Annual Report — Third Year
Industry Canada

Institute for Quantum Computing

Fiscal Year 2010: May 1, 2009 - April 30, 2010

Fiscal Year 2011: May 1, 2010 - April 30, 2011

Fiscal Year 2012: May 1, 2011 - April 30, 2012

UNIVERSITY OF WATERLOO | IQC Institute for Quantum Computing

NOTE FROM THE EXECUTIVE DIRECTOR

Dear Industry Canada,

I am pleased to present this review report summarizing the past three years of research excellence, expansion and scientific leadership at the Institute for Quantum Computing.

IQC has experienced tremendous success over the past three years — from the recruitment of world-leading researchers to the opening of new experimental laboratories and the development of engaging scientific conferences and outreach events. The institute has firmly established its reputation as a global leader in quantum information research and innovation. IQC is now in its 10th anniversary year, which is a perfect opportunity to reflect on the success of the institute so far, and to plan even more ambitious growth for the future.

As you will read in the coming pages, IQC has been tremendously productive on all fronts thanks to the support of Industry Canada. Our researchers and students have achieved scientific breakthroughs across theoretical and experimental approaches to quantum science. The coming years promise to be even more exciting as we move up to a new level of capability when we expand into the Mike & Ophelia Lazaridis Quantum-Nano Centre. This state-of-the-art facility at the heart of the University of Waterloo campus will enable quantum research at the highest international level, and serve as a magnet for the world's brightest minds. This expansion will continue to establish Waterloo's growing reputation as the world's "Quantum Valley."

Of course, this exciting growth and expansion would not have been possible without the visionary support Industry Canada, as well as private, provincial and industry partnerships. We are tremendously grateful for this essential and ongoing support.

As I look back at IQC's growth and accomplishments since inception, I'm proud of what I see. I'm even more excited, however, by what I see in the future for IQC, as we move closer to achieving our vision of harnessing the quantum world for societal benefit.

I invite you to read more about this amazing institute we have built together.

Sincerely,

Raymond Laflamme, Executive Director

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Executive Summary

Curiosity drives discovery. By focusing our innate curiosity on the world around us, we learn about natural phenomena — what they are, how they work, and how we can use them to improve our lives and society. Harnessing and controlling natural forces — fire, steam, electromagnetism and more — has given us technologies that are part of our everyday lives, from cars to phones to computers.

A century ago, scientists unveiled nature's most fundamental forces — those that govern the world of atoms, electrons and reality's other building blocks. The framework scientists built to describe these forces, quantum mechanics, has opened a new window of understanding on our universe and ourselves.

We are now at pivotal point in science, where we can not only describe the forces of the quantum realm, but actually harness and control them. We are building powerful new technologies that function according to quantum mechanical laws — technologies we know will offer incredible advantages over their "classical" predecessors. Such technologies have already emerged from quantum information research; we have only begun to envision the possibilities of this quantum revolution.

The Institute for Quantum Computing is a multidisciplinary research organization within the University of Waterloo supported by a partnership of the federal and provincial governments and the visionary philanthropy of Mike and Ophelia Lazaridis. It aims to develop quantum information science and technology at the highest international level. This is happening through the collaboration of computer scientists, engineers, mathematicians and physical scientists, all working under one roof with a common goal. IQC is establishing Waterloo as a world-class centre for research in quantum technologies and their applications. The institute aims to be a magnet for the world's top minds in quantum information science, and to communicate their results to Canadians and the world.

IQC was launched a decade ago in just two small offices at the University of Waterloo. In one short decade, the institute has grown to become the world's largest concentration of quantum information researchers, with 17 faculty, 5 research assistant professors, 40 postdoctoral fellows and 96 students. The accomplishments of these researchers have made Waterloo a globally renowned centre for quantum information research. This reputation has enabled IQC to attract more truly outstanding scientists, including one of only 19 Canada Excellence Research Chairs and a Nobel Prize winner. IQC's students and postdoctoral fellows come from all the corners of the globe and move on from the institute prepared as the quantum workforce of the future.

Research at IQC is focused on quantum computation, communication and sensors. The pioneering research conducted by IQC scientists has advanced every avenue of quantum information research — from theoretical foundations (quantum error correction, algorithms, complexity theory, quantum information theory) to experimental approaches (quantum processing via spin, optics, nanoelectronics, sensors and more). While practical quantum computers are still a long-term goal, discoveries along this path have already led to innovative spin-offs and start-up companies.

In the last three years we have introduced a collaborative graduate studies program that brings together six university departments from three faculties. Nowhere else in the world can you find a program of similar breadth of scope and expertise. We have launched summer schools to introduce quantum science to high-school students and lets undergraduate students know the University of

Waterloo is the best place to pursue graduate studies in quantum information. IQC has established a communications and outreach team that helps to share the importance of its research with a variety of audiences, from government stakeholders and fellow scientists to the general public.

Renowned visiting scholars from around the world visit IQC on a daily basis — delivering talks and collaborating with IQC scientists — and they carry their IQC experiences with them when they return to their home institutions. Thanks to IQC's ever-growing output of research publications, scientific reviews, conferences, workshops, open houses and online videos, a broader audience has learned about quantum information science. Such awareness-raising reinforces the importance of Canada's major investment and leadership in quantum research, and helps secure the future of that investment.

IQC builds upon and enhances the University of Waterloo's reputation for scientific innovation and entrepreneurial achievement. As quantum technologies emerge from IQC research, the institute will develop strong connections with industry on the path to commercialization. During IQC's first five years, a key goal was to recruit a base of theoretical scientists; the next five years saw the recruitment of experimentalists and building of the infrastructure needed for their work. The opening this fall of the IQC's permanent headquarters, the state-of-the-art Mike & Ophelia Lazaridis Quantum-Nano Centre at the heart of campus, will be another enormous step in the ongoing expansion and evolution of the institute.

The institute will take maximum advantage of new experimental facilities to test fundamental concepts and engineer innovative quantum devices. We will deepen our graduate program to ensure that our students are fully prepared to lead the next wave of quantum research and development. Over the next several years, IQC will reach a total complement of 30 faculty, 50 postdoctoral fellows and 125 graduate students.

IQC will continue to foster meaningful collaborations with the international research community and increase exchange of researchers with national and international institutes. The communications and outreach team will ensure that IQC's research and achievements are conveyed to all audiences — local, national, and international — to develop a widespread intuition and understanding about the benefits of quantum science.

Although quantum information science is still in its infancy, it has already transformed our understanding of the world and shaken the foundations of computer science. It has forced us to rethink not only our basic understanding of nature, but also questions of privacy and national security. Its development will transform information technologies and have societal impact in ways we have only begun to imagine. IQC is providing a fertile ground to develop science; the next five years will also fuel a nascent and tremendously important quantum industry.

The Institute for Quantum Computing has met and exceeded its ambitious goals since inception — and especially since the essential infusion of support from Industry Canada. The benefits of such support are, in many ways, immeasurable. But we hope this report will take you into greater depth about how, thanks to the visionary support provided by the Canadian government via Industry Canada, IQC is establishing Waterloo and Canada as the world's "Quantum Valley."

1. The Institute

1.1 Motivation

Two landmark theories that emerged in the 20th century forever changed our world: quantum mechanics and information theory. The first altered our perception of reality — providing deeper understanding of chemistry, material science and physics — and enabled technologies that have become important parts of our lives, from lasers to superconductors to medical imaging devices. The second theory sparked the information revolution that has forever changed the ways we communicate, work, play and live. Computers and other information technologies have become more and more powerful because scientists have succeeded in continually making transistors — i.e. an information processor's "brain cells" — smaller and smaller. At the current rate of this miniaturization, transistors will reach the atomic scale within the next decade or so (as predicted by Moore's Law). At that scale, the laws of quantum mechanics take hold.

