2011 ANNUAL REPORT

Quantum. Re-imagine the Future.

UNIVERSITY OF WATERLOO

IQC Institute *for* Quantum Computing

> When you change the way you look at things, the things you look at **change**.
>
> *~ Max Planck, father of quantum theory, 1858-1947*

Humans are relative newcomers to the universe, and we have spent our history trying to understand it.

For every new discovery we have made, another puzzle has beckoned us to look deeper.

Around the turn of the last century, a new puzzle emerged — a puzzle whose solution describes the forces and laws that underlie everything we experience, and everything we don’t.

Quantum mechanics was, and remains, a biography of reality.

While some quantum phenomena — such as things existing in two states simultaneously or being mysteriously connected across great distances — run contrary to our everyday intuition, they demonstrate there is more to our world than we can see.

Through the lens of quantum mechanics, scientists are now re-imagining what is possible. By taming and controlling the forces of the quantum realm, we can achieve breakthroughs that were previously unimaginable.

Ultra-powerful computers, impenetrable cryptography and nanotechnologies of remarkable precision — these are just a few of the discoveries made possible through quantum science.

Research at IQC is changing the way we see everything, and promises to change everything we see.

2011 Annual Report

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UNIVERSITY OF WATERLOO | IQC Institute *for* Quantum Computing

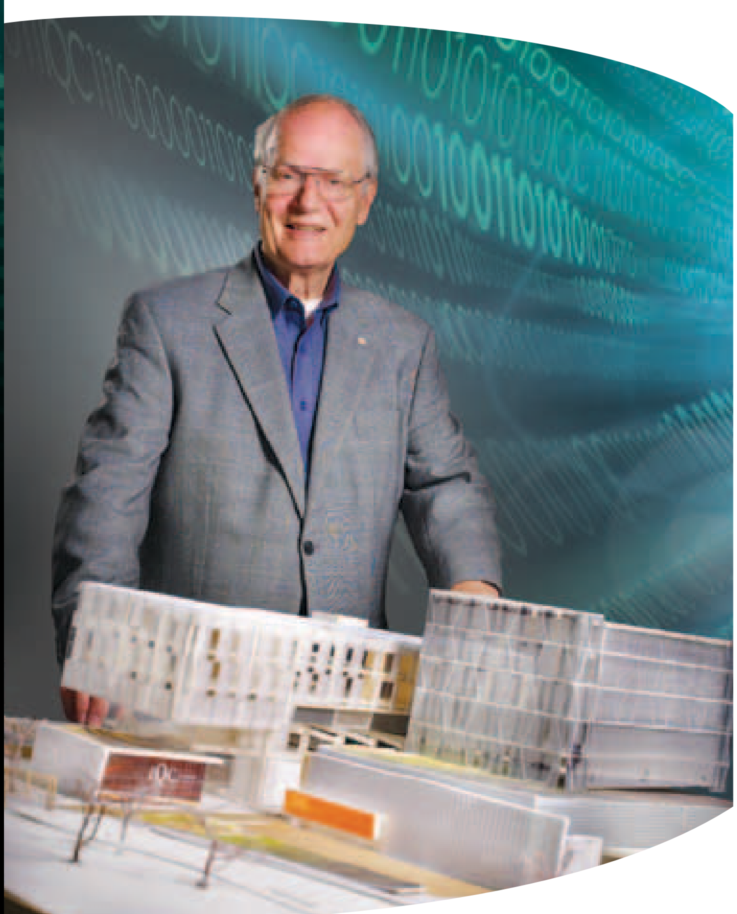
The Quantum Builders

A message from the

Chair of the Board

A global race is underway to realize the full potential of quantum mechanics. IQC is at the leading edge of this effort. In just 10 years, the institute has become known globally for the excellence of its researchers, the calibre of their science and the unrivaled facilities at their disposal. Such rapid growth reflects the fertile academic soil at the University of Waterloo, an institution renowned for its culture of innovation.

On that note, let me formally welcome Feridun Hamdullahpur as Waterloo's sixth President. We thank Feridun for his support of IQC as Provost, and look forward to his continued leadership. Through its commitment to new faculty appointments and its visionary investment in the new Mike & Ophelia Lazaridis Quantum-Nano Centre, the university has provided invaluable support to IQC for which we are truly grateful.



We have been fortunate this year to welcome more exceptional minds to IQC. Prof. David Cory, a scholar of outstanding skill and ingenuity, joined us as the Canada Excellence Research Chair (CERC) in Quantum Information Processing. IQC also welcomed research assistant professors Dmitry Pushin, Marco Piani and Guo-Xing Miao, all of whom are making their mark in quantum information. In addition, 18 new postdoctoral fellows joined the institute this year, for a total of 37 — an amazing team of minds working toward a common goal.

Learning alongside these established scientists are 74 brilliant and enthusiastic graduate students, of whom 20 are new this year. These young scientists will lead the next wave of research and discovery in quantum science. Their research will produce new knowledge, with applications and benefits we are just beginning to realize.

One example is a challenging large-scale project aimed at establishing global quantum communications networks via satellite. This pioneering project, undertaken in close partnership between IQC, the Canadian Space Agency, COM DEV and government partners, offers just a hint of the practical benefits we will see from quantum technologies.

I am proud to be part of the bold and progressive research organization that is IQC. On behalf of the Board of Directors, I thank Prof. Raymond Laflamme, an extraordinary scientific leader who has piloted IQC through its first decade and positioned it for an even brighter future. And I thank all the researchers and staff whose work brings the vision of IQC to life every day.

T.A. Brzustowski

Tom Brzustowski
Chair of the Board, IQC

TOM BRZUSTOWSKI pictured with a model of the Mike & Ophelia Lazaridis Quantum-Nano Centre

A message from the

Executive Director

Ten years ago, I took a gamble: I left a secure job at Los Alamos National Laboratory and moved to my native Canada to help launch a world-class quantum information research institute at the University of Waterloo.

I took the gamble because I believed in the vision of Mike Lazaridis and David Johnston. That vision was to assemble an unparalleled team of scientists, give them the resources to pursue cutting-edge research, and train a new generation of students who will transform research into revolutionary technologies.

That bold vision is becoming a reality. IQC is now the largest research institute of its kind in the world — and growing. It's a place where theorists and experimentalists work side-by-side, pioneering a new branch of science. While building a full-scale quantum computer remains a long-term goal, the great strides we've already made have spawned technologies with applications in communications, cryptography, medicine and beyond.

In the near future, IQC will grow to 30 faculty members, 50 postdoctoral fellows and 125 students. IQC will expand into the Mike & Ophelia Lazaridis Quantum-Nano Centre — a remarkable new facility now nearing completion at the heart of the University of Waterloo. The building will provide the tools and infrastructure necessary to navigate and control the quantum world.

To commemorate the opening of this new building, and to mark IQC's milestone 10th anniversary, the institute will host scientific and cultural events aimed at bringing the science of IQC to the world — and bringing the world to IQC. To quote Canada's Governor General David Johnston, who championed quantum research as president of the University of Waterloo, IQC is establishing Waterloo and Canada as "Quantum Valley."

▲ **RAYMOND LAFLAMME** in front of the Mike & Ophelia Lazaridis Quantum-Nano Centre

IQC has exceeded its goals over the last year — and since its inception. Such success would be impossible without the incredible support the institute has received over the years. The philanthropy of Mike and Ophelia Lazaridis along with generous federal and provincial backing have made possible our many achievements. IQC is proud to continue the tradition of excellence at the University of Waterloo, and I can think of no better place to have launched the quantum revolution.

What seemed a decade ago to be a gamble now strikes me as a very wise bet. The secret to IQC's success — which isn't really a secret at all — lies in the brilliance and passion of the people who make great science happen every day. To them, and to our staff, university colleagues and all who support IQC, thank you.

Raymond Laflamme
Executive Director, IQC

Overview of IQC

Our Vision: harnessing quantum mechanics will lead to transformational technologies that will benefit society and become a new engine of economic development in the 21st century.

Strategic Objectives

ONE — To establish Waterloo as a **world-class centre for research** in quantum technologies and their applications.

TWO — To become a **magnet for highly qualified personnel** in the field of quantum information.

THREE — To establish IQC as the **authoritative source of insight, analysis and commentary** on quantum information.

IQC was officially created in 2002, sparked by the vision of Mike Lazaridis and then-University of Waterloo President David Johnston, to foster pioneering research into the next revolution in technology, quantum information. Harnessing the quantum laws of nature promises powerful new advances in fields spanning computing, communications and sensors — and IQC was created to lead this charge.

Throughout history, humans have learned to tame and control natural phenomena — fire, steam and electromagnetism for example — to improve their lives. IQC is now harnessing nature at its most elemental level.

Building on the University of Waterloo's longstanding strengths in engineering, mathematics and computer science, IQC quickly recruited world-class researchers in the theory underlying quantum information, providing the nucleus of excellence to attract experimentalists. Today, IQC is a highly successful partnership between the University of Waterloo, the private sector and both federal and provincial governments.

Our Mission: 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.

"It takes a visionary to look beyond what's happening now and to imagine what's possible for the future. Mike and Ophelia Lazaridis are visionaries whose forward-thinking philanthropy made possible the Institute for Quantum Computing and the breakthroughs it has achieved."

~Raymond Laflamme

IQC's current home in the Research Advancement Centres I & II.

In just 10 years, IQC has grown to become the world's largest research centre devoted to quantum information science and technology. It has created a unique training program for postdoctoral fellows and students, and is intensifying communication and outreach programs. IQC — and Canada — are becoming internationally recognized as leaders in the global quantum race.

A milestone in the coming year will be the expansion into an extraordinary new home, the Mike & Ophelia Lazaridis Quantum-Nano Centre. This *think tank with labs* will feature a state-of-the-art cleanroom, cutting-edge experimental infrastructure and innovative spaces designed to foster dialogue and collaboration between researchers. It's a simple recipe: attract top scientists, give them the best tools, and breakthroughs will happen.

This Year

17	Faculty
37	Postdoctoral fellows
74	Graduate students
160	New publications in peer-reviewed journals and conference proceedings
96	Institutions collaborating on joint research projects and publications
138	Visiting scientists
16	Long-term visiting scientists

World-Class People, World-Class Science

Computers keep getting smaller and more powerful. The microprocessors of today are unbelievably faster and more useful than the monolithic computing machines of a half-century ago. By fitting more transistors onto every microchip, engineers have continually halved the size, and doubled the power, of computers.

A threshold will soon be reached if this trend continues. The shrinking of transistors will, within the next decade or two, reach the scale of individual atoms — the quantum scale. This, from a physics standpoint, is a whole new ballgame. Quantum objects can be in a "superposition" of two different states simultaneously, and they can be intrinsically linked by "entanglement" — a phenomenon that perplexed even Einstein. What's more, quantum systems are so fragile, even the act of observing them will change them.

Such quantum effects can be seen as hurdles to computing — or as tremendous opportunities. Researchers at IQC harness and capitalize on quantum effects to develop technologies of unprecedented power. They have only begun to envision the scope, power and benefits of quantum information.

As you'll see in the coming pages, the next big thing will come in the smallest packages.

IQC's Core Areas of Research

Quantum Information Theory

Understanding how information can be manipulated with quantum mechanics for computing, communications and sensors.

Quantum Algorithms

The instructions by which quantum information processors will perform computations.

Quantum Complexity

Understanding which problems quantum processors can — and cannot — efficiently handle.

Quantum Cryptography

Providing information security by capitalizing on quantum effects.

Quantum Error Correction & Fault Tolerance

Understanding how to control quantum systems in the presence of imperfections and imprecision caused by noise.

Spin-Based Quantum Information Processing

Developing quantum processors that use the "spins" of quantum particles such as electrons and atomic nuclei.

Nanoelectronics-Based Quantum Information Processing

The use of nano-scale technologies such as quantum dots or superconducting circuits to implement quantum processing.

Optical Quantum Information Processing

Using the properties of light particles, or photons, to carry and process quantum information.

Meet the scientists who are making advancements in these fields. ▶

Faculty

IQC's researchers are in the Faculties of Mathematics, Science and Engineering at the University of Waterloo.

PROFESSORS

Jonathan Baugh
Member since:
2007
Waterloo department:
Chemistry

Andrew Childs
Member since:
2007
Waterloo department:
Combinatorics & Optimization

Richard Cleve
Member since:
2004
Waterloo department:
School of Computer Science

David Cory
Member since:
2010
Waterloo department:
Chemistry

Joseph Emerson
Member since:
2005
Waterloo department:
Applied Mathematics

Thomas Jennewein
Member since:
2009
Waterloo department:
Physics and Astronomy

Raymond Laflamme
Co-founder and Executive Director
Waterloo department:
Physics and Astronomy

Debbie Leung
Member since:
2005
Waterloo department:
Combinatorics & Optimization

Adrian Lupaşcu
Member since:
2009
Waterloo department:
Physics and Astronomy

Norbert Lütkenhaus
Member since:
2006
Waterloo department:
Physics and Astronomy

Hamed Majedi
Member since:
2005
Waterloo department:
Electrical and Computer Engineering

Michele Mosca
Co-founder and Deputy Director
Waterloo department:
Combinatorics and Optimization

Ashwin Nayak
Member since:
2002
Waterloo department:
Combinatorics and Optimization

Ben Reichardt
Member since:
2008
Waterloo department:
School of Computer Science

Kevin Resch
Member since:
2006
Waterloo department:
Physics and Astronomy

John Watrous
Member since:
2006
Waterloo department:
School of Computer Science

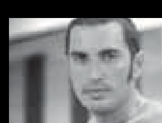
Frank Wilhelm
Member since:
2006
Waterloo department:
Physics and Astronomy

RESEARCH ASSISTANT PROFESSORS

Dmitri Maslov
Member since: **2008**
Waterloo department: **Physics and Astronomy**

Guo-Xing Miao
Member since: **2011**
Waterloo department: **Electrical and Computer Engineering**

Marco Piani
Member since: **2010**
Waterloo department: **Physics and Astronomy**



Dmitry Pushin
Member since: **2010**
Waterloo department: **Physics and Astronomy**

The (Solid) State of the Art

Prof. Raymond Laflamme performs a familiar ritual — remove wallet, keys and cell phone — and then steps inside the wooden fence that surrounds the nuclear magnetic resonance (NMR) equipment in his lab.

