it with the ability to precisely control atomic spins. This opens the door for major advances in understanding new materials, virus particles and proteins that cause diseases like Parkinson's and Alzheimer's.

The paper *High-Resolution Nanoscale Solid-State Nuclear Magnetic Resonance Spectroscopy* was published on February 26 in *Physical Review X*.

WEB **bit.ly/HR-nano-MRI** ■

Novel neutron interferometry technique is more powerful and practical

Phys. Rev. Lett. 120, 113201

IQC researchers, in collaboration with researchers from the National Institute of Standards and Technology (NIST) and the National Institute of Health (NIH), have developed a neutron interferometry technique that is more powerful, robust and practical than existing techniques.

PhD student **DUSAN SARENAC**, faculty members **DMITRY PUSHIN** and **DAVID CORY**, along with a team of international researchers developed a new broadband, two-phase grating interferometer technique. The simple configuration consists of aligning common optics components with the gratings and the detector. Without any absorption, the novel approach uses the whole neutron beam, resulting in significantly faster measurements that are less sensitive to vibration and temperature variances than other types of interferometers.

The new technique, detailed in the paper *Three Phase-Grating Moiré Neutron Interferometer for Large Interferometer Area Applications* published in *Physical Review Letters* on March 12, paves the way for advances in imaging, materials science, and fundamental physics and quantum research.

WEB **bit.ly/new-neutron-interferometry** ■

The role of frequency-shifting in quantum scalability

Quantum Sci. Technol. 3, 034004

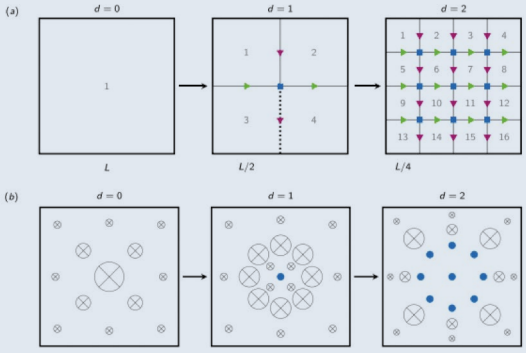
Researchers at IQC have developed new methods for preventing leakage errors due to cavity modes, an important obstacle in building a scalable quantum computer.

PhD candidate **THOMAS McCONKEY**, lead author on the study, and the Digital Quantum Matter (DQM) lab, led by researcher **MATTEO MARIANTONI**, studied two frequency-shifting techniques to prevent a quantum system's own hardware from interfering with qubit operation.

The first solution proposed by DQM, anti-node pinning, involves repeatedly placing pins at the anti-nodes until the resonance frequency of the mode shifts above the frequency of the qubit. The second frequency shifting method, half-wave fencing, creates multiple smaller cavities inside the original cavity, like a faraday cage.

The techniques are explained in the paper *Mitigating leakage errors due to cavity modes in a superconducting quantum computer* published in *Quantum Science and Technology*.

WEB **bit.ly/frequency-shifting-quantum-scalability** ■



A) Half-wave fencing.
B) Anti-node pinning.

SCIENCE
HIGHLIGHTS

CONFERENCES & WORKSHOPS

MARTIN LAFOREST, Senior Manager, Scientific Outreach, tours Chief Science Advisor MONA NEMER through *QUANTUM: The Pop-Up Exhibition.*

Discovery to application at AAAS

Advancing Science: Discovery to Application was the theme of this year's annual American Association for the Advancement of Science (AAAS) meeting held in Austin, Texas in February.

Canada's Chief Science Advisor **MONA NEMER** toured *QUANTUM: The Pop-Up Exhibition* with Senior Manager, Scientific Outreach **MARTIN LAFOREST**, discussing the potential applications and impact areas of quantum research. Showcasing quantum information science and technology, the pop-up exhibit provides interactive exploration of quantum mechanics.

In partnership with fellow Canada First Research Excellence Fund (CFREF) programs at the Université de Sherbrooke and the University of British Columbia, IQC hosted a breakfast panel on recent investments in next generation quantum technologies. Weighing in on the advancement of science from discovery to application from IQC was Canada Excellence Research Chair (CERC) Laureate **DAVID CORY**, along with **MICHEL PIORO-LADRIÈRE**, Institut Quantique, Université de Sherbrooke and **ANDREA DAMASCELLI**, Quantum Matters Institute, University of British Columbia.