Quantum information science is the area of research related to using the laws of quantum mechanics to manipulate information. Research is driven by such questions as: What is the impact of using quantum rules for information processing? What advantages does quantum information hold over classical information? How do we control quantum systems? Can we realize quantum information theory through experiments? Can we build practical quantum computers and other technologies? Research has proven that quantum information technologies will be vastly superior to "classical" technologies in many important ways.

The motivation to study quantum phenomena is the continuation of an ancient cycle — curiosity, control and innovation. Humans have always observed the forces of nature, discerned how to controlled them, and harnessed them in technologies. Fire, steam, electromagnetism — they all began as mysterious natural phenomena that humans learned to understand and control. The phenomena of the quantum world — the underlying fabric of everything — are the next forces of nature we are learning to control and transform. We know the social and economic benefits of taming the quantum world will be tremendous.

The Institute for Quantum Computing was created in 2002 to take advantage of this opportunity. It was sparked by the shared vision of Mike Lazaridis and then-University of Waterloo President David Johnston to foster pioneering research into the next revolution in technology: quantum information. Founding executive director Raymond Laflamme brought this vision to reality by recruiting the core research team and leading efforts to build state-of-the-art infrastructure to support their research. The results of the research happening at IQC will transform the future in ways we have only begun to imagine.

1.2 Vision, Mission and Strategic Objectives

At the foundation of IQC is the **vision** that harnessing quantum mechanics will lead to transformational technologies that will benefit society and become a new engine of economic development in the 21st century.

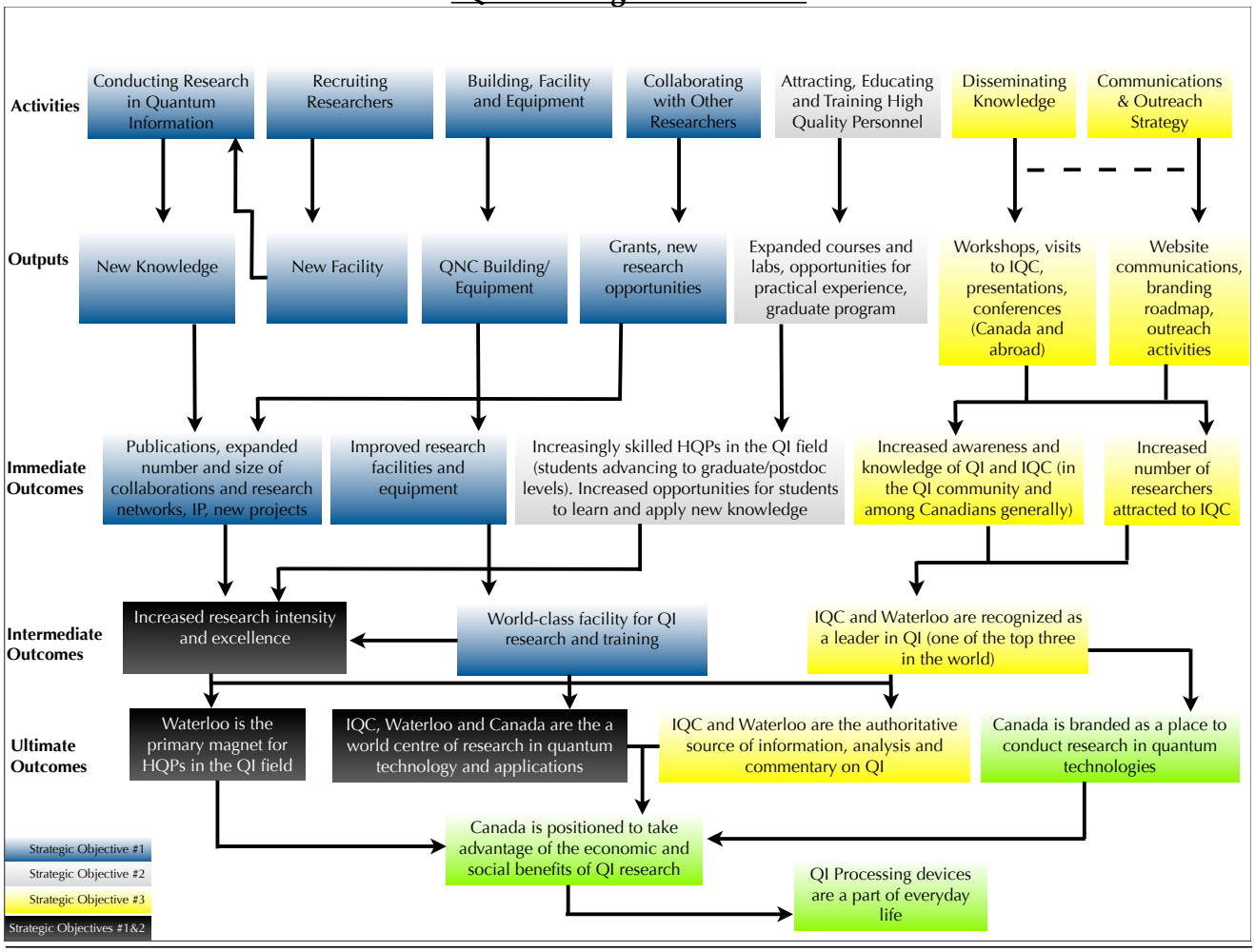
IQC's **mission** is to develop and advance quantum information science and technology at the highest international level through the collaboration of computer scientists, engineers, mathematicians and physical scientists.

To fulfill its mission, IQC is guided by three strategic objectives:

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

The diagram that follows is an elaboration of the strategic objectives and shows how IQC's three main objectives relate to its vision. It also shows how the institute will achieve its long-term goals through a series of shorter-term goals. This framework was developed in consultation with Industry Canada.

IQC's Strategic Framework



1.3 Overview of IQC

Building on the University of Waterloo's longstanding strengths in engineering, math and computer science, IQC quickly attracted world-class researchers in computer science, providing the nucleus of excellence to entice experimentalists. It's a simple recipe: attract the best scientists in the field, give them the best possible research environment and a place to share and test their ideas, and breakthroughs will happen. IQC embodies the entrepreneurial spirit that has become synonymous with the Waterloo Region and is a core value of the University of Waterloo. It has been said that Waterloo is becoming the world's "Quantum Valley," and IQC is turning this dream into a reality.

IQC is supported by the private sector, government, and academia. Mike and Ophelia Lazaridis have given more than $105 million in private gifts to the institute. Industry Canada granted $50 million over a five-year period for the construction of new infrastructure, the purchase of new equipment, and operations. The Ontario government also granted $50 million for the construction of the new building. Several other funding partners have contributed — namely NSERC, MITACS, CFI, QuantumWorks and others.

Research at IQC is fundamentally interdisciplinary — spanning theory and experiment — to pursue many avenues of quantum information science. IQC's core areas of research include quantum information theory, quantum algorithms, quantum complexity, quantum cryptography, quantum error correction and fault tolerance, spin-based quantum information processing, nanoelectronics-based quantum information processing, and optical quantum information processing. Hundreds of advances and breakthroughs in quantum information science have happened through research conducted at IQC, with discoveries published in *Science, Nature, Physical Review Letters* and many other leading journals.

The multi-disciplinary approach involves interaction with the Faculties of Engineering, Mathematics and Science. IQC faculty members are appointed in the departments of Applied Mathematics, Chemistry, Combinatorics and Optimization, Computer Science, Electrical and Computer Engineering and Physics & Astronomy.

In just 10 years, IQC has grown to become the world's largest concentration of researchers devoted to quantum information science and technology with 17 faculty, 5 research assistant professors, 40 postdoctoral fellows and 96 students. The institute has created a unique training program for postdoctoral fellows and students unrivaled around the globe. It is intensifying communication and outreach programs to share the knowledge created and cultivate widespread intuition and understanding of quantum science. IQC — and Canada — are becoming internationally recognized as leaders in the global quantum race.