The same powerful magnetic forces that IQC researchers use to manipulate the spins of molecular nuclei for quantum computation can wreak havoc with a phone, wipe a credit card and leave your keys aggravatingly stuck to the machinery.

While NMR technology has been used for years in a variety of fields (a hospital's MRI machine uses the same principles), it has proven immensely valuable in the development of quantum computing.

"We use the magnetic field to make the 'spin' of nuclei point in a certain direction," Laflamme explains to visitors touring IQC. "We can manipulate the spins — and their interactions with each other — to use as our quantum bits for computation."

It's the simplified explanation of a complex approach to NMR that Laflamme helped pioneer. NMR is one of the earliest, most reliable test-beds for quantum computing. Laflamme, along with **PROF. DAVID CORY** and other collaborators, holds a long-standing world record for universal control of the largest number of well-characterized quantum bits (qubits) in an experiment. Although that record is 12 — not enough to outperform today's computers — the implications of this proof-of-principle experiment are enormous.

"The key," Laflamme tells the tour group, "is to control more qubits with more precision. The knowledge gained here can be applied in other approaches to quantum information processing."

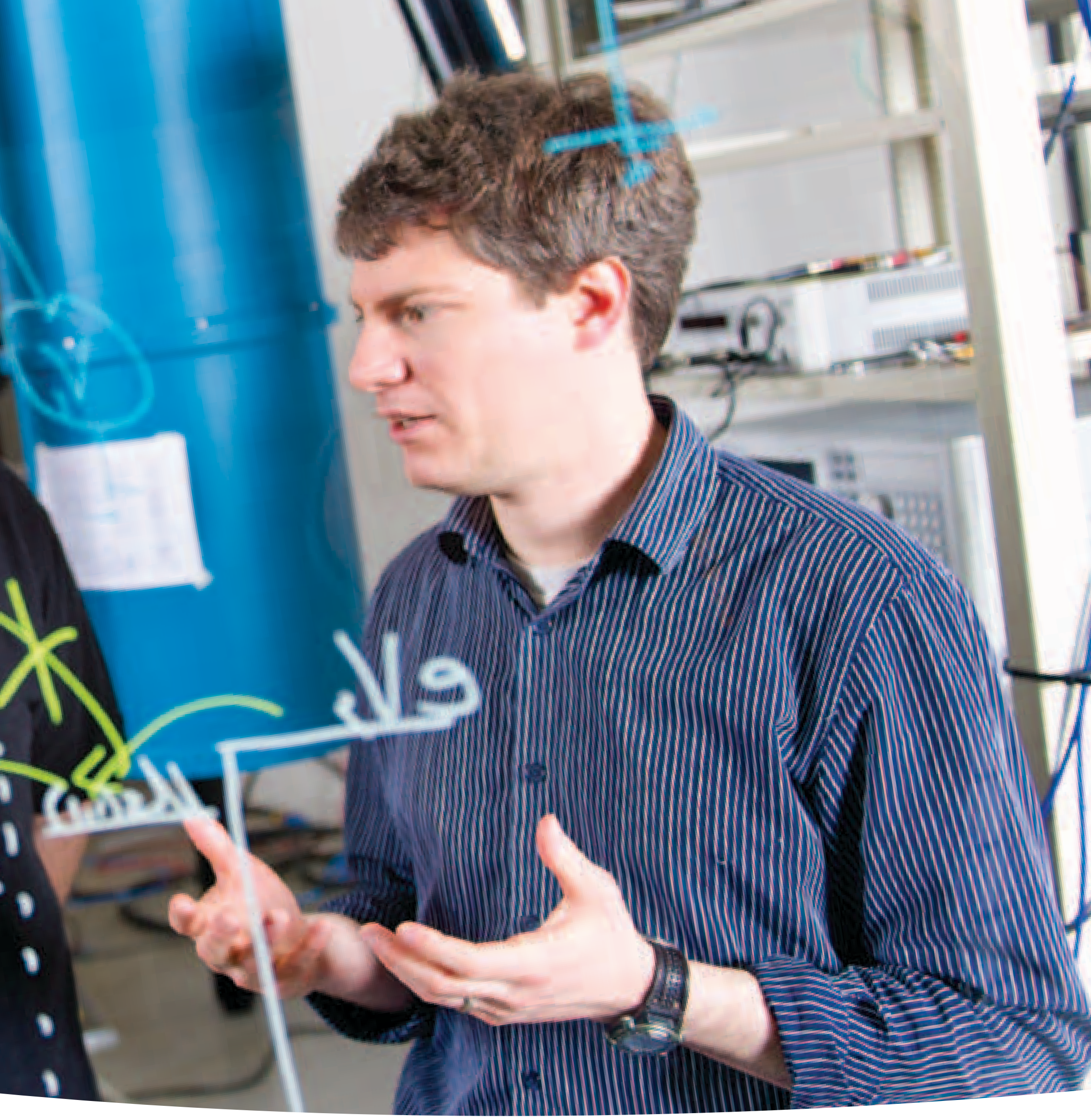
Laflamme points to the vast maze of equipment that occupies the rest of the lab, where scientists are working to achieve greater control of the quantum world. Fine-tuning the controls of a tall blue dilution refrigerator is IQC faculty member **PROF. JONATHAN BAUGH**, whose research aims to harness the spin property of electrons for computation.

Thanks to advances in nanofabrication technologies, Baugh and colleagues can create extremely small devices (roughly a few hundred atoms across) called "quantum dots." These devices behave as artificial atoms in which researchers can trap and manipulate single electrons. Because these are engineered devices, they can be tuned to have desired properties (unlike natural atoms), and potentially be scaled up into much larger systems.

Baugh uses the dilution refrigerator to chill systems to extremely low temperatures (about 0.02 degrees above absolute zero), reducing the thermal "noise" that acts to destroy the quantum coherence of his qubits.

Though the initial development of these single-electron qubits is much more challenging than ensemble qubit approaches like NMR, Baugh's quantum dots can be integrated on a chip much like existing classical semiconductor technology, and thus scaled up.

"Once we get past the initial experimental challenges of demonstrating viable single-spin qubits," explains Baugh, "testing and improving these systems should bring us a lot closer to the dream of realizing a quantum computer."



▲ In front of a dilution refrigerator that protects qubits from thermal noise, professors **JONATHAN BAUGH** (right) and **ADRIAN LUPAŞCU** discuss research involving quantum dots and superconductors.

Deeper into IQC's solid-state lab, **PROF. ADRIAN LUPAŞCU** is working to control a different kind of qubit. Lupaşcu, along with his students and postdocs, works with superconducting qubits — microscopic electrical circuits with superconducting elements. Despite being relatively large systems (almost visible to the naked eye), these systems exhibit quantum behaviors that offer great promise for quantum computing.

Like quantum dots, superconducting qubits can be fine-tuned and are considered viable candidates for the hardware of future quantum computers.

Other researchers at IQC, including research assistant professor **GUO-XING MIAO**, explore the intersections of superconductivity, spin resonance and spintronics.

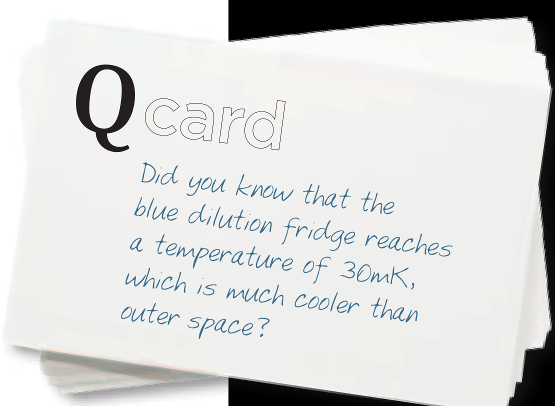
"There is much research yet to be done," says Lupaşcu, "but there is good reason to believe we will achieve sufficient precision and control of our qubits, allowing us to scale-up to a full quantum computer." Q

A NEW SPIN

While its applications in quantum computing are relatively new, nuclear magnetic resonance (NMR) is a long-established technology. Used to power familiar technologies such as magnetic resonance imaging (MRI), it involves the manipulation of nuclear spins in an external magnetic field.

The NMR spectrometer in IQC's solid-state lab is similar to equipment used in hospitals to peer inside the human body. Both applications involve observing nuclei changing energy levels, controlled by radiofrequency pulses in a direction perpendicular to the magnetic field.

Whereas a hospital's MRI machine causes nuclei to produce a rotating magnetic field readable for imaging, the NMR equipment at IQC controls the nuclei so they can be characterized as "bits" for computation. Because it was enabled by pre-existing technology, NMR has been an early and successful test-bed for quantum computing. The techniques developed in NMR quantum computing have also spawned new technologies such as non-invasive glucose monitoring.



To Err is Quantum: Overcoming Errors

How's this for irony: when Prof. Raymond Laflamme first started investigating quantum computing in the early 1990s, he believed quantum computing would never work.

He thought that quantum systems were too fragile, too susceptible to errors caused by disturbances or "noise," to be harnessed for information processing.

He knew that quantumness, as it were, is notoriously tricky to attain and manipulate (remember, even the act of observing a quantum system will irrevocably change its state).

The only way a quantum system could be used for computation, he understood, would be if scientists could devise a way to overcome, or cope with, the noise and errors inherent to any quantum system.

Then he and his colleagues figured out a way to do exactly that. Some of Laflamme's pioneering research into quantum computing processing led to a theory of quantum error correction — a means for achieving quantum computation when errors are within a given threshold.

Later, Laflamme, **PROF. DAVID CORY** and collaborators put the theory to the test by implementing, for the first time, a quantum error correction protocol in a liquid-state Nuclear Magnetic Resonance experiment. Through implementing this three-qubit error correction code, and later a five-qubit universal code, the researchers showed that, while errors are still unavoidable, they can be overcome to achieve computation.

Quantum error correction remains one of the key areas of research at IQC, since "decoherence" — the loss of quantumness due to noise — is an ever-present speed-bump on the road toward full-scale quantum computing.

"We know there are incredible advantages to quantum information processing over classical computers, but the major hurdle we face is errors," says **PROF. JOSEPH EMERSON**, an IQC theorist.

"You have to understand what kind of noise you're dealing with," says Emerson, who has explored how to efficiently measure the relevant noise in a system. "We're getting better at understanding the nature of noise, which helps us find solutions."

Other IQC theorists including professors **BEN REICHARDT**, **FRANK WILHELM** and **DEBBIE LEUNG** are among the researchers working to better understand the causes and effects of errors and how to overcome them. Wilhelm, a leading theorist in optimal control of quantum systems, explores methods of implementing highly precise quantum operations based on certain knowledge about the noise in a system.

▸ **PROF. JOSEPH EMERSON** (right) discusses theoretical approaches to quantum error correction with student **VICTOR VEITCH**.

The trick to error correction is, in a sense, redundancy. If you want to build, say, a 50-qubit quantum computer, you may need to use upwards of 500 qubits. You encode the qubit's information into a larger system such that the quantum information can be retrieved despite the presence of noise.

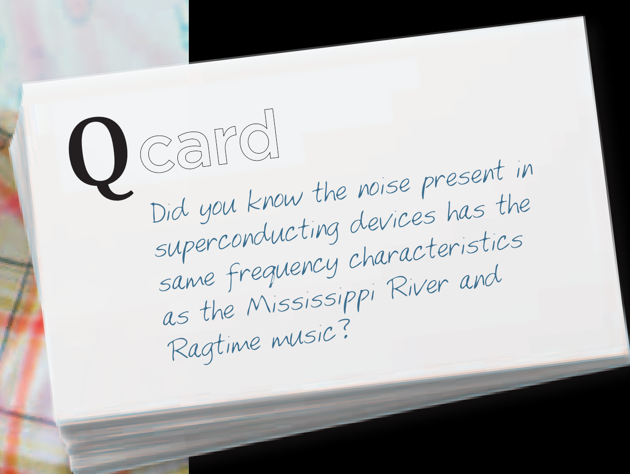
Though quantum error correction is used to preserve a state with minimal errors, quantum computation also requires the manipulation of quantum states. Since the implementations of error correction are themselves noisy, researchers add secondary protocols to ensure the final operations stay below a certain noise threshold. This is the focus of fault-tolerant quantum computing.