Interim executive director **KEVIN RESCH** and Cory also participated in the Canadian Foundation for Innovation's (CFI) Quantum Roundtable to discuss conducting and supporting quantum research with international partners. Chaired by Nemer, the roundtable discussion shared research success stories, identified challenges and explored opportunities to collaborate on the world stage. ■

Scientists gather for APS March Meeting

The American Physical Society March Meeting 2018 brought together physicists, scientists and students from all over the world to share innovative and groundbreaking research.

There was a large IQC presence at this year's meeting, held at the Los Angeles Convention Center (LACC), including:

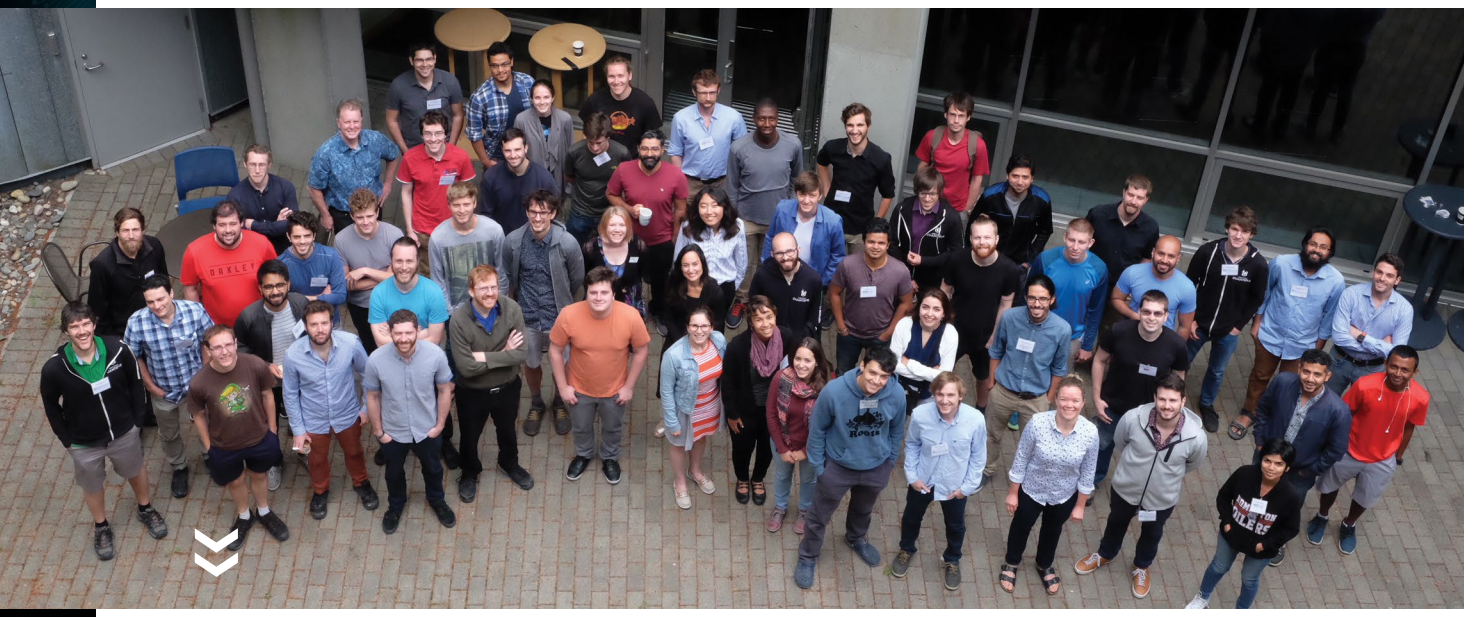
47 IQC research papers shared at the conference	**8** postdoctoral fellows
18 researchers presented	**17** PhD students
9 faculty members	**4** master's students
1 research assistant professor	**6** affiliates/associates

QUANTUM AT THE SPACE SECURITY CONFERENCE

Principal investigator of the Quantum Encryption Science Satellite (QEYSSat) project **THOMAS JENNEWEIN** travelled to Geneva, Switzerland to share his work in advancing secure quantum communication via satellite at the Space Security Conference in May.

Jennewein's research aims to build a communication channel secured by the quantum laws of nature that does not leak information or allow eavesdropping. Recently, his team performed a successful demonstration of an uplink to an airborne quantum satellite receiver prototype, marking another step towards establishing a quantum internet.