1.4 Budget & Financial Statement ($000s)

	2010 (Actual)	**2011** (Actual)	**2012** (Actual)	**2013** (Budget)	**2014** (Budget)	**Total**
Building	12,615	12,385				25,000
Equipment	938	1,062	1,309	691	1,000	5,000
People & Operations	2,947	3,553	3,691	4,809	5,000	20,000
Total	16,500	17,000	5,000	5,500	6,000	50,000

2. Achievements & Results

"The overall consensus is that IQC is a world leader in quantum computing and has continued to make impressive progress towards its vision of becoming the world leader in quantum information science and meeting the strategy it set out for itself."

- NSERC Review Panel Report, 2009

2.1 Establishing Waterloo as a World-Class Centre for Research in Quantum Technologies and their Applications

The first decade of IQC built the foundations of research excellence needed to pioneer the quantum realm and transform the scientific and industrial landscape. The ultimate goal of the institute is to make technological breakthroughs that will benefit society and drive the 21st century economy. The following section outlines the measures and metrics that indicate IQC is continually moving in the right direction to achieve these goals.

IQC's first strategic objective is realized through four specific focus areas:

1. Conducting Research in Quantum Information
2. Recruiting Researchers
3. Collaborating with Other Researchers
4. Building, Facilities & Laboratory Support

Within these areas, IQC has made exciting and continuous progress since the first installment of the Industry Canada grant.

2.1.1 Conducting Research in Quantum Information

The institute's primary mandate is to conduct research in quantum information science at the highest international level. The research at IQC produces new knowledge that leads to publications and presentations at conferences. This knowledge includes a better understanding of quantum information processors and laboratory demonstrations of their control, and the development of technologies based on those processors. Ultimately, research will lead to new technologies and applications.

Objectives:

Fiscal 2012 Objectives:

- Continue leading-edge investigation of theoretical approaches to quantum information processing in order to better understand the impact of quantum mechanics for information processing and to investigate new potential applications
- Continue developing approaches to quantum information using photonic, nuclear and electron spins, quantum dots, superconducting technologies and proceed with studying the requirements needed to design earth-to-satellite quantum cryptography systems

Highlighted Results from Fiscal 2012:

- An important breakthrough in perfectly secure "cloud computing" using principles of quantum mechanics (Anne Broadbent in *Science*)
- A new approach to understanding wave-particle duality — a cornerstone phenomenon of quantum mechanics (Radu Ionicioiu in *Physical Review Letters*)
- A publication in *Physical Review Letters* showing the demonstration of three-qubit error correcting code using the magnetic resonance of carbon nuclei in a single crystal (Osama Moussa)
- Testing of a new uncertainty principle in *Nature Physics* (Robert Prevedel)
- Published 152 research papers during the 2011 calendar year

Fiscal 2011 Objectives:

- Leading-edge investigation of theoretical approaches to quantum information processing in order to better understand the impact of quantum mechanics for information processing and to investigate new potential applications
- Develop approaches to quantum information using photonic, nuclear and electron spins, quantum dots, superconducting technologies and study the requirements needed to design earth-to-satellite quantum cryptography systems

Highlighted Results from Fiscal 2011:

- An IQC research team led by Thomas Jennewein, Norbert Lütkenhaus and Raymond Laflamme is developing the theory and technology necessary to establish a secure global network encrypted by Quantum Key Distribution (QKD) via satellites in collaboration with the Canadian Space Agency. Relevant industry contacts have also been established, including COM DEV and INO
- Published 111 research papers during the 2010 calendar year

Fiscal 2010 Objectives:

- Research will focus on three related paths:
    - Algorithms and protocols (how to control and use quantum information processors

    - Building blocks that make proof-of-principle demonstration of quantum information processing
    - Proof-of-principle experiments of quantum technologies
- Write more than 100 research papers

Highlighted Results from Fiscal 2010:

- IQC theorists Prof. John Watrous and Sarvagya Upadhyay breakthrough in quantum complexity theory (QIP=PSPACE), later named best paper at annual Symposium on the Theory of Computing (STOC)
- Published 151 research papers in the 2009 calendar year

The following section of this report highlights some of the most significant breakthroughs and publications by IQC researchers since the start of the Industry Canada grant. It also has information on other important indicators of success including publication statistics, citations, grant information and faculty awards.

The Research

The research at IQC focuses on quantum information science and technology. In particular, research explores how the laws of quantum mechanics can be used to compute and communicate, or to develop a new generation of highly efficient sensors. In each line of research, fundamental issues and potential applications are investigated through theoretical study. These applications are then put to the test by demonstrating that the necessary quantum effects can be harnessed, forming the building blocks for quantum information science and technology and providing its experimental foundation.

The lines of research mentioned above can be broken into eight themes that outline the day-to-day research at IQC.

1. Quantum Information Theory
2. Quantum Algorithms
3. Quantum Complexity
4. Quantum Cryptography
5. Quantum Error Correction & Fault Tolerance
6. Spin-Based Quantum Information Processing
7. Nanoelectronics-Based Quantum Information Processing
8. Optical Quantum Information Processing

IQC researchers investigate practically every avenue of quantum information science, spanning both theory and experiment. Their work continued to break new ground over the past year, with results published in prominent scientific journals including *Science, Physical Review Letters*, *Nature Physics* and more. Experimental research includes spin-based approaches to quantum processing, superconducting qubits, quantum photonics, quantum sensors and more. Theoretical research investigates how quantum laws can be harnessed and applied through quantum algorithms, complexity theory, quantum error correction and fault tolerance, and quantum cryptography.

2.1.1.1 Case Studies

As a deliverable to Industry Canada, IQC has prepared the following case studies that demonstrate several exciting scientific achievements that have led to transferrable knowledge in the field of quantum information.

Case Study #1: Quantum-inspired biomedical imaging

Quantum optics and quantum information group, PI: Kevin Resch

Project summary

Quantum information science promises transformational technologies in computing, communication, and sensors. Drawing on insights gained from quantum information, my group has developed a novel laser-based interferometric sensor, which exhibits several important effects previously thought to require quantum entanglement. Both interferometers produce signals robust against material dispersion and have enhanced resolution; these features make them attractive alternatives over standard techniques for imaging, such as white-light interferometry. Since our classical device uses lasers instead of entangled photons, it achieves these features with a signal that is millions of times larger. We are working toward an advanced optical coherence tomography imaging prototype based on our interferometer, and applying it to complex biological systems.

Scientific description and past accomplishments

Optical coherence tomography (OCT) is an imaging technique that uses interference to measure the distances between interfaces in materials such as biological samples [3]. It works by placing the sample of interest into one arm of a Michelson (or equivalent) interferometer and measuring the resulting interferogram either in the time or frequency domains. Axial or depth resolution is obtained through interference of broadband light, typically from an ultrafast laser or superradiant diode. The axial resolution is theoretically limited by the coherence length of the light and can be as less than 1 micron for high-resolution systems [9]. In practice, however, material dispersion limits the resolution achievable, and the negative effects of dispersion become more pronounced for larger bandwidths (dispersion refers to a property shared by most materials where the speed of light is colour dependent). While there are techniques for post-processing data to remove dispersion, they remain computationally intensive and difficult to use. A dispersion-cancellation technique, where the interference signal is automatically immune to dispersive degradation, is far superior since no post-processing of data is required.

In 2003, it was proposed that the two-photon Hong-Ou-Mandel interferometer could form the basis of a new OCT technology, coined *quantum*-optical coherence tomography (Q-OCT) [7]. The original motivation for this technology was to harness several potentially advantageous effects observed in the quantum device, including: automatic dispersion cancellation, enhanced resolution, robustness against loss, and phase insensitivity. However, this technique relies on frequency-entangled photon pairs, and the best sources to date are able to produce roughly one million photon pairs per second corresponding to miniscule optical powers of picowatts. This leads to slow data accumulation times and increased sensitivity to background light. In addition, entangled photon pairs are expensive to create. The complexity and expense of the sources, coupled with the low intensities, has constrained the adoption of this technique.