Developments in error correction and fault tolerance, made side-by-side with experimental and theoretical demonstrations of qubit implementations and control, are essential to the development of a quantum processor. Q

RESEARCHERS IMPLEMENT MAGIC STATE

In 2010, an IQC research team developed a novel way to cope with errors inherent in quantum systems by implementing, for the first time, the so called magic-state distillation — a protocol for creating high-purity quantum states from states of lower quality. The team — JINGFU ZHANG, ALEXANDRE D'SOUZA, COLM RYAN and PROF. RAYMOND LAFLAMME — described in a *Nature Communications* paper how they implemented this protocol by achieving an unprecedented level of control over their seven qubit system.

Experimental magic state distillation for fault-tolerant quantum computing, *Nature Communications* 2, 169 (2011)



The Power and Limits of Quantum Computing

In the offices, kitchens, meeting rooms and hallways of IQC, whiteboards — invariably filled with diagrams and theorems — are never more than a few paces away.

They are canvases for collaboration, where impromptu discussions between colleagues are carried out in search of deeper, cross-disciplinary understanding. Whether a diagram depicting a new experimental apparatus or a purely mathematical construct, the contents of a whiteboard represent the *raison-d'etre* of IQC: scientists from disparate fields working together toward a shared goal — understanding and taming the quantum world.

Although the writing on whiteboards is typically the result of fleeting conversations (except for writings accompanied by "DNE" — Do Not Erase) there is nearly always a deeper underlying meaning.

Strip away the specific formulae and illustrations, and a recurring question resonates between the lines: "How can we use quantum mechanics to our advantage?"

This is a bedrock question that pervades nearly all work in quantum information science — what advantages does quantum mechanics give us over classical physics when it comes to computing, communications and more, and how do we capitalize on those advantages?

Such foundational questions — and the highly specialized methods for answering them — are the domain of IQC's theorists, whose work, in part, guides and informs the experimental implementations of quantum science.

The theorists at IQC specialize in a variety of disciplines, from complexity theory to algorithms to communication theory, all of which examine the potential, the possibilities and the limitations of quantum information science. **PROF. NORBERT LÜTKENHAUS**, for instance, has made key contributions to the theory of quantum information and quantum cryptography, while **JOSEPH EMERSON**'s work examines fundamental questions about the nature of quantum information. Research assistant professor **MARCO PIANI** investigates theoretical questions of entanglement and the quantumness of certain systems.

Early thinkers in the field ("early" being a relative term, since the field of quantum information only emerged in the 1980s) demonstrated the potential for an exponential quantum speed-up to computation. But it wasn't until the mid-1990s, when Peter Shor (a mathematician then working at Bell Laboratories) developed a quantum algorithm for factoring large numbers significantly faster than the best-known factoring algorithm for classical computers, that the field launched in earnest.

Shor's algorithm had immediate and important implications: it proved that a quantum computer, if built, could radically outperform its classical counterpart in certain tasks.

"Quantum mechanics allows this audacious prediction — the exponential speed-up — and the theorists try to understand the potential, the boundaries and the limits of this idea," says IQC Deputy Director **MICHELE MOSCA**, a leading expert in quantum algorithms and cryptography. "We need to know what is quantumly possible, versus what is classically possible."

▲ **PROF. NORBERT LÜTKENHAUS** (front) and postdoctoral fellow **OLEG GITTSOVICH** discuss the *Kochen-Specker Theorem*, a foundational concept in the theory of quantum information.

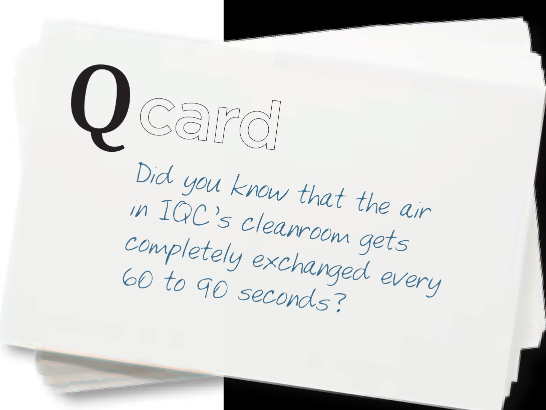
IQC researchers including professors **JOHN WATROUS, RICHARD CLEVE** and **ASHWIN NAYAK** are pioneers in quantum complexity theory — essentially, identifying the computational problems efficiently solvable by a quantum computer and those that derive no benefit from quantum processing.

Watrous, for example, achieved a long-sought breakthrough in which he proved the equivalence of two classes of problems (namely QIP and PSPACE), demonstrating a specific limit on the quantum advantages. Such work is crucial in demonstrating the potential uses and applications for quantum information, and raises questions for future investigation. Q

THEORISTS ON THE THREE-SLIT EXPERIMENT

The famous two-slit experiment is known as one of the quintessential demonstrations of quantum phenomena. While the interference patterns resulting from the two-slit experiment are well documented, relatively little attention has been paid to what happens (or, more importantly, what doesn't happen) when a third slit is introduced. The absence of third-order interference has been experimentally demonstrated, and recent work by IQC researchers **JOSEPH EMERSON** and **COZMIN UDUDEC**, along with **HOWARD BARNUM** of Perimeter Institute, seeks to better understand what is behind this absence. In their paper, the team characterized a broad class of theories that, like quantum mechanics, predict no three-slit interference.

Three Slit Experiments and the Structure of Quantum Theory, *Foundations of Physics 3*, Vol. 41, 398-405 (2011)



Making Qubits Work for You

A computer — whether quantum or classical — is only as useful as the operating instructions you give it, which is why the theoretical development of quantum algorithms is essential to the long-term goal of quantum computation.

Algorithms are the recipes of computation, and quantum information algorithms are as drastically different from their classical counterparts as atoms are from classical transistors.

Researchers at IQC including professors **RICHARD CLEVE**, **ANDREW CHILDS**, **MICHELE MOSCA**, **BEN REICHARDT** and **ASHWIN NAYAK** are leaders in the theory of quantum algorithms and related fields.

Cleve and Childs, for example, are widely known for having developed — jointly and separately — quantum walk algorithms that offer exponential speedups over classical computation, while Reichardt's accomplishments include solving a longstanding problem in the area of "query complexity." **DMITRI MASLOV**, a research assistant professor at IQC, develops tools for efficiently mapping quantum algorithms to elementary circuit operations.

Whereas theoretical research into quantum algorithms explores the instructions to give a quantum computer, quantum information theory looks at more fundamental questions, such as the very nature of information itself.

"The primary goal of my research is to understand how quantum information and computation affects information processing," explains Watrous.

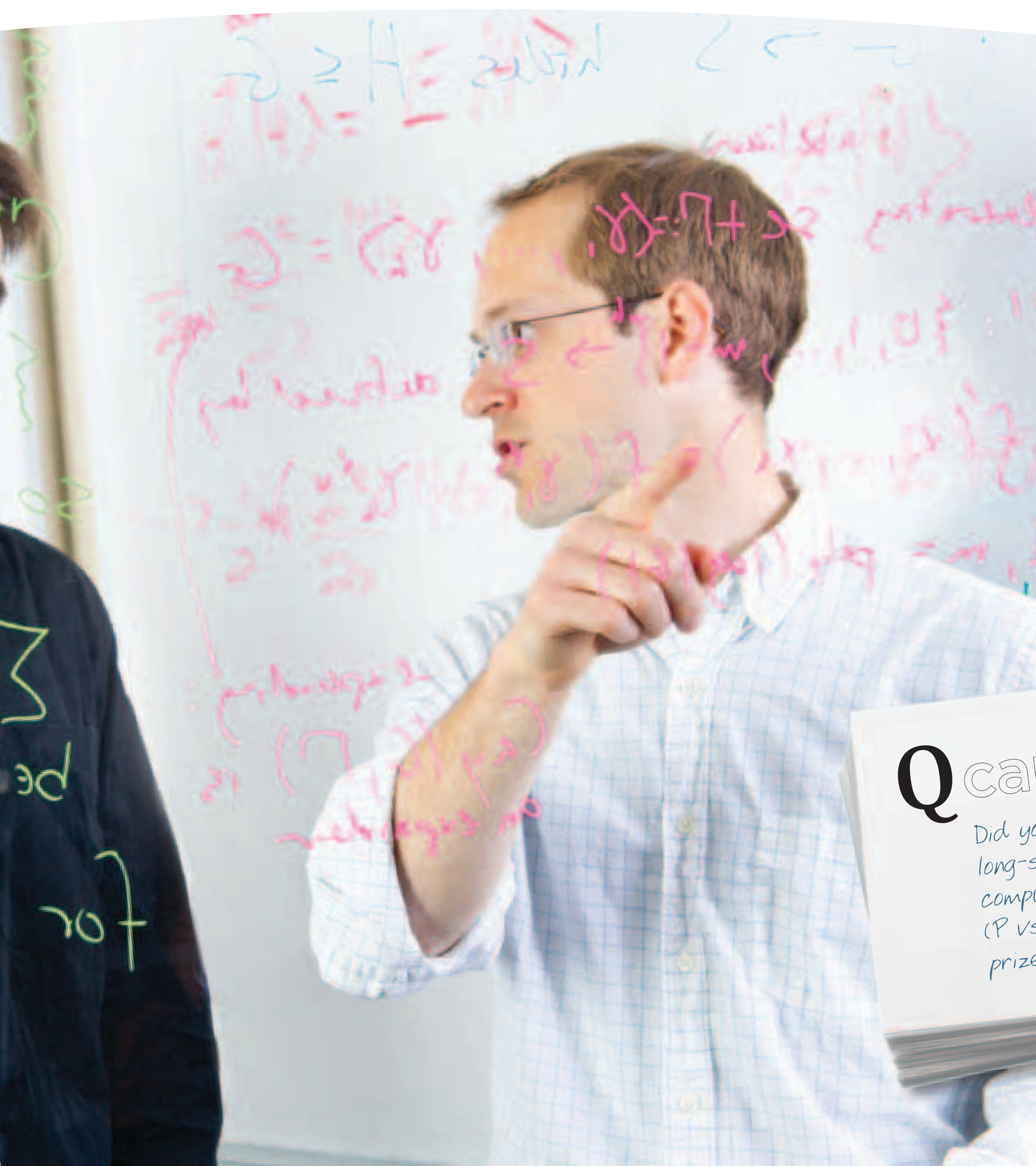
"You need to ask and answer these theoretical questions about quantum information when developing a comprehensive theory. Like building a skyscraper, you can't begin until you've got a solid foundation and understand the materials you're working with."

Professors **ANDREW CHILDS** (right) and **JOHN WATROUS** are leading researchers in theoretical approaches to quantum information, including algorithms and complexity theory.

Theoretical research in quantum information is continually providing new insights into how we can harness and exploit quantum phenomena. Not long ago, concepts such as "teleportation" were the stuff of science fiction, but quantum theory allows — and experiments have borne out — this remarkable means of transporting quantum information.

Every technology we use and enjoy today — our computers, smartphones, cars and appliances — can be traced back to the theoretical physics that preceded it.

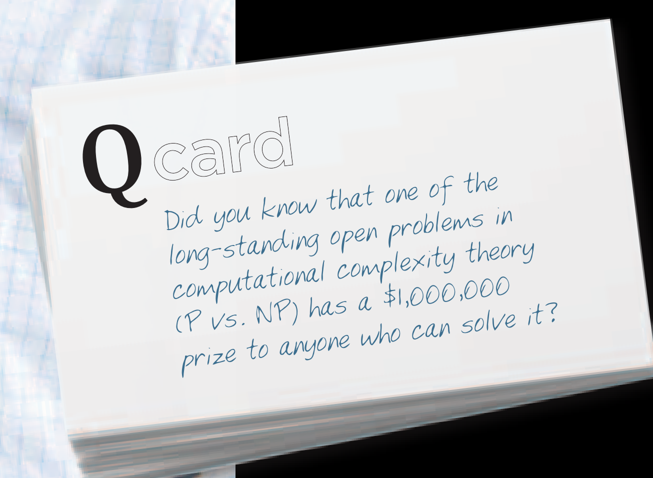
On the whiteboards that hang on nearly every wall of IQC, researchers are laying the foundations for the technologies of tomorrow.



TESTING FOR QUANTUM "ATTACKS"

At the January 2011 QIP Conference in Singapore, PROF. ANDREW CHILDS and collaborators presented a paper which addresses a quantum attack on a certain kind of public-key cryptographic protocol. Childs, DAVID JAO and VLADIMIR SOUKHAREV address classical cryptography systems based on elliptic curves. While a certain kind of elliptic curve cryptosystem was already broken by Shor's discrete logarithm algorithm (a twin sibling of his famous factoring algorithm), Childs and collaborators examined a cryptosystem based on a different elliptic curve problem believed to be exponentially harder even on a quantum computer. They found a significantly faster sub-exponential algorithm which limits the practicality of this system and reduces confidence in its resilience against other quantum attacks.

Constructing elliptic curve isogenies in quantum subexponential time, Arxiv:1012.4019v1 (December 2010)



Lighting the Way to New Technologies

When visitors first step into one of IQC's optics laboratories for a tour, several things tend to happen immediately.

First, their pupils dilate, adjusting to the almost pitch-blackness that is essential for conducting precise research with photons — the individual quantum particles of light.