WEB **bit.ly/Jennewin-SSC-interview**



New quantum conference ignites cross-country collaboration

Written by **Madelaine Liddy**

June 20-22 saw the inaugural Canadian Graduate Quantum Conference (CGQC) take place at the University of British Columbia. Jointly organized by Transformative Quantum Technologies (TQT) (University of Waterloo), Institut Quantique (IQ) (Université de Sherbrooke) and the Quantum Matter Institute (QMI) (University of British Columbia), the aim of the conference was to connect both the student and postdoctoral fellow communities from each of the three Canada First Research Excellence Fund (CFREF) centres to inspire collaborative projects for quantum research across Canada.

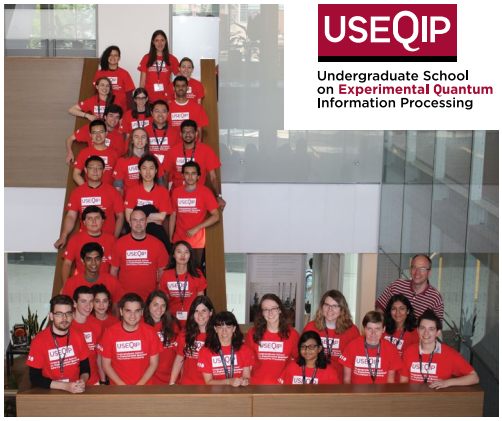
Graduate students organized and executed the conference for their peers. The intent was to make sure attendees felt open and comfortable discussing their research with each other, and create natural bonds for future work. Conference activities opened with remarks by a keynote speaker from each CFREF institute, an array of student presentations, lab tours of QMI, poster sessions, and an industry panel and workshop. It could be argued, though, that the most collaborative interactions happened in between sessions over a coffee and donut, or watching the sun set over the mountains at UBC's beach.

CGQC 2019 will take place at Université de Sherbrooke's Institut Quantique. ■

Many-body States & Dynamics Workshop

Experimentalists working on several platforms, and theoreticians specializing in many-body theory and numerical simulations, met to collaborate and share efforts to experimentally realize quantum many-body states and dynamics. The workshop brought researchers from IQC and the Perimeter Institute for Theoretical Physics (PI) together on Thursday, June 7.

IQC faculty members who presented at the workshop were **KYUNG CHOI**, **RAJIBUL ISLAM, NA YOUNG KIM, CRYSTAL SENKO**, and Canada Excellence Research Chair Laureate **DAVID CORY**, as well as affiliates **DANIEL GOTTESMAN**, **ROGER MELKO** and **GUIFRE VIDAL**. ■



USEQIP
Undergraduate School on Experimental Quantum Information Processing

Undergraduates get bootcamp introduction to quantum information science

Once again, IQC welcomed students to the Undergraduate School on Experimental Quantum Information Processing (USEQIP), a crash course on quantum information science and technology from May 28 to June 8. Thirty-one students arriving from 13 countries participated in lectures introducing quantum information theory and experimental approaches to quantum devices, followed by 30 hours of hands-on experimental exploration in the labs. ■

PRESENTATIONS

The future is quantum

In April, **DAVID CORY**, Canada Excellence Research Chair Laureate and professor in the Department of Chemistry, was invited to speak at the Canadian Club of Ottawa, a dynamic forum known for discussing the elements and factors of Canada's development. Cory elaborated on the role quantum computing plays in shaping Canada's future on the world stage as a leader in technology. ■

BB84 protocol inventor Gilles Brassard talks no-signalling theories

Quantum cryptography pioneer and 2018 co-recipient of the Wolf Prize in Physics **GILLES BRASSARD** gave a talk at IQC in March. Brassard, Canada Research Chair and professor at the Université de Montréal, shared his recent work on no-signalling theories. He countered common beliefs about the implications of experimental violation of Bell's inequalities, suggesting that all reversible-dynamics no-signalling operational theories (including unitary quantum theory) can be given a local-realistic interpretation. ■

Quantum connections in Europe: IQC at the Ecsite conference

TOBI DAY-HAMILTON, Director, Communications and Strategic Initiatives shared IQC's experience creating and executing *QUANTUM: The Exhibition*, the first-ever travelling exhibit of its kind, on a quantum-focused panel at Ecsite in June. This conference, hosted by the European Network of Science Centres and Museums, gathers science engagement professionals from around the world for five days of programming on the advancement of science communications, outreach and public engagement. Held this year in Geneva, Switzerland, Ecsite provides an opportunity to exchange ideas and strengthen international partnerships in the science communications field. ■

Sharing the quantum vision

Sharing quantum information science and technology research with industry, government and academic partners strengthens and builds collaborative opportunities. In the first half of the year, IQC was honoured to host more than **140 visitors from 40 delegations**, including:

- **SABINE SPARWASSER**, Ambassador of the Federal Republic of Germany to Canada
- **BEAT NOBS**, Ambassador of Switzerland to Canada and the Bahamas
- UK Quantum Mission
- Global Senior Trade Commissioners from Global Affairs Canada
- Daimler Chrysler
- Fujitsu
- Toshiba Research Europe Ltd. ■

Delegates of the UK Quantum Mission were welcomed with a reception and poster session in the Mike and Ophelia Lazaridis Quantum-Nano Centre where they learned about the quantum research happening at IQC.