We have very recently realized a completely classical interference technique capable of producing all of the metrological advantages of the Hong-Ou-Mandel interferometer including: enhanced

resolution, phase insensitivity, robustness against loss, and automatic dispersion cancellation [10]. This technique does not require any entanglement at all. We refer to this new technique as chirped-pulse interferometry (CPI) because it relies on stretched (or chirped) ultrafast laser pulses. As an added feature, by using bright classical laser light instead of dim sources of photon pairs, our technique yields signal levels millions of times larger than the quantum device. We used the CPI setup shown in Fig. 1 to 'image' the front and back surface of a microscope coverslip, clearly showing the advantageous features of this technique in the resulting data.

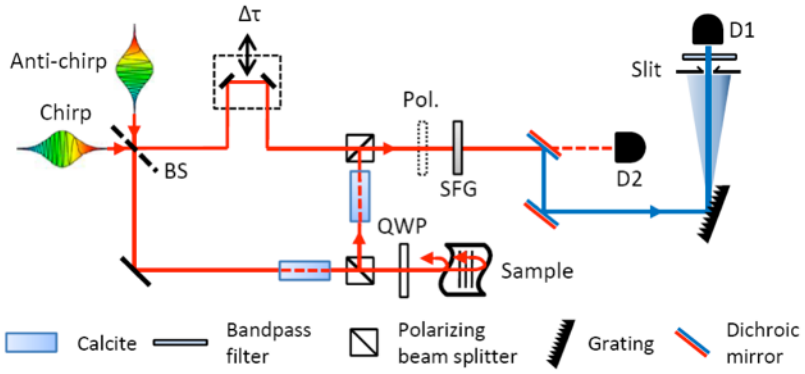


FIG. 1 [from Lavoie et al., Optics Express 17, 3818 (2009).]: Experimental setup for axial profiling with chirped-pulse interferometry.

Research directions

We are working to use CPI to image a complex biological sample with resolution competitive with conventional OCT systems. Doing so requires solving the two major drawbacks to quantum optical coherence tomography — low signals and artifacts. The solution to the first problem is straightforward. Technologies based on entangled photon pairs are limited to approximately 1 million photon pairs per second, which is a miniscule pW of power. By converting to bright classical lasers, power levels have been demonstrated 7 orders of magnitude higher. The artifact problem is more subtle. The signals from Q-OCT and the original demonstrations of CPI contain extraneous features in the interference pattern that do not correspond to real physical interfaces. Narrowband spectral filtering can, in principle, remove all artifact signals.

We have constructed and calibrated a new pulse-shaping apparatus using a broadband titanium sapphire laser and a spatial light modulator. While our first chirped-pulse interference experiments required two oppositely chirped pulses, chirping the red half of a pulse spectrum and oppositely chirping the blue half produces very similar correlations and interference; this can be done with our setup. We have used this system to image simple, idealized samples, such as stacks of glass plates. We are now working on imaging onion cells, a standard test pattern for interferometric imaging, but these techniques could be very generally applied, from materials characterization to medical imaging and disease detection.

Accomplishments at IQC

Chirped-pulse interferometry was invented at the Institute for Quantum Computing. The original experimental demonstrations were also carried out here by postdoctoral fellow Rainer Kaltenbaek, graduate students Jonathan Lavoie and Devon Biggerstaff, and faculty member Kevin Resch.

Subsequent work has been done by postdoctoral fellow Robert Prevedel and graduate students Kurt Schreiter and Mike Mazurek.

Publications

R. Kaltenbaek, J. Lavoie, D.N. Biggerstaff, and K.J. Resch, Quantum-inspired interferometry with chirped laser pulses, Nature Physics 4, 864 (2008).

R. Kaltenbaek, J. Lavoie, and K.J. Resch, Classical analogues of two-photon quantum interference, Physical Review Letters 102, 243601 (2009).

J. Lavoie, R. Kaltenbaek, and K.J. Resch, "Quantum-optical coherence tomography" with classical light, Optics Express 17, 3818 (2009).

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R. Prevedel, K.M Schreiter, J. Lavoie, and K.J. Resch, Classical analogue for dispersion cancellation of entangled photons with local detection, Physical Review A 84, 051803 (2011).

Patents

K.J. Resch, *System and method for chirped-pulse interferometry*
Canadian patent application #2,710,296 filed Dec/08
US Formal application #12/809,776 published under US-2010-0271635-A1 Oct/10
European application #8863902.6 July/10
provisional 61/008,593, filed Dec/07
provisional 61/136,523 filed Sept./08
PCT application PCT/CA2008/002199 filed Dec./08

Case Study #2: Neutron interferometry and applications

Quantum Devices group: PI: Prof. D. Cory, Dr. D. Pushin

Neutron research has a rich history in studies of materials and precision-measurements for fundamental physics, because neutrons make for powerful probes. Due to the unique penetration properties of neutrons and very high scattering cross-section for such elements as hydrogen and lithium, neutrons are used to study water formation and transport in hydrogen fuel cells, hydrogen transport and stress in metals, and transport of lithium in Li-batteries. Because they have no electrical charge but have a magnetic moment, neutrons are excellent magnetic probes of materials, nuclear/electron spin transport, and magnetic domains. Neutron interferometric techniques are among the most precise methods for characterization of neutron interaction. These techniques sense the change in a neutron phase due to interaction with a sample.

Building upon recent initial successes (ref 1-3) in using Quantum Information Processing (QIP) tools such as Quantum Error Correction Codes (more specific Decoherence Free Subspace (DFS)), we are using improved neutron interferometer design to build a User Facility for condensed matter applications and studying materials science (such as spintronic materials), biology, and quantum physics. A quantum error-corrected interferometer will be the first-ever instrument in which tools of quantum information, such as error correction, will be applied. This DFS interferometer will not only make the neutron interferometer robust against mechanical vibrations, but will also make the

instrument available to the neutron research community to perform high-precision measurements. To be robust against low-frequency vibrations means there is no need for massive vibration isolation systems, and thus we can move the interferometer close to the neutron guide brake. This will result in higher neutron fluency and signal-to-noise ratios. The goal is at least a tenfold gain in neutron fluency. Also, incorporating a cold sample stage to neutron interferometry will open up new frontiers for use of neutron interferometers in materials science, condensed matter, and spintronics research.

IQC Research Component

The design of this neutron interferometer and other QIP-enabled devices was performed by IQC scientists (Prof. D. Cory, Prof. R. Laflamme, Dr. D. Pushin) in collaboration with a team at NIST (Dr. M. Arif, Dr. M. Huber). IQC is uniquely suited to facilitating this work due to the high concentration of leading experts in quantum error correction techniques, alongside world-leading expertise in neutron interferometry. A long and fruitful collaboration with NIST provides the opportunity to test our theory and designs at North America's best neutron facility in Gaithersburg, MD. This QIP-enabled design of NI has inspired other scientists to utilize the same principles in developing an atom interferometer (ref. 4).

A recent discovery of new magnetic materials prompted new developments in the field of spin-related electronics (spintronics). The advantage of spintronic devices is the lower power of consumption than in conventional electronics. Spintronic devices might be used in the field of quantum electronics to advance quantum information processing and build quantum computers. The two key materials-related properties, whose characterization is crucial for building spintronic devices, are the domain structure and the spin coherence length. Typically these properties are not studied in functional devices, but are measured in test devices. Since neutrons are penetrating and their magnetic phase is integrated over their path, we can use spin-dependent neutron interferometry as an in-situ and direct measurement of the magnetic properties in functional devices. We anticipate that this new capability will enable greater insight into the function and design of spintronics. With successful realization of QIP enabled NI facility we will involve another world expert in fabrication spintronic devices Prof. G. Miao from University of Waterloo to build methods and transfer NI techniques to study spintronic materials and condensed matter applications.