Second, their feet stick to the floor, thanks to the adhesive mat that removes dust and dirt from shoes, a single speck of which could disrupt one of the highly sensitive optics experiments.

Third, their jaws drop. A quantum optics lab, with its array of lasers and mirrors and beam-splitters and lenses, can be a rather mind-boggling sight to behold.

Though everyone has an intuitive understanding of light — it illuminates and reveals the world around us — its behaviour at the quantum level is counter-intuitive yet highly useful to the research conducted at IQC.

"Light-matter interactions can be used to explore a wide range of interesting quantum-mechanical effects," says IQC faculty member **PROF. KEVIN RESCH**. "Optics research at IQC spans everything from fundamental investigations of quantum mechanics to practical applications such as cryptography and communications."

There's a well-worn Catch-22 in quantum optics that goes something like this: "The nice thing about photons is that they don't interact with each other. The trouble with photons is that they don't interact with each other."

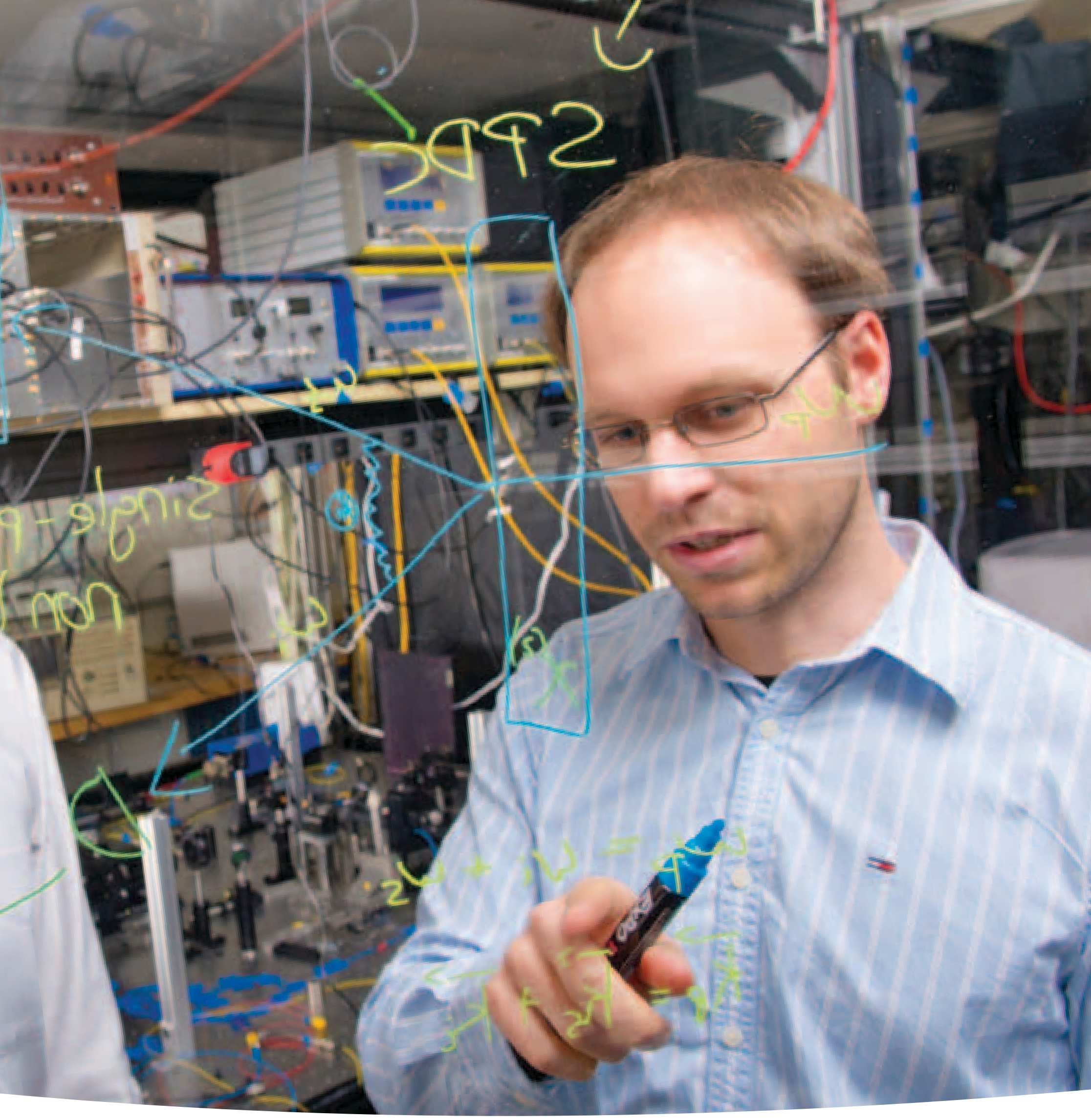
That is, photons are useful for encoding quantum information, because they don't bump into one another in the same manner as, say, atoms do. But sometimes interaction between particles is exactly what you want in quantum science.

For example, entanglement between two photons — a uniquely quantum correlation between particles despite being spatially separate — arises from such interactions.

Entanglement is difficult to achieve, but very useful once attained. Entangled photon pairs are used, for instance, in generating the eavesdropper-proof "keys" in quantum key distribution, a form of ultra-secure cryptography.

Much of the optics research at IQC is, therefore, devoted to generating single and entangled photons, detecting their presence with ever-greater precision, and putting them to use in quantum technologies.

While Resch and his team primarily investigate the foundations and protocols of quantum communication and computation, including new ways of generating entanglement, **PROF. HAMED MAJEDI** and colleagues are working on the development of better photon detectors. Majedi's research is leading toward ultra-sensitive, high-efficiency detectors, which will be crucial for the continued advancement of quantum optics research.



▲ Postdoctoral fellows **KRISTER SHALM** (left) and **ROBERT PREVEDEL** investigate the use of light particles, or photons, for quantum computation and communication.

OPTICS TEAM IN *Nature Physics*

An IQC optics team described an important advancement they achieved in measurement-based quantum computing in an issue of *Nature Physics*. The team created and characterized, for the first time, a so-called AKLT (Affleck-Kennedy-Lieb-Tasaki) state, which can serve as a quantum processor.

The experiment "capitalized on the fact that photonic states can simulate other quantum systems," summarized IQC student JONATHAN LAVOIE, who co-authored the paper with PROF. KEVIN RESCH, BEI ZENG and RAINER KALTENBAEK, along with STEPHEN BARTLETT of the University of Sydney.

Optical one-way quantum computing with simulated valence-bond solid, *Nature Physics* 6, 850-854, (2010)

PROF. THOMAS JENNEWEIN, meanwhile, is developing systems to transmit entangled photons through free space, with the ultimate goal of creating quantum-encrypted communication networks on a global scale via satellite.

"There is so much to learn and accomplish within quantum optics research," says Jennewein. "Through optics experiments, we can learn more about the foundational questions of quantum mechanics, and we can develop new technologies that have important, real-world applications." Q

Q card

Did you know that one of the lasers in an IQC optics lab creates a femtosecond burst of light? A femtosecond is to a second what a second is to 32 million years.

Protecting Privacy in a Quantum World

It's one of the most sophisticated forms of information security on earth — but it won't stay on earth for long. Plans are underway to launch a quantum cryptography system, currently in prototype form inside an IQC laboratory, into near-earth orbit aboard a satellite — the first step in a global communications network protected by quantum-enabled security.

"Our goal is to take quantum cryptography to the global scale, creating secure networks around the world," says IQC faculty member **PROF. THOMAS JENNEWEIN**, the lead experimental researcher behind taking quantum cryptography into orbit.

Quantum cryptography — the use of quantum mechanical phenomena to securely protect information — is among the first real-world technologies to have emerged from quantum information research.

One facet of quantum cryptography, quantum key distribution (QKD), is reaching the market and has been used to protect information communications ranging from election results to bank transfers. Because merely observing a quantum system will change it, eavesdropping on a quantum key transmission will leave a "fingerprint" that is detected before any private information is communicated.

Although QKD has proven an extremely secure tool for encrypting private information, there is a hurdle yet to overcome — after about 200 kilometres, photons transmitted through free space or fibre-optic cables are scattered to the point that they are no longer useful.

Free-space QKD via satellite, however, will overcome this distance limit thanks to the thinness of the atmosphere, allowing the creation of long-distance secure networks worldwide.

"It will be a big step towards quantum communications on a global scale," says IQC faculty member **PROF. NORBERT LÜTKENHAUS**, a leading theorist whose research examines the possibilities and limits of QKD and other forms of quantum cryptography. "In the long term, we can envision full-scale networks connected via satellite and fibre-optics, protected by quantum cryptography."

QKD is just one approach IQC researchers are exploring to use quantum mechanical principles such as entanglement, superposition and Heisenberg's Uncertainty Principle to protect private communications. Faculty members including

Professor **THOMAS JENNEWEIN** (left) and **JEAN-PHILIPPE BOURGOIN** discuss quantum key distribution, an ultra-secure means of protecting information.

professors **RICHARD CLEVE**, **RAYMOND LAFLAMME**, **ASHWIN NAYAK**, **DEBBIE LEUNG** and **MICHELE MOSCA** have made pioneering contributions to other facets of quantum cryptography such as quantum fingerprints, quantum money and quantum private channels.

"Nature at its most fundamental level presents us with some wonderful tools," says Mosca. "Our job is to understand the benefits of using these tools for information security. For example, in the information age it's crucial to make sure our private information — from banking data to matters of national security — remains private." Q

THE TALE OF ALICE & BOB

A third-storey office at IQC is home to Alice, a photon receiver in a Quantum Key Distribution system. Alice's counterpart, a lookalike device nicknamed Bob, is housed in an office a few kilometres away at Waterloo's Perimeter Institute for Theoretical Physics.

Alice and Bob each receive entangled (that is, highly correlated) photons emitted by a source stationed halfway between them on the University of Waterloo campus. By measuring the polarization of the photons they receive, Alice and Bob receive random (but identical) "keys," which they can use to encode their communications.

Thanks to the laws of quantum mechanics, which hold that a quantum system in an unknown state cannot be observed without being perturbed, Alice and Bob will immediately "notice" whether an eavesdropper has looked at the transmission of keys. Only when they've established identical (un-eavesdropped) keys do they encrypt whatever secret messages they wish to exchange.

Q card

Did you know that quantum key distribution was used to transmit ballot results in the 2007 Swiss election?

A New Breed of Technology

A Sense for Something New: Quantum Sensors

In IQC's newest laboratory, researchers are using the tools of the quantum trade to design and engineer a new breed of technologies.

The equipment in IQC's Research Advancement Centre II (RAC II) is similar to that in other labs at the institute — nuclear magnetic resonance spectrometers, electron spin resonance machines and more — but is used toward a different goal: the development of quantum sensors and actuators.

Countless present-day technologies already rely on sensors — from thermostats to weather radar to Geiger counters.

Quantum sensors, which can achieve precision and selectivity far beyond their classical counterparts by capitalizing on quantum mechanical effects, will allow researchers to better navigate the nano-scale world.

Developing these technologies requires expertise and experimental apparatus spanning practically every other branch of quantum information research.

"Our lab brings many modalities together to build devices based on the spin of quantum particles," explains **PROF. DAVID CORY**, IQC faculty member and Canada Excellence Research Chair in Quantum Information Processing. "We want to change the efficiencies and powers of classical devices, replacing them with more powerful and more precise quantum devices. We're aiming for better control, more efficient control and better-efficiency readout."

The experimental setups in Cory's lab, ranging from nuclear and electron spin spectrometers to low-temperature dilution refrigerators and optics equipment, allow detection and control of quantum spins with ever-greater refinement. Cory and his team are also developing quantum actuators, which control nuclear and electron spins, superconducting circuits and other bases for sensors.

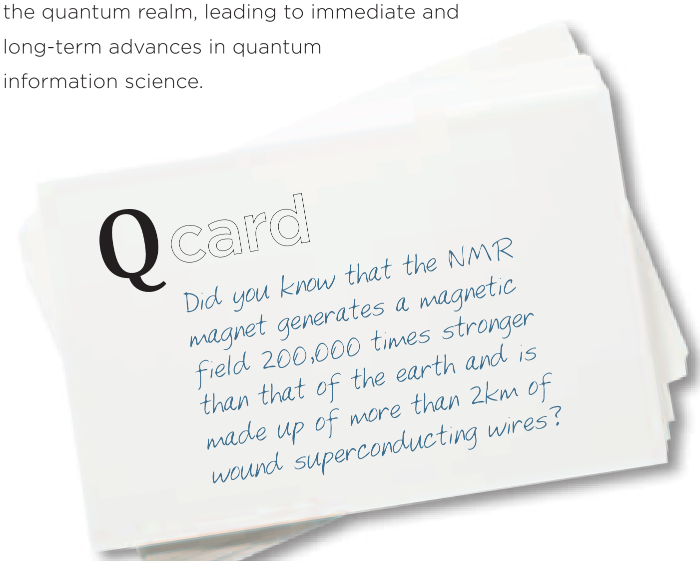
Ultimately, this research will lead to quantum sensors and actuators being integrated into more complex hybrid systems, including quantum computers.