Life in a tech startup:
Manku shares entrepreneurial experience

By popular demand, the CryptoWorks21 Intellectual Property (IP) Management Lunch and Learn series returned and included a distinguished lecture on April 6 by **TAJ MANKU,** founder and CEO at Cognitive Systems Corp.

"A great idea is only 10% of being a successful entrepreneur. The other 90% is all the hard work it takes to make it real," Manku said. Drawing heavily from his own journey and personal experience being involved in a startup technology company, he talked candidly about the lessons he learned in the process.

The lunch and learn series, which occurred monthly from October through June, featured in-depth presentations designed for researchers working in information technology, including cryptography and quantum technology. ■

IQC OUTREACH

Inspiring future scientists

School's out for the summer, but the learning doesn't stop! Throughout the month of July, IQC welcomed students and teachers to explore the basics of quantum mechanics through lectures, activities, workshops and tours.

Participants included:

- EinsteinPlus
- International Summer School for Young Physicists (ISSYP) Waterloo's IDEAS Summer Experience and
- Exploring Science Program. ■

Senior Manager, Scientific Outreach **MARTIN LAFOREST** demonstrates the levitating superconducting train for students at the Canada-Wide Science Fair in Ottawa.

Canadian students celebrate science

QUANTUM: The Pop-Up Exhibition showcased the potential future impact of quantum information science and technology research for more than 10,000 elementary and high school students at the Canada-Wide Science Fair (CWSF) in Ottawa from May 15-19. Senior Manager, Scientific Outreach **MARTIN LAFOREST** demonstrated the power of magnets with the superconducting levitating train. Special visitor, the Honourable **KIRSTY DUNCAN**, Minister of Science and Sport, encouraged students to continue exploring their scientific curiosity beyond the week-long celebration of science. ■

Exploring unexpected connections

Logic and literature were the contemporary topics recently explored within the context of the quantum realm at two public lectures hosted by IQC as part of *Entangled: The series*.

Taking the logical route

On February 22, **FAY DOWKER** from Imperial College London described a way of thinking about quantum mechanics in which logic is something to which we must pay careful attention to if we want to see a picture the quantum world. She used a hypothetical experimental demonstration to show that logic is physical and left the audience with a thought-provoking question: "It's one world, but it's not one history. So what is it?"

WATCH ONLINE **bit.ly/quantum-logic**

The entanglement of physics and literature

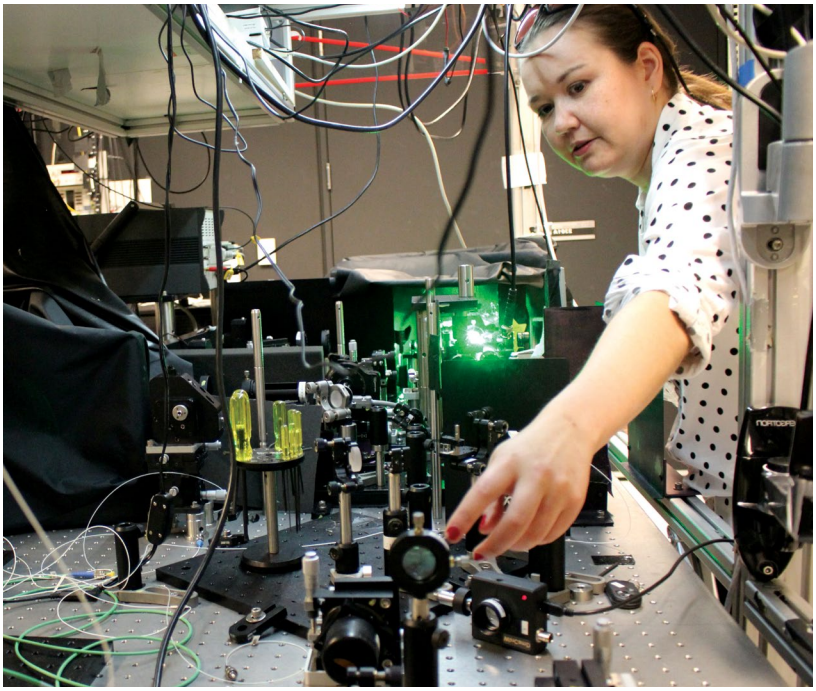
Author and professor **CHAD ORZEL**, Union College, described how quantum phenomena – like entanglement, quantum measurement and Schrödinger's infamous cat – have been a source of metaphor and inspiration for fiction. Orzel reviewed the Copenhagen and Many-Worlds Interpretation, and linked each concept to story ideas and prompts in the worlds of literature and film.