Application to spintronic materials and biochemistry

Understanding spintronic materials requires a simultaneous understanding of their structural, magnetic and electrical behavior. In particular, it requires correlations of these over many length scales. Domain walls and exchange lengths are 1-100 nm, domains may be 10's of μm, the spin diffusion paths and coherence extend to 100 nm. A particular challenge is that the structure and magnetic properties need not be commensurate. Polarized neutron scattering is today the premiere approach to understanding these materials. Neutron interferometry, however, will permit greater ranges of studies. First, today's scattering experiments are best performed in a reflectivity configuration. This requires large samples and reports on the average properties over these large surface selective measurements. Second, these present-day methods are difficult to extend to 300nm and beyond. Finally, there is no reference arm to the experiment and so the neutron phase is not reliably measured.

Neutron interferometry has the potential to significantly change our approach to characterizing spintronic materials. First we will move the experiments from a reflectivity configuration to transmission. This will permit the study of small samples and make low temperature/high field studies more reliable. We will use the long coherence length of the NI to extend the studies to length scales beyond 300 nm. Third, we will arrange the measurement to allow the simultaneous variation of two q vectors, one reciprocal to real space structure and the other related to

the spin magnetization gratings. By varying each we obtain the correlation function of structure/ magnetism.

An essential element of the study is the inclusion of a dilution refrigerator to extend the measurements to the interesting region below 100 mK where most correlated electron dynamics occur for 2D systems.

The applications to biomaterials similarly find needs at very low q, either for studies of membrane bound materials or for slow, long-scale transport (such as through pores in membranes). By extending the q-vector to reciprocal few microns we open up new areas of applications.

Selected applications in materials science and biology

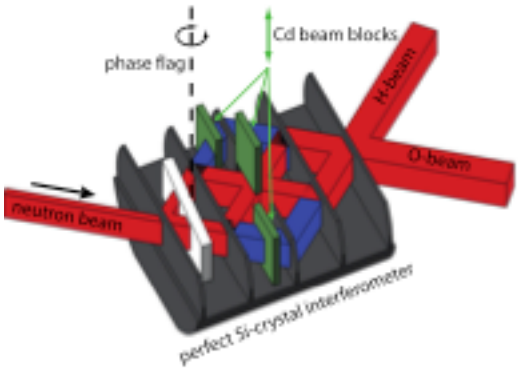
- Phase-sensitive high-precision mass density measurements of very thin biological membranes and polymer films.
- Non–destructive evaluation of isotopic abundance and distribution of elements in biological tissues and bone slices for diagnostics of disease and forensic applications.
- Phase contrast image of tissues and membranes to determine microscopic damage and tissue hardening due to ageing and disease.
- Studies of magnetic domains and phase transitions related to iron-based high-Tc superconductors.
- Real-time study of low Z ion dynamics in batteries, fuel cells, and hydrogen storage devices.
- Morphology of porous materials and void fraction determination.
- Phase map of residual stress and strain in materials used in critical defense applications.

Publications:

1. Measurements of the Vertical Coherence Length in Neutron Interferometry, D. A. Pushin, M. Arif, M. G. Huber, and D. G. Cory, *Physical Review Letters*, 2008, 100, 250404
2. Decoherence-free Neutron Interferometry, D. A. Pushin, M. Arif and D. G. Cory, *Physical Review A*, 2009, 79

A, 2009, 79

3. Experimental Realization of Decoherence-Free Subspace in Neutron Interferometry, D.A. Pushin, M.G. Huber, M. Arif, D.G. Cory, *Phys. Rev. Lett.,* 2011, 107, 150401
4. Prototyping method for Bragg-type atom interferometers, B. Benton, M. Krygier, J. Heward, M. Edwards and C. W. Clark, *Phys. Rev. A,* 2011, 84, 043648



Case Study #3: Quantum science is headed to space

PI: Thomas Jennewein

Space offers a very unique environment for quantum physics experiments at distances and velocities not possible on earth. Theoretical and experimental studies have shown the feasibility of performing quantum physics and quantum information science experiments in space.

Global Quantum Networks using Satellites

The Institute for Quantum Computing (IQC) and other leading research institutions in this field are pioneering new applications for quantum technologies as the future means for communications. One of the most important and promising of such technologies is global quantum security via satellites.

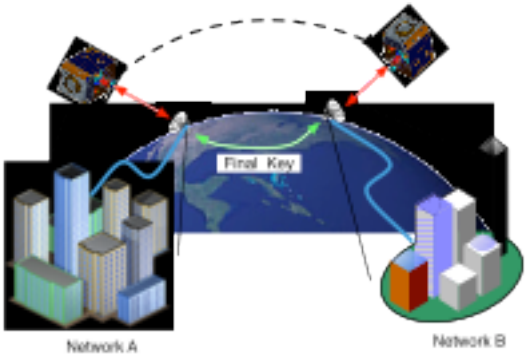
Quantum Key Distribution (QKD) establishes highly secure keys between two (or more) distant users using single photon to transmit each bit of the key. Since single photons are systems behaving according the to laws of quantum mechanics, they cannot be tapped, copied or directly measured without leaving a "fingerprint". The huge benefit for users of such systems is the peace of mind of knowing that any attack, manipulation, or copying of the photons can be can be immediately detected and overcome. Essentially, QKD solves the long-standing problem of securely transporting cryptographic keys between distant locations.

This quantum technology is already a well-proven concept with fibre optical solutions and is commercially available. However, ground-based technologies can only cover distances of about 200 km [Waks et al, Phys.Rev.A,2002], after which the photons get absorbed. Because practical quantum repeaters are still decades away, satellite-based systems offer the best approach to surpass this distance with today's technology. IQC is actively studying various satellite-based schemes for establishing quantum keys on the global scale.

Impact of a quantum-satellite mission

Launching these experiments via satellite would greatly advance quantum technologies, opening the door to real-world applications and deepening our understanding of fundamental quantum science. With satellite-based quantum transceivers, the following experiments become feasible:

- Satellite-to-ground Quantum Key Distribution (QKD) for highly secure encryption
- Global QKD networking by combining separate satellite overpasses with different ground stations; connection between any locations on the ground, even at transcontinental distances
- Secure key exchange between two ground stations, without any security requirements on the satellite, via entangled photon distribution over simultaneous down-links
- Clock synchronization based on entangled photons
- Tests of fundamental quantum physics over large distances.



The large separations between separate ground networks can be bridged with a quantum communication satellite.

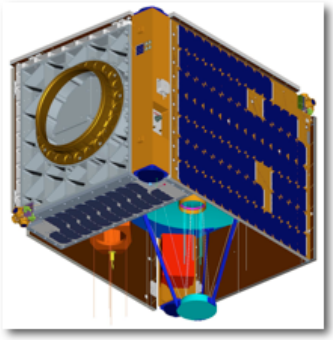
Canadian Initiative - QEYSSAT

The *Quantum Encryption and Science Satellite (QEYSSat)* mission concept is currently being investigated and supported by the Canadian Space Agency. The aims of this mission are to demonstrate the feasibility of global quantum key distribution and perform tests of quantum science over large distances. The principle investigator, Thomas Jennewein, together with colleagues Raymond Laflamme and Norbert Lütkenhaus of the Institute for Quantum Computing at the University of Waterloo, lead this project.

A team of core users with members from academia and government organizations across Canada will pursue the mission goals and experiments.
The possibility of performing quantum transmissions via satellite systems has led to strategic partnerships with Canadian institutions and industry. In particular, COM DEV and INO have been partners with IQC on several feasibility and technology studies on the requirements of this mission concept and the technologies.
In addition, a strong partnership of Canadian researchers and industry in relevant European Space Agency (ESA) programmes (Space-QUEST) are anticipated. The ESA has also a strong interest in quantum experiments in space.

Technology
The main challenge is to advance existing quantum devices to make them suitable for space. QEYSSAT will include the capability to analyse and detect single optical photons with high efficiency. The quantum signals are generated in photon sources located at the ground-based transmitter location, thereby keeping the more sensitive and complex structure on the ground. The photons are confined by the optical transmitter into a tight beam, which is pointed toward the satellite. This concept keeps the complex technologies such as quantum sources on the ground and ensures the satellite has a simple and cost-effective technology.