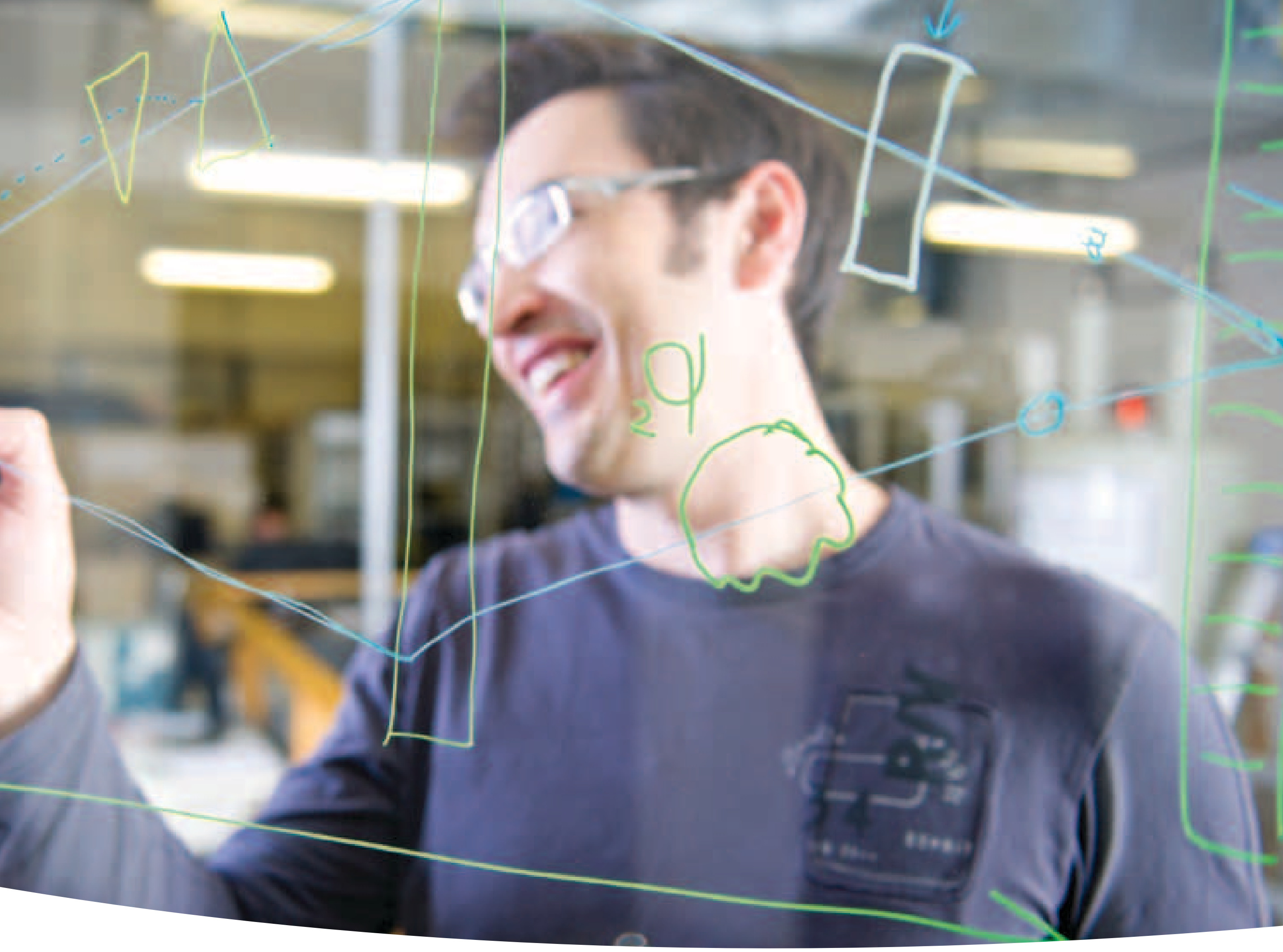
Meanwhile, Cory and research assistant professor **DMITRY PUSHIN** are working in collaboration with NIST (the National Institute of Standards and Technology) in Gaithersburg, MD, to implement quantum information concepts for developing neutron interferometry.

DMITRY PUSHIN, a research assistant professor at IQC, sketches a neutron interferometer used as a type of highly accurate quantum sensor.

Neutrons, which are subatomic particles with no electric charge, are at the heart of this research, since they make durable and highly sensitive probes of materials. Using concepts developed in quantum information processing, including quantum error correction, Pushin, Cory and colleagues are developing quantum devices robust enough to withstand specific sources of noise. For example, they designed a new four-blade interferometer resistant to mechanical vibration, which is the main limiting factor in using neutron interferometry for practical applications.

Quantum sensors and actuators enhance control over the quantum realm, leading to immediate and long-term advances in quantum information science.





From The Lab to the Marketplace: Quantum Companies

Practically every technology we use — TV, computers, smartphones and countless more — can be traced back to pure, non-commercial research.

The scientists who developed the first laser, for example, were pursuing fundamental optical science, and could not have imagined the technologies it would enable, from eye surgery to DVDs to supermarket checkout scanners.

Some of the discoveries arising from pure research at IQC are beginning to spawn the first wave of real-world quantum technologies.

A number of IQC researchers have recently founded spin-off companies to produce specialized devices that will prove invaluable to other quantum researchers worldwide.

PROF. THOMAS JENNEWEIN and collaborators have founded Universal Quantum Devices Incorporated (UQD Inc.), a builder and distributor of top-tier optical instruments. UQD's flagship product, the IQCLogic Unit, is a high-level time-tagging product for photon experiments "that outperforms anything previously available," says Jennewein, a co-founder of the company.

A pair of IQC researchers, postdoctoral fellow **ROLF HORN** and PhD student **CHRIS ERVEN**, recently launched QuSpin, a company that specializes in technologies for free-space quantum key distribution, including on-chip waveguide sources for entangled photons.

Spin-off companies such as UQD and QuSpin exemplify a crucial step forward in quantum information research — turning the fundamental breakthroughs and discoveries at IQC into practical technologies that will redefine the ways we work, communicate and live. Q

Building for the Future

The Mike & Ophelia Lazaridis Quantum-Nano Centre

Shared with the Waterloo Institute for Nanotechnology, the facility has been designed to foster inter-disciplinary collaboration between researchers, students and visitors. A large six-storey central atrium at the heart of the building is surrounded by flexible mind spaces that will encourage interaction among researchers in different disciplines.

Special Features

- **Meets highest scientific standards including stringent vibration and temperature, humidity and low electromagnetic radiation standards**
  - *Labs buried below grade to minimize electro-magnetic interference and vibration*
- **An architecturally stunning showpiece at the centre of campus**
- **Six-storey atrium with floating staircase provides a common meeting ground for scientists of all disciplines to meet and collaborate**
- **Highly convertible mind spaces located on the ground floor to accommodate conferences, workshops, lectures and more**
  - *Multi-tiered retractable seating that splits into two or four rooms to accommodate up to 200 people*

University of Waterloo President, **FERIDUN HAMDULLAHPUR** and IQC's Executive Director, **PROF. RAYMOND LAFLAMME** stand in the main entrance. The 285,000 square-foot building is a state-of-the-art platform for research at the University of Waterloo's main campus.

> "This remarkable new building, unique in the world, will add tremendous new capacity to the University of Waterloo's global impact in research and discovery as a state-of-the-art research facility where scientists from many disciplines will work together towards the next big breakthroughs in science and technology."
>
> ***~Feridun Hamdullahpur***
> ***President, University of Waterloo***

"IQC offers scientists access to the very best resources and allows them to conduct some of the most sophisticated experiments in the world. The institute's future headquarters, the Mike & Ophelia Lazaridis Quantum-Nano Centre, will further establish IQC as the world's foremost facility for quantum information research. IQC has heightened the international visibility of Waterloo's Faculty of Science and our departments of chemistry and physics and astronomy."

~Terry McMahon
Dean of Science, University of Waterloo

VITO LOGIUDICE, Director of Operations, Fabrication Facility, is pictured here atop the new Metrology Suite and Cleanroom. The new fabrication facility will give IQC researchers the necessary tools and infrastructure to build quantum devices.

A Magnet for the World's Best

Working alongside IQC's faculty and students are 37 postdoctoral fellows who represent the next wave of leaders in the field of quantum science. In the coming pages, a few of these postdoctoral fellows share their perspectives on life, research and IQC.

Postdoctoral Fellows

Krister Shalm, **Quantum Optics**

The legendary jazzman Count Basie, when asked for his secret to great music, responded: "It's not the notes you play, it's the notes you don't play that are important." The same could be said for quantum mechanics. The quantum world is a strange place, and trying to harness its properties to build new technologies is a sophisticated and subtle dance. Quantum systems are so delicate that it's just as important to know when to interact with them as when to leave them alone. What you don't see is often as important as what you do.

My two passions in life are swing dancing and quantum physics. While these pursuits may seem a world apart, they demand similar attributes — creativity, persistence, passion and ingenuity. The beginning of the 20th century saw the birth of both swing dancing and quantum mechanics. Quantum mechanics was a revolution in physics that shook our understanding of the world; swing dancing was a street dance that crossed racial barriers and embraced jazz improvisation. I have always been curious about the world around me. With quantum physics I explore the inner workings of nature; with swing dancing I connect with my internal rhythm.

Emily Pritchett, **Quantum Information Theory**

I've been painting longer than I can remember. My dad and grandfather were artists and we've been going on painting trips my whole life. My dad's outlook on art has always been abstract, subjective, intuitive. Even though he's an engineer, he's perfectly comfortable liking a painting for no reason at all — he accepts that an accomplished painter has secrets that we just can't put our finger on.

My grandfather, on the other hand, was a practical artist who believed anybody could learn to draw. After showing him a drawing that a typical grandparent would laud as a masterpiece, he'd tell me it was "not bad." He'd then take a long drag on his pipe and continue: "How can we see things where there isn't light?" he'd ask. "Does light cover a scene like a blanket, or bend around corners and under surfaces?"

Although I'm certain these analytical conversations with my grandfather affected my approach to physics, these days I strive to paint like my dad: motivated more by progress than perfection. After a long day working on a challenging theoretical physics problem, a painting session is therapeutic. Progress is obvious, creativity is essential, the goals are intangible. Sometimes, however, long contemplation over the best colour to offset a sunset can be exactly what it takes to reset a thought process and approach a problem from a different angle...

2011

Gorjan Alagic
Mohammad Ansari
Dominic Berry
Anne Broadbent
Jianxin Chen
William Coish
Motohisa Fukuda
Oleg Gittsovich
Patryk Gumann
Gus Gutoski
Brendon Higgins
Rolf Horn
Hannes Huebel
Lawrence Ioannou
Tsuyoshi Ito
Rainer Kaltenbaek
Piotr Kolenderski
Xiongfeng Ma
William Matthews
Seth Merkel
Rajat Mittal
Osama Moussa
Florian Ong
Robert Prevedel
Emily Pritchett
Colm Ryan
Robabeh Rahimi Darabad
David Rideout
Aidan Roy
Krister Shalm
Urbasi Sinha
Yipu Song
Jon Tyson
Nathan Weibe
Zhizhong Yan
Bei Zeng
Jingfu Zhang

Postdoctoral Fellows *continued*

Oleg Gittsovich, **Quantum Key Distribution**

When I came to interview for a postdoctoral fellowship at IQC in January 2010, I didn't expect to show off my slap shot.

I was excited about the prospect of working at IQC, since I knew the institute's reputation for high-level research in both theoretical and experimental quantum science. By the time I completed my PhD in Austria, my interests had begun shifting from theoretical physics to experiment-based research — so the interdisciplinary environment of IQC seemed like a perfect fit. It was also during my five years in Austria that I discovered my other passion: playing hockey. The combination of strategy, speed and reflex was a perfect counter-balance to the rigours of my PhD work.

So when I came to Canada for my job interview, I was secretly excited to be visiting the kingdom of hockey (I'm originally Russian, so I clearly remember the hockey rivalries between Canada and the USSR). Imagine my surprise when, following my interview, I was invited to join a group of researchers on the frozen pond behind IQC for a game of pick-up. What a great introduction to Canada and IQC!

Thankfully, the interview went well too. At IQC, my research bridges the gap between theory and implementation of quantum cryptography. It is rewarding but complex work, so I rarely miss an opportunity to hit the rink (or the parking lot when it's warm) for a stress-relieving game of hockey.

Graduate Program

A message from the

Quantum Information Graduate Program Director

Graduate students are a vital part of the Institute for Quantum Computing. Their fresh perspectives make them invaluable contributors to IQC's discoveries. As more graduates enter the workforce, they will build on the knowledge created and share it throughout their careers internationally.

Our collaborative graduate program, launched in 2010, has attracted some of the brightest and most creative mathematics, computer science, chemistry, physics, and engineering graduate students from six continents. They are the first wave of students to learn the foundations, applications and implementations of quantum information processing with peers from widely different academic backgrounds.

We offer a growing array of courses in collaboration with the faculties of Engineering, Mathematics and Science at the University of Waterloo. Our students research all aspects of quantum information processing — and are making fascinating and important discoveries.

This generation of quantum-educated scientists will turn the scientific breakthroughs of IQC's first 10 years into the revolutionary technologies of the future.

The following pages introduce this year's graduate students, several of whom have commented on what the IQC experience means to them.