WATCH ONLINE **bit.ly/quantum-literature**

Around the INSTITUTE

A well-rounded approach to research

PhD student PROFILE: **AIMEE GUNTHER**



There's more to the field of science than just experimenting and analyzing data for PhD student **AIMEE GUNTHER**. For her, stepping out of the lab is an important part of becoming a well-rounded scholar.

Gunther specializes in the development and manipulation of quantum photon pair sources. Her PhD thesis project centers on designing a source for specially correlated photon pairs, or indivisible particles of light. Focusing on quantum and nonlinear optics, her work investigates energy-time entanglement for applications in biological imaging and sensing.

Beyond the lab, Gunther actively seeks opportunities with causes that interest her. She has earned leadership and university teaching certifications, developing skills in higher education and science policy and communication.

"These experiences have definitely given me a well-rounded approach to research," she says.

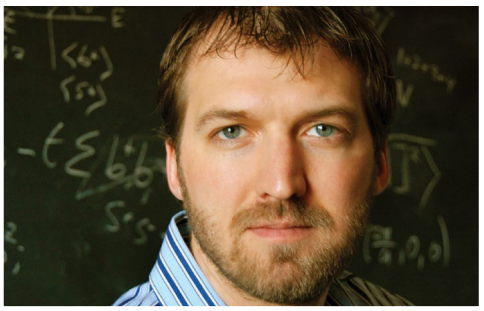
She has dedicated time to science outreach and volunteered for various causes, becoming a student leader on campus and advocating for graduate students. She was part of a team sponsoring a refugee family new to the Kitchener-Waterloo area.

For her contributions to the optics, physics and broader scientific communities, Gunther earned the joint Canadian Association of Physicists Foundation (CAPF) and OSA Foundation (OSAF) Boris P. Stoicheff Memorial Graduate Scholarship. She was awarded the scholarship in June 2018 at the CAP Congress in Halifax.

"Even though I've spent a whole decade looking at experimental quantum optics and energy — an incredibly niche field of quantum research — I believe there are a lot of other fascinating problems out there," said Gunther when discussing career options post-PhD. "I'm excited that they will be just as complex and rich."

As she prepares for new challenges, Gunther credits her love for learning and transferable skillset to her time studying at IQC: "I am a stronger researcher because of the opportunities and experiences I've had." ■

Beyond THE LAB



ROGER MELKO

KEVIN RESCH

IQC members renewed as Canada Research Chairs

Two IQC researchers were renewed as Canada Research Chairs (CRC). The announcement made by the Government of Canada is part of national funding for CRCs worth $158 million.

The Natural Sciences and Engineering Research Council of Canada (NSERC) reappointed **KEVIN RESCH**, interim director of IQC, as Canada Research Chair (CRC) in Optical Quantum Technologies. The $500,000 over five years Tier 2 renewal allows Resch and his team to focus on three interrelated objectives: developing entangled photon sources, single photon time lensing, and experimental tests of generalized probability theories.

IQC affiliate **ROGER MELKO** also received an NSERC Tier 2 renewal in Computational Quantum Many-Body Physics. This funding will allow Melko to continue his theoretical research as he studies the big questions of quantum condensed-matter physics using computational methods such as Monte Carlo simulations. ■

Quantum cryptography expert Mosca recognized

Faculty member **MICHELE MOSCA** received the Security and Anti-Fraud Innovation Award for his work advancing quantum cryptography at the Webit Congress in June, an event for leaders and key influencers in technology, digital policy and global innovation.

Mosca was also honoured with a knighthood by the Government of Italy, appointed as a Knight of the Order of Merit for his research, commercial and outreach contributions to the fields of quantum information and cybersecurity. ■

Renewed funding positions Canada as a global leader

IQC received a tremendous boost from the Government of Canada in Budget 2018 with $15 million in renewed funding over three years. The government's continued support for IQC further positions Canada as a global leader in quantum science and technology. Discoveries in quantum research have already made an impact in cybersecurity, health, and resource exploration, and future discoveries will lead to transformative technologies in other areas. Thank you to all IQC partners for your continued support.