Roadmap
QEYSSAT focuses on the implementation of a small-scale mission, fast-tracked within Canada. This will serve as the baseline for other international quantum satellite projects, such as the Space-QUEST proposal by ESA, and also open possibilities for commercial ventures.
The key project milestones that were recently completed, include:
2010: Preliminary technology feasibility studied with DRDC.
2011: Phase-0 study with CSA, with partners COMDEV and INO.
2011-2012: Development of technological payload concepts in the IQC laboratory.
2012: Demonstrate breadboard-systems for key components.
2011-2012: CSA funded study on the fine-pointing requirements and concepts, together with COMDEV, INO, UTIAS, NEPTEC.
Once the mission is decided upon, a launch of QEYSSAT could be possible in 3 – 5 years.



View of the proposed QEYSSAT, which contains a quantum optical receiver for single photons.

Partnerships
IQC has built up crucial partnerships with Canadian industry in view of the particular technologies required for this mission proposal. In particular, Canadian industry would be very well set up to perform this mission, because all the essential technologies already exist in Canada. In particular, we are working very closely with COMDEV on developing the overall mission concept, and the concept of adapting the payload for a micro satellite bus. We are also working in several projects with INO on the advancement of the technical readiness level of optical components such as quantum sources. We are in close contact with EXCELITAS, who is a world-leading manufacturer of single-photon detectors, and they have an interest to partner in upcoming projects for delivering the required detector devices for this payload. On-going CSA activities for the satellite pointing also include partnerships with NEPTEC, who brings in their expertise on optical fine steering and control-loops, as well as UTIAS , who are experts in micro-satellite experiments, have also partnered with the expertise on attitude control of microsatellites.

IQC and the University of Waterloo has furthermore entered very fruitful and strong academic partnerships . The partners in developing and performing the experiments performed with QEYSSAT are researchers at Universities across Canada, including University of Toronto and University of Calgary; and in studying the theoretical aspects of the experiments include researchers at the Perimeter Institute, University of Montreal, and several international locations including Cambridge University and University of California.

Case Study #4: Randomization Methods for Efficient Characterization of Quantum Devices

Research Groups: Emerson, Cory and Laflamme

Harnessing the power of quantum mechanics to solve problems in computation, secure communication and metrology still requires substantial improvements over present-day control over quantum devices, i.e., physical systems which exploit quantum mechanical effects. The key feature of these quantum systems that enables such novel technological advantages is the "quantum coherence" between distinct states. Coherence is the basis for quantum interference effects and is a necessary requirement for quantum entanglement, a core ingredient in many quantum algorithms and protocols. As is well-known, quantum coherence is extremely sensitive to the noise due to residual coupling to other systems (the environment) and imperfections in the control of the quantum systems. The term "decoherence" is used as a catch-all concept for how a quantum system loses its "quantumness" as a result of these noise effects. A major challenge for the development, diagnosis, and improvement of quantum control in various experimental modalities is identification of the sources and relative importance various decoherence mechanisms.

Hence, an important step towards the realization of quantum algorithms in physical devices is the means to quantify progress in the experimental demonstrations of quantum computation. Ideally what is required is the means of efficiently characterizing the quantum states and quantum processes of a given implementation for diagnosis and optimization of various implementation modalities. Unfortunately, complete quantum state and process characterization (tomography) is a very hard problem – it requires experimental resources that grow exponentially with the number of qubits in the quantum system. In a sense, the inherent complexity of quantum systems that enables them to supersede conventional technology (based on classical physics) also introduces novel challenges to the old problem of device characterization.

A crucial insight, pioneered by the work of IQC members Emerson and Cory and their collaborators, is that some of the important characteristics of quantum processes can be estimated experimentally in an efficient way. A key theoretical feature of these methods is the discovery and development of efficient "randomized sampling" methods in the quantum setting. Randomized sampling methods offer a means of shrinking the device development cycle for experimental modalities and of optimizing the coherent manipulation of quantum information on these devices.

IQC researchers J. Emerson, R. Laflamme, D. Cory, working in collaboration, developed and refined these methods and also demonstrated the robustness and efficiency of their experimental realization. The efficient benchmarking and diagnostic methods pioneered by IQC researchers have been implemented by the leading experimental groups around the world working with diverse experimental modalities ranging from trapped ions to superconducting qubits.

Description of the Science and the role of IQC researchers.

A critical step in the development of robust experimental demonstrations of quantum computation is the characterization of the quantum states and processes that are produced by the

implementation. Unfortunately, complete quantum state and process characterization (tomography) requires experimental resources that grow exponentially with the number of qubits. This problem is not just restricted to the hundreds of qubits that will produce working quantum technology. The experimental resources and conventional post-processing of tomographic quantum data is already a practical limitation for current experimental capabilities [Haffner et al, Nature 438, 643 (2005) and C Negrevergne, et al, Phys. Rev. Lett., 96, 170501 (2006).]

A crucial insight, pioneered by the work of IQC researchers Emerson, Cleve, Cory, and their collaborators, is that some of the important characteristics of quantum processes can be estimated experimentally in an efficient way [Emerson et al., J Opt B 2005; Dankert et al, Phys Rev. A (2009); Levi et al, Phys Rev A (2007)]. Such results were obtained originally as means to estimate an important figure of merit, the process fidelity, which characterizes how well an experimental quantum process reproduces the intended target transformation in spite of decoherence and other control imperfections.

A key theoretical feature of these methods is the discovery and development of efficient "randomized sampling" methods in the quantum setting. IQC researchers J. Emerson, R. Laflamme, D. Cory collaborated to further develop these methods and also pioneered their experimental realization. In particular, randomization methods were extended to include the ability to estimate the overall failure probabilities of a noisy quantum transformation under a wide class of quantum error-correcting codes [J. Emerson et al, Science 317, 1893 (2007)]. The group of IQC researcher R. Laflamme demonstrated the first implementation of a randomized benchmarking scheme to characterize the error-rates on the quantum gates of a system of 3 qubits [Ryan et al, 2009]. The group of IQC researcher J. Emerson showed that efficient randomization approaches can be extended to a robust and efficient experimental method for "benchmarking" the average error-rates on arbitrarily large systems of qubits, in a way that is efficient, robust, and insensitive to state preparation and measurement errors [E. Magesan, J. Emerson and J. Gambetta, Phys. Rev. Lett. 106, 180504 (2011)]. Recently, Laflamme's group demonstrated how randomized sampling can be extended to characterize individual Clifford operations (O. Moussa et al, arxiv.org/abs/1112.4505).

These efficient benchmarking and diagnostic methods pioneered by IQC researchers have been implemented by IQC experimental groups and other leading experimental groups around the world. Variations of these randomized protocols have been implemented in liquid-state NMR (Ryan et al 2009), solid-state NMR (Emerson et al 2007), superconducting qubits at Yale (Chow et al, 2009), atomic ion systems for different types of traps (Knill et al 2008, Biercuk et al 2009), and atoms in optical lattices (Olmschenk et al., 2010). Most recently the IBM superconducting qubits group has been making rapid experimental progress thanks in part to the efficient diagnostics offered by randomization methods (Gambetta et al, arxiv.org/1204.6308, and Magesan et al, arxiv.org/1203.4550). Additional realizations are in progress. The breadth of realizations in such a short time speaks to the immediate and practical impact of this research program.