Michele Mosca
Deputy Director, IQC

GRADUATE STUDENTS

2011

Jeyran Amirloo
Razeih Annabestani
Jean-Philippe Bourgoin
Jeremy Chamilliard
Alessandro Cosentino
Ben Criger
Pierre-Luc Dallaire-Demers
Chunqing Deng
Amin Eftekharian
Chris Erven
Agnes Ferenczi
Chris Ferrie
Kent Fisher
Jen Fung
MirMotjaba Gharibi
Sevag Gharibian
Behnood Ghamsari
Nickolay Gigov
Luke Govia
Christopher Granade
Peter Groszkowski
Nupur Gupta
Deny Hamel
Fatin Haque
Tyler Holden
Catherine Holloway
Amir Jafari Salim
Stacey Jeffery
Tomas Jochym-O'Connor
Artem Kaznatcheev
Mohsen Keshavarz
Botan Khani
Milad Khoshnegar Shahrestani
Nathan Killoran
Robin Kothari
Jonathan Lavoie
Nicholas LeCompte
Xian Ma
Easwar Magesan
Laura Mancinska
Iman Marvian
Thomas McConkey
Matthew McKague
Evan Meyer-Scott
Sergei Mikheev
Hamid Mohebbi
Abel Molina Prieto
Felix Motzoi
Varun Narasimhachar
Mohamad Niknam
Jean-Luc Orgiazzi
Yingkai Ouyang
Maris Ozols
Adam Paetznick
Kyungdeock Park
Gina Passante
Om Patange
David Pitkanen
Farzad Qassemi
Wenling Qiao
Ansis Rosmanis
Yuval Sanders
Kurt Schreiter
Cheng Shen
Jamie Sikora
Jamie Smith
Jason Soo Hoo
Gelo Noel Tabia
Cozmin Ududec
Sarvagya Upadhyay
Christopher Wood
Rui Xian
Mengyun Zhai
Yingjie Zhang

Meet our Graduate Students

Gina Passante

I was profiled in the local newspaper here in Waterloo Region and had a chance to not only explain my research, but to provide a personal story that helps readers identify with the science. This opportunity was available because of the scientifically engaged public in the area.

Evan Meyer-Scott

The first time I made entanglement in the lab, that was spectacular. I thought, "Wow — this is quantum, and we are able to control it."

Farzad Qassemi

Many things about IQC were intriguing for me — the cutting-edge research on quantum technologies, the interdisciplinary nature of IQC and the first-class scientists and students. The environment at IQC is one of the most stimulating environments for research I have ever seen.

Chris Erven

IQC and the University of Waterloo is a great place to have a complete life, not just a job. I've met so many great friends and colleagues here and had the chance to play on intramural teams with some of them. Additionally, I've had the good fortune to be part of the uWaterloo Varsity Badminton team since my first term as an undergraduate engineering student, first as a player, then a captain, and finally as a coach for the last four years. Not very many other places would have given me such a diverse life outside of experiments.

Ben Criger

At IQC, I'm presented with an endless array of fascinating research questions, and I'm completely unconstrained as to how I pursue them. I don't think I would get this academic freedom anywhere else.

Stacey Jeffery

I began at IQC as an undergraduate research assistant, working with Anne Broadbent and Michele Mosca. The thing that most impressed me was the number of leading researchers in the field who were just down the hall. It seemed that wherever my research took me, there was an expert in that area close by.

Laura Mancinska

The large number of faculty members, postdocs and grad students ensures that you can find someone to collaborate with or ask questions of no matter which theoretical or experimental aspect of quantum computing interests you. The different seminars provide exposure to different areas of quantum computing, allowing you to better understand the main challenges and goals of the field.

Hamid Mohebbi

The relationships between students, postdoctoral fellows, professors and staff are very good. I have made lots of friends here at IQC. The involvement of families in social activities is a unique aspect of IQC. My family was glad to meet Prof. Raymond Laflamme at the holiday party. This close involvement inspired my son to proudly talk about IQC at school when his teacher introduced some new advances in science and technology.

Courses

FALL 2010 COURSES

QIC 710 Quantum Information Processing
Instructor: Prof. Ben Reichardt

An introduction to quantum information, quantum algorithms, quantum complexity theory, entropy and noiseless coding, error-correcting codes and fault-tolerance, nonlocality and cryptography.

QIC 890 Applied Quantum Cryptography
Instructor: Prof. Norbert Lütkenhaus

WINTER 2010 COURSES

QIC 750 Implementations of Quantum Information Processing
Instructor: Prof. Frank Wilhelm

An introduction to physical implementations of quantum computers with an emphasis on common and connecting themes.

QIC 890 Spin-based Implementations
Instructor: Prof. Jonathan Baugh

An in-depth introduction to quantum information processing implementations based on nuclear and electron spin.

QIC 885 Quantum Electronics and Photonics
Instructor: Prof. Hamed Majedi

For engineers interested in applied quantum mechanics. The course covers the quantum behaviours of electrons, photons and their interaction.

QIC 845 Open Quantum Systems
Instructor: Prof. Joseph Emerson

Explores the theory of open quantum systems, which consists of a set of mathematical techniques and phenomenological models for describing generalized quantum dynamics and quantum measurements, and methods of quantum control.

QIC 823 Quantum Algorithms
Instructor: Prof. Andrew Childs

An investigation of algorithms that allow quantum computers to solve problems faster than classical computers.

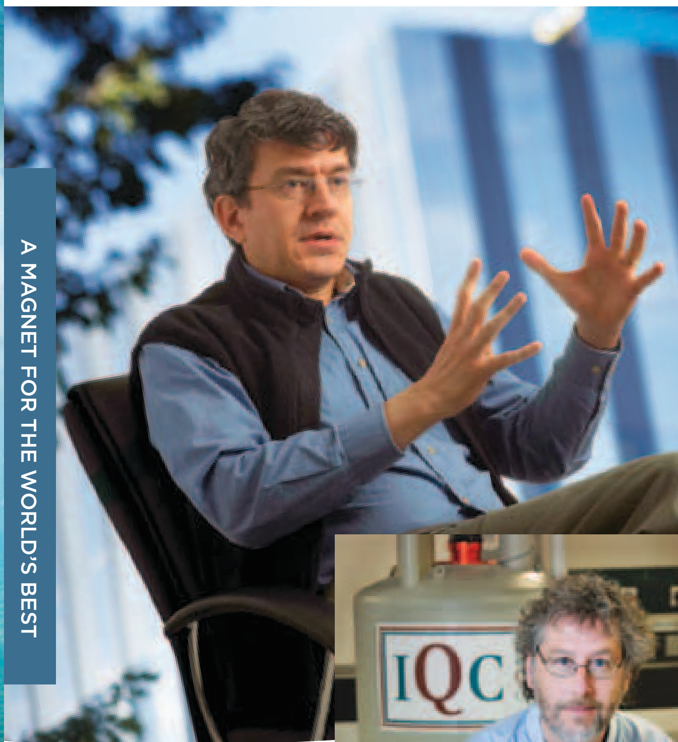
SPRING 2011 COURSES

QIC 890 Implementations of Quantum Communication
Instructor: Prof. Thomas Jennewein

QIC 891 Sir Anthony Leggett Lecture Series
Foundations of Quantum Mechanics and Quantum Information

QIC 890/891 Selected Advanced Topics in Quantum Information
Course co-ordinator: Prof. Michele Mosca

A MAGNET FOR THE WORLD'S BEST



Awards & Recognition

Cleve named Fellow in the Royal Society of Canada

PROF. RICHARD CLEVE, who joined IQC in 2004, was among 75 new Fellows elected to the Royal Society of Canada this year. Cleve was recognized for "having discovered various quantum computer algorithms and communication protocols that utilize quantum mechanical behavior to compute exponentially faster than possible in the current computing paradigm."

Cory joins IQC as Canada Excellence Research Chair

PROF. DAVID CORY was appointed Canada Excellence Research Chair in Quantum Information Processing in June 2010. Cory, a renowned pioneer and innovator in quantum computing, joined IQC and the University of Waterloo following a tenure as professor of nuclear engineering at Massachusetts Institute of Technology. His research is expected to contribute to the world's first generation of practical quantum devices. These new technologies will have immediate and future applications in medicine, communications, biochemistry, physics, nanoscience and more.

FACULTY AWARDS

"40 Under 40" Award
from *The Waterloo Region Record* (February 2011)

Prof. Joseph Emerson

Doctor Honoris Causa
The University of Sherbrooke (September 2011)

Prof. Raymond Laflamme

Sloan Research Fellowship
from the Alfred P. Sloan Foundation (February 2011)

Prof. Adrian Lupaşcu

Outstanding Performance Award
University of Waterloo (January 2011)

Prof. Kevin Resch
Prof. John Watrous
Prof. Frank Wilhelm

POSTDOCTORAL FELLOW AWARDS

NSERC Postdoctoral Fellowship (2008)
NSERC Doctoral Prize (January 2009)
CIFAR Junior Fellow (August 2011)

Anne Broadbent

MRI Award (October 2009)
Erwin Schrödinger Fellowship (November 2009)

Robert Prevedel

University of Waterloo Fields Postdoctoral Fellowship (August 2010)

Aidan Roy

CIFAR Fellowship (October 2010)

Krister Shalm

Prof. Mosca (right) pictured with Blair Pollard, VP of Talent Management and Total Rewards. *Photo credit: Greg Henkenhaf*

Mosca wins national *Top 40 Under 40* award

For his tremendous contributions to science in Canada, IQC's Deputy Director **PROF. MICHELE MOSCA** was named among the country's *Top 40 Under 40* this year. The award celebrates young Canadians who are "outstanding leaders in their chosen fields and are shaping our country's future" — a description that certainly applies to Mosca. As one of the founders of the Institute for Quantum Computing, and a founding researcher at Perimeter Institute, he has made incalculable contributions to establishing Waterloo as a globally recognized hub for quantum information research.

Broadbent earns prestigious Polanyi Prize

Anne Broadbent with the Honourable David C. Onley (centre) and John Polanyi (right).

IQC researcher **ANNE BROADBENT** earned the prestigious $20,000 Polanyi Prize for her cutting-edge work exploring the frontiers of quantum mechanics and communications. Awarded annually by the Ontario government, the prize recognizes up to five outstanding young researchers whose work contributes to the advancement of science and discovery.

The following awards were granted to IQC students during the 2010-2011 fiscal year.

Twenty of IQC's 32 eligible Canadian students hold NSERC scholarships.

Mike and Ophelia Lazaridis Fellowship

Yingkai Ouyang, Iman Marvian, Amin Eftekharian, Sarvagya Upadhyay, Abel Molina Prieto and Ansis Rosmanis

NSERC Vanier Canada Graduate Scholarship

Deny Hamel, Gina Passante and Kurt Schreiter

NSERC Alexander Graham Bell Canada Graduate Scholarship — Masters

Ben Criger, Pierre-Luc Dallaire-Demers, Robin Kothari, Evan Meyer-Scott, Stacey Jeffery, Kent Fisher, Luke Govia, Tomas Jochym-O'Connor and Nickolay Gigov

NSERC Alexander Graham Bell Canada Graduate Scholarship — Doctoral

Easwar Magesan, Jonathan Lavoie, Sevag Gharibian and Farzad Qassemi

NSERC Postgraduate Scholarship — Master's Extension

Deny Hamel

NSERC Postgraduate Scholarship — Doctoral

Chris Erven, Chris Ferrie, Jamie Sikora, Jamie Smith and Felix Motzoi

David R. Cheriton Graduate Scholarship

Sevag Gharibian, Sarvagya Upadhyay, Abel Molina Prieto and Robin Kothari

Ontario Graduate Scholarship

Cozmin Ududec, Thomas McConkey, Hamid Mohebbi, Nathan Killoran, Evan Meyer-Scott and Fatin Haque

Ontario Graduate Scholarship in Science & Technology

Peter Groszkowski, Thomas McConkey, Chunqing Deng and David Pitkanen

President's Graduate Scholarship

Cozmin Ududec, Deny Hamel, Ben Criger, Robin Kothari, Pierre-Luc Dallaire-Demers, Thomas McConkey, Chris Erven, Hamid Mohebbi, Stacey Jeffery, Nathan Killoran, Jamie Sikora, Chris Ferrie, Easwar Magesan, Jamie Smith, Evan Meyer-Scott, Kent Fisher, Luke Govia, Fatin Haque, Tomas Jochym-O'Connor, Jonathan Lavoie, Sevag Gharibian, Felix Motzoi, Farzad Qassemi and Nickolay Gigov

IQC Achievement Award

Felix Motzoi, Farzad Qassemi, Sarvagya Upadhyay, Evan Meyer-Scott, Kent Fisher, Luke Govia, Tomas Jochym-O'Connor, Nickolay Gigov and Christopher Wood

IQC to the World; the World to IQC

A message from the

Manager, Scientific Outreach

The fundamental goal of IQC is to perform world-class research at the forefront of science. This cannot happen in isolation. It should be shared with the people who fuel it, support it, are fascinated by it and will ultimately benefit from it. While the science speaks for itself, we want to share it with a broader audience and to inspire widespread awe, understanding of and support for the quantum revolution happening now at IQC.