Canada invests in research

The Honourable **KIRSTY DUNCAN**, Minister of Science and Sport, announced $1.6 billion in federal funding for research during her visit to the University of Waterloo on March 6. The biggest investment in research in Canadian history, the money is pledged for scientific research and scientist support. Also present for the announcement was Waterloo MP **BARDISH CHAGGER**, Minister of Small Business and Tourism, who said the government relies on science-based evidence to support sound decisions. The funding commitment allows scientists to pursue research that drives innovation, helping to position Canada as a leading expert in fundamental research.

WEB **bit.ly/science-budget-announcement**

The Honourable KIRSTY DUNCAN, Minister of Science and Sport, announced $1.6 billion in federal funding for research at the University of Waterloo.

CryptoWorks21 supported by RBC investment in cybersecurity research

The Royal Bank of Canada (RBC) announced in January the opening of a new cybersecurity lab with a $1.78 million investment for cybersecurity and privacy tool research at the University of Waterloo. The funding supports researchers in the David R. Cheriton School of Computer Science and the Department of Combinatorics and Optimization in Waterloo's Faculty of Mathematics. It includes $300,000 for IQC faculty member **MICHELE MOSCA** for CryptoWorks21, an education program focused on quantum-safe cryptosystems and training graduate students and postdoctoral fellows in next-generation cryptographic tools.

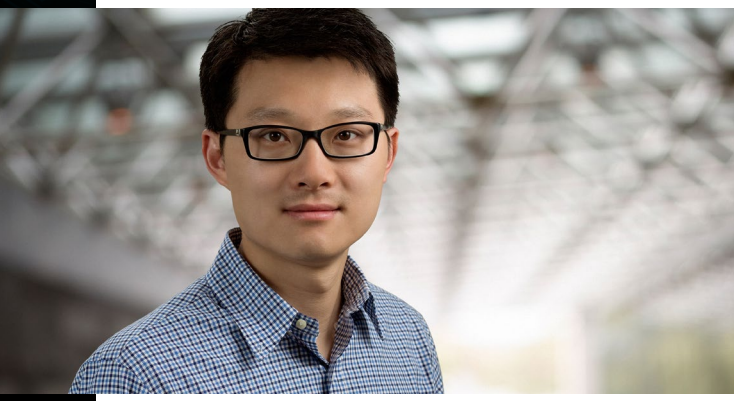
RBC Royal Bank

CryptoWorks21

ANNOUNCEMENTS

Christine Muschik named Emmy Noether Visiting Fellow

IQC researcher and assistant professor in the Department of Physics and Astronomy **CHRISTINE MUSCHIK** was named an Emmy Noether Visiting Fellow at the Perimeter Institute for Theoretical Physics. Muschik is launching an interdisciplinary research effort connecting the field of quantum technologies with high-energy physics to explore quantum simulations of lattice gauge theories. Her aim is to develop new tools for basic science, including a new type of quantum simulator, and to provide applications for near-term quantum devices. ■



Faculty member recognized with Early Researcher Award

The Government of Ontario announced **WEI TSEN**, an assistant professor at IQC and in the Department of Chemistry, as a recipient of an Early Researcher Award. Tsen leads the Quantum Materials and Devices Lab where he is studying atomically thin quantum materials and developing novel quantum devices based on their exotic properties. He uses a combination of experimental techniques for materials characterization at the nanoscale, such as transmission electron microscopy, micro-optical spectroscopy and magnetotransport measurements, as well as state-of-the-art nanofabrication processes for device engineering. ■

TQT supports new quantum projects

Transformative Quantum Technologies' Quantum Quest Seed Fund (QQSF) has allocated more than $900,000 in support of new quantum projects. Exploring how biological processes use quantum effects, and developing new nanowire arrays to detect light at the single photon level, are two of 10 projects being funded. ■

UNIVERSITY OF WATERLOO | TQT Transformative Quantum Technologies

New book focuses on the mathematics of quantum information

IQC faculty member **JOHN WATROUS** published a textbook exploring fundamental concepts in quantum information. *The Theory of Quantum Information*, looks at the development of concepts and methods that are fundamental to a broad range of studies in quantum algorithms and complexity, quantum cryptography and quantum Shannon theory, and is accessible to those with a solid background in basic mathematics.