Randomization: Theory and Constructions. The randomization tasks described above motivated a better theoretical understanding of random quantum operators. In Dankert et al (Phys Rev A, 2009), IQC researchers Emerson and Cleve and their collaborators defined a hierarchy for the degree of randomness of sets of unitary operators, introducing the concept of "unitary t-design", and showed the Clifford operations formed an efficient unitary 2-design. This theoretical insight has had a far-reaching impact. For example, the existence of efficient unitary 2-designs has been applied to resolve the black-hole information paradox (Hayden and Preskill, JHEP 0709:120, 2007). More recently, the

concept of efficient unitary 3-designs has been applied to show that exponential quantum speed-ups (in an oracle model) are generic (Brandao et al, 2011).
Another important research direction came from IQC researchers Ambainis and Emerson (IEEE. Complexity 2007) who gave an explicit construction for an approximate state 4-design which was needed for a quantum algorithm proposed by Pranab Sen (2006) and Radhakrishnan et al. (2005).

Future plans related to this research
*Randomized Benchmarking and Partial Tomography for Quantum Information Devices***.** The progress we have made to date towards efficient noise estimation is encouraging - but still there are major unsolved problems. For example, efficient benchmarking methods are limited to Clifford gates, which are insufficient for universal quantum computation. Furthermore, methods that can estimate the error-rate associated with each individual Clifford gate are unable to distinguish additional contributions to the estimated error-rate from state preparation and measurement errors [M. P. da Silva, O. Landon-Cardinal, and D. Poulin. Phys. Rev. Lett. 107, 210404 (2011)]. Moreover, the benchmarking method of Ref. [Magesan, Emerson and Gambetta, Phys. Rev. Lett. 106, 180504 (2011)], which can overcome this limitation, can only estimate the average error-rate averaged over the full set of Clifford transformations. Hence an important remaining objective is to either find a unique method which overcomes these limitations or else develop a "suite" of complementary noise estimation methods, with the goal being to identify essential features of the noise which will enable improvements to the experimental design and optimization of the algorithmic error-correction strategies.
Another important objective is to understand the relative role of average vs norm figures-of merit for quantifying the performance of noisy quantum processors. In the fault-tolerant literature, the focus is on norms, which bound the worst case performance. However, these may be overly pessimistic bounds because the worst case performance will almost certainly occur on states that can never be realized efficiently and are not useful for computation. Hence, an immediate challenge is to establish a stronger connection between the efficient information that may be extracted from such partial tomography methods to the thresholds associated with fault-tolerance proofs.
Another key challenge is to follow-through with the experimental implementation of these noise-estimation methods and evaluate their effectiveness in various experimental modalities. Emerson's research group has begun a collaboration with the Laflamme group as well as the IBM superconducting qubits effort (led by former IQC postdoc Jay Gambetta) in order to further develop the use of randomized benchmarking and symmetrization techniques in order to characterize spatial correlations and temporal (non-markovian) effects in the noise models.
A related theoretical objective is to develop a full theory of random and pseudo-random states and transformations for quantum information science. The idea is that such a theory would be play as fundamental of a role to quantum information as classical random and pseudo-random numbers provide for classical information theory.

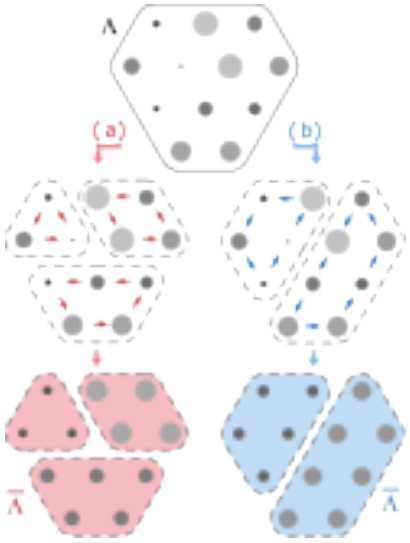
Anticipated significance of the work - As noted above, randomized sampling methods offer a means of shrinking the device development cycle for experimental modalities and of optimizing the coherent manipulation of quantum information on these devices. The short-term impact of this work would be a suite of theoretical methods that enable experimentalists to characterize and improve the performance of the quantum devices in their labs.

Role of IQC - IQC researchers are ideally positioned to take-up these challenges. As noted above, IQC researchers Cory, Emerson and Laflamme have pioneered the development of efficient methods of partial tomography, and this group combines both theoretical and experimental expertise for further developing these approaches and carrying-out their experimental realization. Moreover, IQC researchers Laflamme and Leung bring the expertise in quantum error-correction and fault-tolerance

to help bridge the gap between the experimentally accessible average error-rates obtained from partial tomography and the theoretical fault-tolerance thresholds.

Related IQC publications

1) J. Emerson, E. Livine, S. Lloyd, *Convergence Conditions for Random Quantum Circuits,* Phys. Rev. A 72, 060302(R) (2005).
2) J. Emerson, R. Alicki, K. Zyczkowski, *Scalable Noise Estimation with Random Unitary Operators,* J. Opt. B: Quantum and Semiclassical Optics 7, S347-S352 (2005).
3) E. Magesan, J. Gambetta, J. Emerson, *Robust Randomized Benchmarking*, Phys. Rev. Lett. 106, 180504 (2011).
4) E. Magesan, J. Gambetta, J. Emerson, Phys. Rev. A 85, 042311 (2012)
5) B. Lévi, C. C. López, J. Emerson, and D. G. Cory, *Efficient Error Characterization in Quantum Information Processing*, Phys. Rev. A 75, 022314 (2007).
6) E. Magesan, R. Blume-Kohout, J. Emerson, *Gate fidelity fluctuations and quantum process invariants*, Phys. Rev. A 84, 012309 (2011)
7) M. Silva, E. Magesan, D. Kribs, and J. Emerson, *Scalable Experimental Protocol for Identification of Correctable Codes,* Phys. Rev. A. 78, 012347 (2008).
8) J. Emerson, *Symmetrization Methods for Characterization and Benchmarking of Quantum Processes*, Can. J. Phys. 86(4): 557-561 (2008).
9) J. Emerson, M. Silva, O. Moussa, C. Ryan, M. Laforest, J. Baugh, D. Cory, R. Laflamme, *Symmetrized Characterization of Noisy Quantum Processes*, Science 317, pp.1893-1896 (2007).
10) A. Ambainis and J. Emerson, *Quantum t-designs: t-wise Independence in the Quantum World,* Proceedings of the Twenty-Second Annual IEEE Conference on Computational Complexity, pp.129-140 (2007).
11) C. Dankert, R. Cleve, J. Emerson, and E. Livine, *Exact and Approximate Unitary 2-Designs and their Application to Fidelity Estimation*, Phys. Rev. A 80, 012304 (2009).
12) J. Emerson, *Pseudo-Random Operators: Theory and Applications,* Proceedings of the Seventh International Conference on Quantum Communication, Measurement and Computing, edited by S. M. Barnett, E. Andersson, J. Jeffers, P. Ohberg, O. Hirota, pp. 139-142 (2004).
13) O. Moussa et al, arxiv.org/abs/1112.4505
14) C.A. Ryan, M. M. Laforest, and R. Laflamme. Randomized benchmarking of single and multi-qubit control in liquid-state nmr quantum information processing. New Journal of Physics, 11(013034), 2009
15) E. Magesan et al, arxiv.org/abs/1203.4550



Caption for this figure: Schematic of how randomized sampling from an appropriate group of operations can distill a complex quantum operation down to a few measurable parameters of interest.

2.1.1.2 Highlights of Research Results

The following section highlights some of the results that have come from IQC research since the start of the Industry Canada grant.

IQC Postdoc's international team achieves secure quantum cloud computing
Science 20 January 2012: Vol. 335 no. 6066 pp. 303-308

IQC Postdoctoral Fellow Anne Broadbent was part of an international research team whose latest achievement in secure quantum computing was published a January 2012 issue of *Science*. The team's interdisciplinary research yielded a breakthrough in perfectly secure "cloud computing" using principles of quantum mechanics — a crucial step toward secure globalized quantum computing.