Our outreach efforts are tailored to each of our audiences: prospective graduate students, undergraduates, high school students and educators, as well as our university, government, business and community partners. We aim to inform and inspire, educating the public and attracting the next generation of exceptional scientists who will shape the quantum-enabled future.

People are taking the quantum leap — interest in our camps and programs is skyrocketing, tour requests have doubled and the positive responses keep rolling in. We've only just begun! Next year will mark IQC's 10th anniversary milestone with new experiences for everyone — from scientists to the merely quantum-curious.

These pages offer a snapshot of our outreach activities.

Martin Laforest
Manager, Scientific Outreach, IQC

The IQC David Johnston Award for Scientific Outreach

Congratulations to the winners of IQC's new Scientific Outreach Award

Up to three awards valued at $2,500 are given annually to current graduate students at IQC who have shown an outstanding commitment to scientific outreach and community engagement. This award was created to celebrate Canadian Governor General David Johnston's vital contributions to IQC, his passion for leadership and his enthusiasm for continuous learning, innovation and achievement. David Johnston was president of the University of Waterloo from 1999 to 2010. This award is funded by Industry Canada.

▲ Left to right: **MARTIN LAFOREST**, award winners **GINA PASSANTE**, **CHRIS ERVEN** and **JEAN-LUC ORGIAZZI**, with Prof. **RAYMOND LAFLAMME**.

Events & Tours

2010 Open House

The largest Open House in IQC's history welcomed more than 800 visitors to explore a Discovery Zone, tour labs and attend a public lecture by Prof. David Cory.

TEDxWaterloo

x = independently organized TED event

IQC was a sponsor of this annual meeting of the minds and presented a scientific Discovery Zone for attendees.

Quantum Frontier Distinguished Lecture Series

The lectures presented once per term explore the ways researchers are harnessing quantum mechanics to advance various fields at the forefront of science. The first lecture in April 2011 featured IBM's Don Eigler and the second in June 2011 hosted Ralph Merkle of Singularity University.

Academic, Business & Government Tours

IQC provided presentations and lab tours to a large variety of groups: high school field trips, student associations, industry members, government officials, etc.

The Quantum Physics of Harry Potter

IQC postdoc Krister Shalm and magician Dan Trommater explored mind-bending concepts of quantum science, as seen through the lens of Harry Potter. From photon entanglement to quantum superposition to teleportation, the show shed light (often via lasers) on how the real science behind quantum research is just as fascinating as the Hogwarts School of Witchcraft and Wizardry.

Conferences, Workshops & Schools

Cross-Border Workshop on Laser Science

The workshop fostered interaction between graduate students and leading experts in laser science.

Quantum Cryptography School for Young Students (QCSYS)

An introductory workshop to key concepts in quantum information processing aimed at high school students aspiring to study quantum science at university. This year, the summer school hosted 40 students from around the world. The program also began accepting international applicants.

Undergraduate School on Experimental Quantum Information Processing (USEQIP)

The program is designed to provide exceptional undergraduate students hands-on experience in the field of quantum information processing. Nineteen students from around the globe came to Waterloo to participate in the two-week long camp and participate in experimental activities and theoretical lectures at IQC.

Theory and Realization of Practical Quantum Key Distribution

The workshop brings together leading experts from around the world who investigate all aspects of quantum key distribution spanning theory and experimental approaches to quantum science.

Quantum Information Processing with Spin and Superconductors

The goal of this workshop is to bring leaders in superconducting and spin-based research together to discuss recent progress, unanswered questions, and future directions for building a solid-state quantum-information processor.

IQC Online

The Quantum Library

Visit pubs.iqc.ca to see IQC's publications database — home to hundreds of peer-reviewed journal articles, conference proceedings, commentaries and other publications by IQC researchers. Searchable by author, publication, subject keywords and other criteria, the site is an online repository of IQC's leading contributions to quantum information science.

USEQIP on YouTube

From public lectures to summer workshops to interviews with scientists — the IQC YouTube channel is home to a library of videos that bring quantum information science to the world. For example, whereas enrollment in the Undergraduate School on Experimental Quantum Information Processing was limited to 19 students, the lectures and hands-on lab sessions are available on YouTube for anyone to watch.

Find our YouTube channel at **youtube.com/quantumiqc**.

The QuantumFactory Blog

Visit **quantumfactory.wordpress.com** for news, videos, commentary and miscellaneous oddities from the amazing (and often amusing) world of quantum science.

Twitter @QuantumIQC **facebook.com/quantumiqc** **flickr.com/quantumiqc** **youtube.com/quantumiqc**

Twitter

Follow **@QuantumIQC** to see our tweets on events, quantum news, new publications and other fun stuff. Tag us **#quantumiqc** in your own tweets!

Facebook

Join our fan page at **facebook.com/quantumiqc** for photos, news updates, event info and more.

Flickr

See photos of Stephen Hawking's visit, the Mike & Ophelia Lazaridis Quantum-Nano Centre, IQC's Open House, special visitors and more. At **flickr.com/quantumiqc**.

IQC's Global Reach

Because collaboration is a catalyst for discovery, IQC researchers work closely and publish results with peers from across the globe. "We seek the best collaborators in the world," says Prof. Raymond Laflamme, "and we want the best collaborators to seek us. It's how great science happens."

During the 2010 calendar year, IQC researchers collaborated with:

- 166 external researchers leading to the publication of 56 joint papers
- 96 institutes from 20 countries

National and International Agreements

IQC has signed six agreements to promote research and exchange of science with other organizations.

- National Research Council
- National University of Singapore
- IBM
- National Science Council of Taiwan
- Indian Institute of Technology, Kanpur
- National Institute of Informatics, Japan

International Outreach & Recruitment Events

IQC seeks the best young minds in the world at international recruitment events.

- Beijing Normal University Student Seminar, China
- Roundtable, Canadian Embassy, China
- Graduate Fair, Beijing, China
- Tsinghua and Peking University Student Seminar, China
- American Association for the Advancement of Science: Annual Meeting, Washington, USA
- World Conference of Science Journalists 2011, Doha, Qatar

Grad fairs and undergraduate seminars

IQC was present at several top Canadian universities to promote quantum information, IQC, the University of Waterloo and the quantum information graduate program.

IQC also participated in *PhDChina*, a large graduate fair open to 1,200 top Chinese students.

Tony Leggett: Distinguished Research Chair

He is a Nobel Prize winner who has been knighted by the British Crown, but within the Institute for Quantum Computing, he is known to most simply as Tony.

Despite his many scientific achievements and accolades, **SIR ANTHONY LEGGETT** is an approachable peer and valued collaborator during his summer sojourns as IQC's Mike & Ophelia Lazaridis Distinguished Research Chair.

Arriving at the institute by bicycle each day, the British-born Leggett has spent the past five summers delivering lectures on specialized topics in quantum mechanics, mentoring students and sharing ideas with IQC faculty.

IQC is honoured to host a Nobel Prize winning scientist — and Leggett insists the honour is mutual.

"Without flattery, I just cannot think of any other institute which has the all-round strength of IQC over the quantum information field as a whole," says Leggett, who is based at the University of Illinois at Urbana-Champaign.

"More than any other institution, IQC has created a culture in which, for example, a computer scientist can find himself or herself 'on the same wavelength' as a theoretical physicist or a materials chemist, all in pursuit of a common goal."

Leggett was one of three physicists to share the Nobel Prize in physics in 2003, and he was knighted the following year for his significant contributions to low-temperature physics and superfluidity.

His recent research involves the use of condensed physical systems to test the foundations of quantum mechanics.

Leggett's 2011 lecture series at IQC covered a range of topics from fundamental questions of quantum theory to new implementations of quantum-enabled technologies. He's impressed with the pace and success of quantum information research, and hopes further work will lead to a "qualitatively different" capability of quantum computers over their classical counterparts.

"As long as the advantages of quantum computing are basically speed-ups of classically feasible operations, I fear the engineering motivation to build a quantum computer may decrease over time," he says. "I hope — and believe — we will find some qualitatively new things that we can do with a quantum computer, and the result will have a revolutionary impact. But, alas, I can't guess what these 'new things' will be. It reminds me of a Louis Armstrong quote: 'Man, if I knew where jazz was going, I'd already be there!'"

The only thing that is certain about the future of quantum information research, Leggett adds, is that it will be full of fascinating surprises.

"When it comes to quantum mechanics," he says, "don't take anything for granted!" Q

IQC is happy to announce that Leggett's position at the institute has been extended for another five years.

Video recordings of Leggett's lectures are available at **iqc.uwaterloo.ca**

Special Visitors

Finance Minister of Canada

The Honourable Jim Flaherty

September 9, 2010

Flaherty lauded the “amazing evolution of technology” happening at IQC during a tour of innovation centres around Waterloo Region.

Freeman Dyson

Physicist and mathematician

June 2, 2011

Freeman Dyson (second from left), one of the world’s most renowned theoretical physicists, visited IQC on June 2, the day after his Perimeter Institute Public Lecture.

Ontario Lieutenant Governor

The Honourable David C. Onley

April 11, 2011

The Honourable David C. Onley toured IQC labs and told researchers their work “will have a real impact that’s going to affect people’s lives in positive ways.”

International Women’s Forum of Canada

Waterloo Chapter

January 13, 2011

“It is truly incredible to have the largest institute of this kind right here in our own backyard,” said Laura Gainey, Regional President (Southwestern Ontario) of the Royal Bank of Canada, following the group’s visit to IQC.

Academic and Scientific Visitors

Visitors from May 1, 2010 to April 30, 2011

Mohamed Abutaleb, Massachusetts Institute of Technology
Antonio Acin, Institut de Ciències Fotòniques
Andris Ambainis, University of Latvia
Henri Angelino, National Institute of Informatics, Tokyo
Joonwoo Bae, Korea Institute for Advanced Study
Mustafa Bal, Dartmouth College
Olaf Benningshof, Universiteit Leiden
Jacob Biamonte, University of Oxford
Jonathan Blackman, University of British Columbia
Hendrik Bluhm, Harvard University
Fabien Boitier, L'École Polytechnique
Aggie Branczyk, University of Queensland
Fernando Brandao, Imperial College, London
Andrew Briggs, University of Oxford
Winton Brown, Dartmouth College
Oliver Buerschaper, Max Planck Institute of Quantum Optics
Guido Burkard, University of Konstanz
Jianming Cai, University of Innsbruck
Tommaso Calarco, University of Innsbruck
Krishna Chetry, University of Cincinnati
Chen-Fu Chiang, University of Central Florida
Giulio Chiribella, Perimeter Institute
Eric Chitambar, University of Toronto
Andrew Cleland, University of California, Santa Barbara
Christophe Couteau, Universitè de Technologie de Troyes
Marcos Curty, University of Vigo
Carlos Perez Delgado, University of Sheffield
Ivan Deutsch, University of New Mexico
John Donohue, University of Windsor
Frédéric Sébastien Dupuis, Eldgenössische Technische Hochschule Zürich
Don Eigler, IBM
Alessandro Fedrizzi, University of Queensland
Stephen Fenner, University of South Carolina
Joe Fitzsimons, University of Oxford
Sergey Frolov, Delft University of Technology
Silvano Garnerone, University of Southern California
Mike Geller, University of Georgia
Shohini Ghose, Wilfrid Laurier University
Jérémie Gobeil, Université du Québec à Trois-Rivières
Robert Hadfield, Heriot-Watt University
Avinatan Hassidim, Massachusetts Institute of Technology
Patrick Hayden, McGill University
Brendon Higgins, Griffith University
Richard Hughes, Los Alamos National Laboratory
Atac Imamoglu, Eldgenössische Technische Hochschule Zürich
Rahul Jain, National University of Singapore
Zhengfeng Ji, Perimeter Institute
Nathaniel Johnston, University of Guelph
Rainer Kaltenbaek, University of Vienna
Changdong Kim, Texas A&M University
Vadym Kliuchnikov, University of Ukraine
Sacha Kocsis, Griffiths University
Robert König, Institute for Quantum Information at Caltech
Matthew Leifer, University College London
Chen Lin, National University of Singapore
Seth Lloyd, Massachusetts Institute of Technology
Mirko Lobino, University of Bristol
Brian Lowans
Shunlong Luo, Chinese Academy of Sciences
Alex Lvovsky, University of Calgary
Lars Lydersen, Norwegian University of Science and Technology
Xiongfeng Ma, University of Toronto
Frederic Magniez, Laboratoire de Recherche en Informatique
Vadim Makarov, Norwegian University of Science and Technology
Rachael Mansbach, Swarthmore College
Alexandra Mech, University of Vienna
Zhenghua Mie, McMaster University
Gerard Milburn, Queensland University
Peter Milonni, Los Alamos National Laboratory
Vesna Mitrovic, Brown University
Christopher Monroe, University of Maryland
Cristopher Moore, University of New Mexico
Shahpoor Moradi, Ravi University
Mustafa Muhammad, University of Cincinnati
Ion Nechita, University of Ottawa
Beth Nordholt, Los Alamos National Laboratory
Kumar Patra, University of York, UK
Michael Peskin, Stanford University
Laszlo Petho, University of California, Berkeley
Tilman Pfau, Universität Stuttgart
Robert Pfiefer, University of Queensland
Eric Platon, National Institute of Informatics, Tokyo
Britton Plourde, Syracuse University
Chris Pugh, Brandon University
Dmitry Pushin, Massachusetts Institute of Technology
Chandrasekhar Ramanathan, Dartmouth College
Samuel Ranellucci, Université de Montréal
Robert Raussendorf, University of British Columbia
Joseph Rebstock, University of Alberta
Michael Reimer, Delft University
Martin Roetteler, NEC Laboratories America
Mary Beth Ruskai, Tufts University
Colm Ryan, Massachusetts Institute of Technology
Mark Saffman, University of Wisconsin, Madison
Akira SaiToh, Kinki University
Sophie Schirmer, University of Cambridge
Hartmut Schmeck, Karlsruhe Institute
Volkher Scholz, University Hannover
Norbert Schuch, California Institute of Technology
Pranab Sen, Tata Institute of Fundamental Research
Zahra Shadman, Institut für Theoretische Physik
Yutaka Shikano, Tokyo Institute of Technology
Marcus Silva, University of Sherbrooke
Stephanie Simmons, Magdalen College, Oxford
Christoph Simon, University of Calgary
John Sipe, University of Toronto
Paul Skrzypczyk, University of Bristol
Graeme Smith, IBM TJ Watson Research Centre
John Smolin, IBM TJ Watson Research Centre
Rolando Somma, Los Alamos National Laboratory
Ajay Sood, Indian Academy of Sciences
Douglas Stebila, Queensland University of Technology
DJ Strouse, University of Southern California
Martin Suchara, Princeton University
G. Sundararajan, ARCI Hyderabad
Kristan Temme, University of Vienna
John Teufel, National Institute of Standards and Technology
Mike Thewalt, Simon Fraser University
Falk Unger, University of California, Berkeley
Anton Van der Ven, University of Michigan
Umesh Vazirani, University of California, Berkeley
Lorenzo Campos Venuti, Institute for Scientific Interchange
Thomas Vidick, University of California, Berkeley
Arlette de Waard, milliKelvin Technologies
Zak Webb, University of Washington
Christian Weedbrook, University of Queensland
Chieh Wei, University of British Columbia
Tzu Chieh Wei, University of British Columbia
Gregor Weihs, University of Innsbruck
Nathan Wiebe, University of Calgary
Mark Wilde, McGill University
Andreas Winter, University of Bristol
Ronald de Wolf, Centrum Wiskunde & Informatica
James Wootton, University of Leeds
Faxian Xiu, University of California, Riverside
Albion Yang, Simon Fraser University
Man Hong Yung, Harvard University
Wojciech Zurek, Los Alamos National Laboratory and Santa Fe Institute