"The mathematical theory that underlies quantum information and computation is both interesting and beautiful," said Watrous. "I wanted to write a book focused solely on this mathematical theory – which of course is not only interesting and worthy of study in its own right, but also supports both the applications-focused and experimental aspects of the field."

WEB **bit.ly/DownloadTheoryofQuantumInformation**

WEB **bit.ly/BuyTheoryofQuantumInformation** ■

Avalon Holographics partners with the Quantum NanoFab

Using holographics as a powerful new tool for communicating information may be closer than we think. Researchers in the nanofabrication facilities at IQC are working in collaboration with industry partner Avalon Holographics to create and test holographic display technologies.

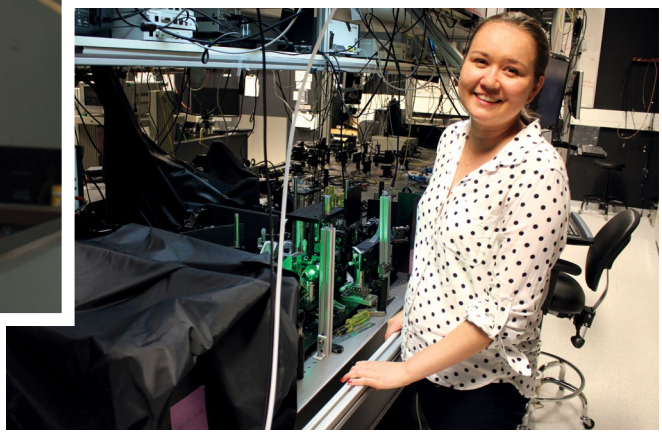
Researcher and Electron Beam Lithography Scientist **GREG HOLLOWAY** is a part of this work, which uses nano-sized structures on the scale of the wavelength of light that, when light is shone upon them, create a much higher-fidelity 3D projection than past holograms.

Avalon Holographics president **WALLY HAAS** says these research facilities are indispensable to the company's success. "Without it we'd shut down. We are lucky to have access to its size and capability, and if there were more facilities like that in Canada, you'd have more start-ups like ours."

Read the full story by Canada Foundation Innovation (CFI) online: **bit.ly/from-2D-to-holographics**. ■

SEBASTIAN SLAMAN

AIMEE GUNTHER



Celebrating scientific achievements

The 2018 Canadian Association of Physicists (CAP) Congress held at Dalhousie University in Halifax, Nova Scotia showcased and celebrated the achievements of physicists in Canada and abroad. Over the week-long conference from June 10-16, IQC students were recognized with awards, including:

Master's student **SEBASTIAN SLAMAN** won the poster category of the CAP Best Student Paper Competition – Poster in the Division of Atomic, Molecular and Optical Physics, Canada, and placed third overall in CAP Best Student Poster for his poster *Modeling Polarisation Distortion from Mechanical Stress for Real-world Quantum Key Distribution*.

PhD student **AIMEE GUNTHER**, received the Boris P. Stoicheff Memorial Graduate Scholarship in recognition of both research excellence and significant service to the optics (Optical Society Foundation) or physics (CAP) community. ■

THESIS DEFENCES

Congratulations to everyone who successfully defended their thesis including:

THOMAS ALEXANDER, MSc
MATTHEW BROWN, MSc
HYERAN KONG, MSc
THEERAPAT TANSUWANNONT, MSc
ELENA ANISIMOVA, PhD
ANQI HUANG, PhD
MIKE MAZUREK, PhD
THOMAS MCCONKEY, PhD
DUSAN SARENAC, PhD ■

The IQC GSA springs into action

It was a busy spring for the IQC Graduate Student Association (GSA). There were plenty of opportunities for students to socialize and de-stress as part of the GSA's activity calendar, including a Video Game Night, Therapy Dog Visit, Mental Health Forum, Quantum Crawl Social Night and the infamous Chili Cookoff. Interim director **KEVIN RESCH** defended his title as chili champion, taking home the golden spoon for best overall chili. PhD student **RUBAYET AL MARUF** won the spiciest chili with his ghost pepper fish chili, and PhD student **DANIEL GRIMMER** claimed the best vegetarian chili, "the one with the pineapples." Congratulations to all! ■

COURSES

WINTER 2018

QIC 890
Functional Analysis Methods for Quantum Information Technologies

QIC 890
Advanced Topics in Quantum Optics

SPRING 2018

QIC 890
Introduction to Noise Processes ■

CONGRATULATIONS, GRADUATES! Spring 2018

Convocation Graduates include:

- **HELEN PERCIVAL**, MASc, Electrical & Computer Engineering (Quantum Information)
- **ANQI HUANG**, PhD, Electrical & Computer Engineering (Quantum Information)
- **SHIHAN SAJEED**, PhD, Electrical & Computer Engineering (Quantum Information)
- **JIE LIN**, MSc, Physics (Quantum Information)
- **BENJAMIN LOVITZ** MSc, Physics (Quantum Information)
- **CHRISTIAN MASTROMATTEI** MSc, Physics (Quantum Information)
- **ZIMENG WANG** MSc, Physics (Quantum Information)
- **ELENA ANISIMOVA** PhD, Physics (Quantum Information)
- **MICHAEL MAZUREK** PhD, Physics (Quantum Information)
- **COREY RAE MCRAE** PhD, Physics (Quantum Information)
- **PAULINA CORONA UGALDE** PhD, Physics ■

Congratulations to **ALLISON SACHS** (MSc, Physics, Fall Convocation), who was honoured with the Dean of Science Award in recognition of creative research presented in a student Master's thesis. Announced at Spring Convocation, Sachs earned the award for the thesis titled *Entanglement Harvesting and Divergences in Unruh-DeWitt Detector Pairs*.

ARRIVALS

Students

Eugene Adjei
Paul Anderson
Jamal Busnaina
Brian Duong
Jie Lin
Ben Lovitz
Shayan Majidy
Caroline Mbakob Tchouawou
Hamoon Mousavi
Danny Paulson
Youn Seok Lee
Joshua Skanes-Norman

Postdoctoral fellows

Dmitry Akhmetzyanov
John Peterson Pinheiro da Silva
Pardis Sahafi
Behrooz Semnani
Sacha Schwartz
Roland Habluetzel
Arjun Shetty
Daniel Tennant

Staff

Chantal Cote
Greg Digulla
Sandra Gibson
Louise Green
Md Hussain
Brian Moffat
Amy Sigvaldason

Visitors

Raphaël Aymeric
Hengameh Bagherianlemraski
Austin Bradley
Lorenzo Catani
Andy Ding
Daniel Eduardo Galviz Blanco
Frankie Fung
Noah Greenberg
Zhengcheng Gu
Cheng Guo
Martin Houde
Louisa Huang
Maren Ilango
Aditya Jain
Maria Julia Maristany
Dmitry Kronberg
Ashwin Kumar
Ahreum Lee
Youning Li
Botao Li
Zhipeng Li
Chi-Kwong Li
Irene Lopez Gutierrez
Dawei Lu
Shengqiao Luo
Vinod Raj Rajagopal Muthu
Anuj Shripad Apte
Benjamin Soloway
Ingrid Strandberg
Anton Trushechkin
Yiu Tung Poon
Yidun Wan
Dai Wei
Hiacheng Xuan
Qian Xue
HeeBong Yang
Hailin Yu
Sara Zarar Jafarzadeh
Han Zhang
Kirill Zhernenkov ■

USEQIP

Undergraduate School on Experimental Quantum Information Processing

Undergraduate School on Experimental Quantum Information Processing 2018 at a glance:

288 applications

31 participants

52% women
48% men

Canada **(7)**
United States **(7)**
India **(5)**
China **(3)**
Greece **(1)**
France **(1)**
Germany **(1)**
Mexico **(1)**
Chile **(1)**
Serbia **(1)**
Spain **(1)**
Russia **(1)**
United Kingdom **(1)**

637 cups of coffee and tea in **12 days** to fuel **33.5** hours of experimental discovery and **35.5** hours in the classroom

A NEWSLETTER FROM THE **INSTITUTE FOR QUANTUM COMPUTING**, **UNIVERSITY OF WATERLOO**, WATERLOO, ONTARIO, CANADA

QCSYS

Quantum Cryptography
School for Young Students

August 9-16, 2019

Apply now for the summer experience of a lifetime.

The Quantum Cryptography School for Young Students (QCSYS) is an exciting eight-day enrichment program for high school students hosted by the Institute for Quantum Computing at the University of Waterloo.

QCSYS offers an engaging blend of lectures, hands-on experiments and group work focused on quantum cryptography. This cutting-edge field harnesses the fascinating features of quantum mechanics, like superposition, entanglement and uncertainty, to develop unbreakable encryption that protects our information.

Apply by March 22, 2019: uwaterloo.ca/iqc/qcsys

UNIVERSITY OF WATERLOO | IQC Institute for Quantum Computing

Ontario Canada