A Year in Review

IQC By the Numbers

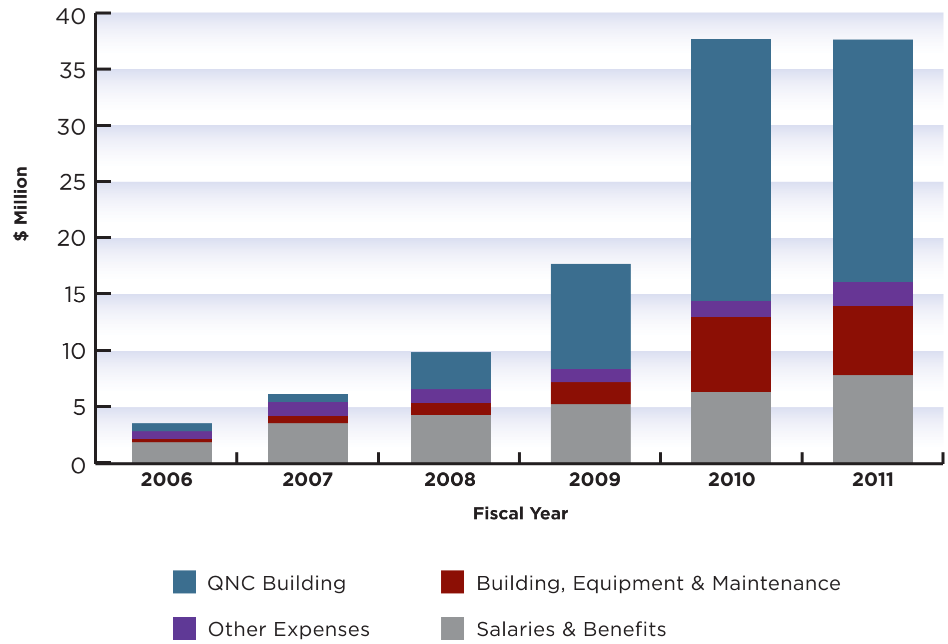
May 1, 2010 to April 30, 2011

Top Citation Awards

Sciencewatch.com conducted a review of the top 20 most-cited papers in quantum computing over the past decade. Two publications by IQC faculty members made the top 10. In the top spot, “A scheme for efficient quantum computation with linear optics” by **PROF. RAYMOND LAFLAMME** and collaborators in *Nature* 409, 46-52 (2001) with 1160 total cites.

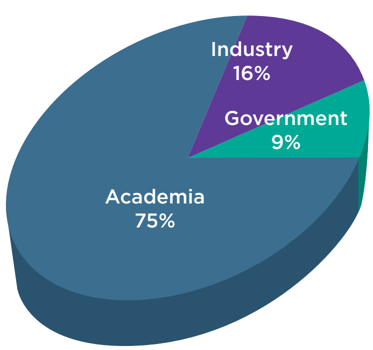
Number 10 on the list was “Experimental one-way quantum computing” by **PROF. KEVIN RESCH** and collaborators in *Nature* 434, 169-176 (2005) with 284 total cites.

Annual Expenditures

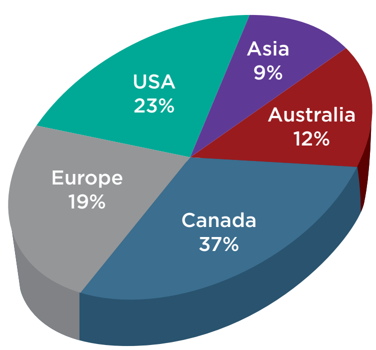


Student Alumni: Where are they now?

Field of employment



Global employment

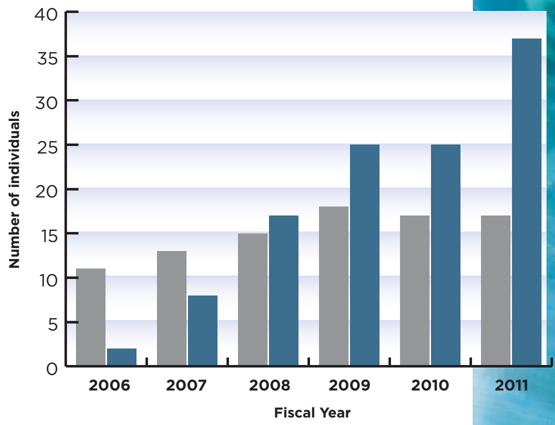


Faculty & Postdoctoral Fellows

The numbers of faculty members and postdoctoral fellows at IQC have been steadily increasing since inception in 2002.

Faculty

Postdoctoral Fellows



Publications

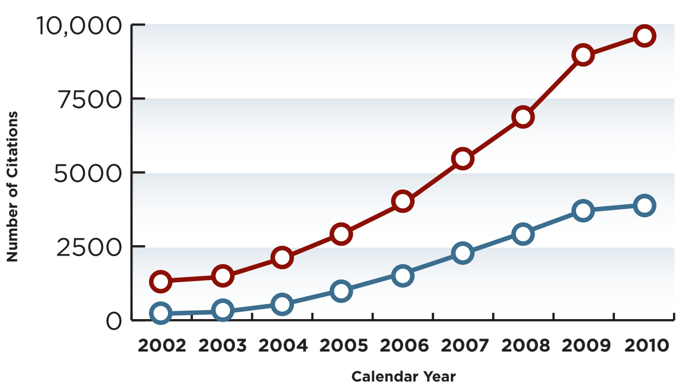
Notable publications in the journals *Nature, Nature Photonics, Nature Physics, Physical Review Letters* and *Science* are important additions to the publications database.

Publication	Number
Nature	3
Nature Photonics	1
Nature Physics	5
Physical Review Letters	13
Science	1
STOC	2

Year	Publications
2002	4
2003	9
2004	21
2005	30
2006	39
2007	66
2008	95
2009	193
2010	160

Citations

ISI Web of Science   Google Scholar



Governance

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VITO LOGIUDICE, Director of Operations, Fabrication Facility

LASZLO PETHO, Thin Film Process Development and Integration Engineer

RODELLO SALANDANAN, Senior Equipment Technologist

IVAR TAMINIAU, Laboratory Technician

Life @ IQC

Pick-up Skills

IQC researchers and students join participants of the Undergraduate School for Experimental Quantum Information Processing (USEQIP) for a game of pick-up in the back parking lot.

Puttering Around

Winners of the 2010 IQC Summer Golf Tournament, Gina Passante, Brad Huiskamp, Matt Volpini, Emily Pritchett and Osama Moussa.

Minute to Win It

Students play a game of “Minute to Win It” at a social gathering for IQC members.

Women in Physics Canada

Participants in the Women in Physics Canada conference held in July 2011 tour the labs and learn about quantum key distribution from student Chris Erven.

Thank you

IQC thanks Mike and Ophelia Lazaridis, the Province of Ontario, Industry Canada and Canada's Economic Action Plan for their continued support.

The tremendous success of the Institute for Quantum Computing would not have been possible without the vision and generosity of Mike and Ophelia Lazaridis who have donated over $100 million in private funding.

Industry Canada granted IQC $50 million over a period of five years to enable the establishment of a new world-class research facility. This grant supports the Canadian government's science and technology strategy aimed at building a strong economy via knowledge and innovation.

The Province of Ontario (through the Ministry of Research and Innovation) granted $50 million to IQC to help strengthen Ontario's leading-edge research capacity. The grant was used partially to fund the construction of the new research facility.

IQC wishes to thank the following individuals and organizations for their generous and continued support:

Advanced Research and Development Activity
Army Research Office
Bell Family
Bruker Biospin Canada
Canada Excellence Research Chairs
Canada Foundation for Innovation
Canada Research Chairs
Canada's Economic Action Plan
Canadian Institute for Advanced Research
Canadian Institute for Photonic Innovations
Centre for Applied Cryptographic Research
COM DEV
Communications Security Establishment Canada
Defense Advanced Research Projects Agency
Disruptive Technology Office
Early Researcher Awards
European Research Association
Government of Canada
Government of Ontario
IBM
Industry Canada
Intelligence Advanced Research Projects Agency
Mathematics of Information Technology and Complex Systems
Mike and Ophelia Lazaridis
Natural Science and Engineering Research Council
Ontario Centres of Excellence
Ontario Innovation Trust
Ontario Ministry of Research and Innovation
Ontario Research and Development Challenge Fund
Ontario Research Fund
Perimeter Institute for Theoretical Physics
Premier's Research Excellence Fund
Province of Ontario
QuantumWorks
Research In Motion
The University of Waterloo

Special thanks to the University of Waterloo, IQC's home, that celebrates and supports research, innovation and excellence.

Open the page for a sneak peek of how we'll be celebrating our upcoming 10th anniversary!

Science and Society: IQC's 10th Anniversary

IQC's 10th anniversary is more than a milestone — it represents another giant leap forward in the evolution of the institute. Highlighted by the expansion into the remarkable new Mike & Ophelia Lazaridis Quantum-Nano Centre, IQC's 10th anniversary events will showcase quantum information science like never before, including a new slate of academic conferences, grand opening events, cultural activities, international collaborations and more.

10th Anniversary Activities:

Scientific Conferences and Workshops

A new series of academic events aimed at fostering communication and collaboration between top quantum researchers from around the globe.

Distinguished Lecture Series
In collaboration with the Waterloo Institute for Nanotechnology, IQC continues its Quantum Frontiers Distinguished Lecture Series, featuring renowned experts from around the world.

Recent Progress in Quantum Algorithms
April 11-13, 2012

Undergraduate School on Experimental Quantum Information Processing
May 28-June 8, 2012

12th Annual Canadian Summer School on Quantum Information
June 11-15, 2012

9th Canadian Student Conference & 2nd AQuA Student Congress on Quantum Information
June 18-22

Tropical QKD
July 25-29, 2012

Quantum Cryptography School for Young Students
August 13-17, 2012

Quantum Information Processing with Spins and Superconductors
Date to be determined

10th anniversary

Grand Opening Gala

A celebration to commemorate IQC's expansion into its permanent headquarters, the Mike & Ophelia Lazaridis Quantum-Nano Centre.

Open Houses and Tours

The Mike & Ophelia Lazaridis Quantum-Nano Centre will be a magnet to the University of Waterloo, and will welcome fellow researchers and members of the public to explore its labs and meeting spaces.

Quantum Concert

A musical and educational collaboration between IQC and the Kitchener-Waterloo Symphony titled *Quantum: Music at the Frontier of Science*, to be held Feb. 23 and 24, 2012, at Kitchener's Conrad Centre for the Performing Arts.

Quantum Expressions

A contest and exhibition in which artists depict their creative interpretations of quantum information science through painting, music, poetry, video and more.

More details will be posted on **iqc.waterloo.ca**

Published by:

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Katharin Harkins
Colin Hunter
Martin Laforest

iqc.uwaterloo.ca

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