First-generation quantum computers will likely be housed in a few specialized facilities, and therefore computation will be done in the "cloud" — that is, central remote servers will be used to process and store data. Because multiple users will "outsource" their computations to these centralized facilities, protecting information security will be of paramount importance. The innovation achieved by researchers in Canada, Austria, Singapore and the UK is the implementation of "blind quantum computing," which perfectly safeguards private information in this "cloud" scenario.

In the experiment, conducted in Vienna, data is encoded with photons as qubits in a state known only the user, who then sends the qubits to the "cloud" quantum computer, which entangles the qubits according to a standard scheme. The computation is carried out and measured in such a way that only the original user can interpret and utilize the results. An eavesdropper — or even the quantum computer itself — cannot gain any useful information without knowing the initial state. They are, in a very real sense, "blind" to the information being transmitted. The theoretical work that led to this experimental implementation was published 2009 by Broadbent, Elham Kashefi and Joseph Fitzimons. The 2011 experiment in Austria was carried out by Stefanie Barz, Anton Zeilinger and Philip Walther.

Quantum Error Correction advance draws attention
Phys. Rev. Lett. 107, 160501 (2011)

An advance made by an IQC research team in experimental quantum error correction was showcased on the science website PhysOrg.com. In order to perform quantum computation, researchers must also implement error correction to overcome the effects of "noise" that disrupts quantum systems. The IQC research team demonstrated a three-qubit error correcting code using the magnetic resonance of carbon nuclei in a single crystal (their results were published in *Physical Review Letters* in October). The PhysOrg article about the advance featured an interview with lead investigator Osama Moussa, a postdoctoral fellow at IQC, who explains the significance of his team's work in solid-state nuclear magnetic resonance (NMR).

IQC's experimental tango draws attention
Phys. Rev. Lett. 107, 170503 (2011)

An experimental result by IQC researchers was likened to an elegant "tango" between nuclei and electrons in article on the American Physical Society website. The APS "Viewpoint" article, written by University of Buffalo physicist Xuedong Hu, describes how IQC researchers put nuclear spins "into

lockstep" with instructions from an electron — an important step forward in using nuclear spins for quantum computation. Hu's article is a commentary on a paper published in an October 2011 edition of *Physical Review Letter*s, jointly authored by IQC researchers Yingjie Zhang, Colm Ryan, Raymond Laflamme and Jonathan Baugh. The paper explores a new technique developed at IQC — a novel method for controlling quantum bits (qubits) using nuclear spins. The technique capitalizes on the "anisotropic hyperfine interaction" between an electron and two nuclear spins in a solid-state system.

The result indicates that these types of interactions may be exploited to create other more controllable and scalable systems for quantum computing. Writes Hu: "The future of the technique described in this paper seems bright."

IQC optics team tests new uncertainty principle
Nature Physics 7, 757–761 (2011)

In a January 2011 issue of *Nature Physics*, IQC optics researchers explained how they experimentally tested a novel variant of a cornerstone principle in physics — and discovered a useful new application for it. The research was sparked by the publication the previous fall of a different *Nature Physics* paper, which proposed a modified uncertainty principle (a variation of the famous Heisenberg Uncertainty Principle). The new uncertainty principle shows that uncertainty can be dramatically reduced when entanglement is involved, and the amount by which is it reduced is quantified by the amount of entanglement. The researchers tested this new uncertainty principle and verified the theoretical predictions. What's more, they showed that the new relation described by the uncertainty principle can be used as an effective "witness" of entanglement. Authors on the paper were: Robert Prevedel, Deny R. Hamel, Roger Colbeck, Kent Fisher & Kevin J. Resch

"Simple yet elegant" result achieved with quantum dots
Scientific Reports 1, Article number: 110 (September 2011)

A research team including IQC doctoral candidate Farzad Qassemi and IQC affiliate Bill Coish, with collaborators in Australia, achieved an important advance in the control and measurement of quantum particles for computation. Qassemi and Coish partnered with Andrew Dzurak's experimental group at the University of New South Wales to attain a deeper understanding of how to harness and utilize the properties of electrons.

Quantum information processing requires highly precise preparation, control and measurement of the particles used as quantum bits (qubits) for computation. An electron magnetic moment in quantum dots — essentially electrons confined in nano-scale structures — has been shown to be a promising system for the building blocks of a quantum information processor. However, electrons in quantum dots present unique and difficult hurdles, such as unwanted interactions between the magnetic moments of electrons and nuclei of the surrounding environment. One way to avoid difficulties raised by the nuclear magnetic moments is to use a material (such as silicon) in which only a small fraction of the nuclei have a finite magnetic moment. Even in these materials, the electron magnetic moments can be randomized by other environmental influences, as investigated in this work.

The team's results, published in *Nature*'s online journal *Science Reports*, demonstrate a more thorough understanding of such interactions in silicon quantum dots The paper represents an effective

collaboration between theoretical and experimental facets of quantum information research, said Qassemi.

QIP=PSPACE
Rahul Jain, Zhengfeng Ji, Sarvagya Upadhyay, John Watrous: QIP = PSPACE. STOC 2010: 573-582

A landmark paper co-authored by IQC faculty member John Watrous and doctoral student Sarvagya Upadhyay earned the prestigious Best Paper Award at the Symposium on Theory of Computing (STOC) in 2010. The paper, entitled QIP = PSPACE, was chosen from a field of 279 submissions and 79 finalists as having made the most significant contribution to theoretical computer science over the past year.

Watrous and his team resolved a decade-old problem in the theory of quantum computing by proving the equivalence of two collections of computational problems called QIP and PSPACE. Watrous, with collaborators Zhengeng Ji (Perimeter Institute), Sarvagya Upadhyay (IQC and David R. Cheriton School of Computer Science) and Rahul Jain (National University of Singapore), demonstrated that QIP is equivalent to PSPACE. To understand the importance of their result, it is helpful to summarize some historical developments that pre-date quantum computing:
PSPACE ("polynomial space") is the collection of all computational problems that can be solved by a computer whose memory usage scales according to some fixed power of the instance size. IP ("interactive proof") designates the class of all computational problems whose solutions can be "verified" through an interaction with a "prover" agent that answers a series of challenge questions, in time bounded by a fixed power of the instance size. A celebrated result of twenty years ago asserts that IP and PSPACE are in fact two descriptions of the same entity (any problem in PSPACE is in IP, and vice versa).

Watrous was among the first researchers to investigate the quantum analogue of IP, namely QIP. Although he and his collaborators uncovered several interesting properties of QIP, its true relationship to PSPACE remained a mystery until Jain, Ji, Upadhyay and Watrous demonstrated their equivalence in 2009.

Explained Watrous: "We want to understand the impact of quantum information on the way we classify the inherent difficulty of computational problems. In the case of interactive proof systems, we now have an answer: quantum information doesn't actually have any effect at all on the class of problems they define."

Lab Experiments Breed Photon Triplets
Nature, 446, 601-603 (2010)

In the paper "Direct Generation of Photon Triplets Using Cascaded Photon-Pair Sources" published in *Nature*, researchers in IQC's quantum optics laboratories, in collaboration with scientists in Austria and Australia, explained how they achieved a longstanding milestone in the field — the direct generation of photon triplets. In the past, the generation of pairs of photons (particles of light) revolutionized quantum optics and made possible emerging technologies such as quantum cryptography and quantum computing with photons. Typically, these photon pairs were created from strong lasers sent through a crystal — a process known as "parametric down-conversion."

The creation of photon triplets had been sought for years, but never achieved until the IQC-led team first produced a pair of photons with an optical crystal, then split one of the pairs into two additional photons in a second crystal. Further research will aim at producing GHZ states, well known in quantum information theory, as they predict deterministic violation of classical behavior, in contradistinction with Bell pairs.

Researchers Test Fundamental Rule of Quantum Physics
Science 23, 418-421 (2010)

A 2010 experiment tested a fundamental tenet of quantum mechanics, Born's rule in "Ruling out Multi-Order Interference in Quantum Mechanics." The rule, which gives the probability that a measurement on a quantum system will yield a given result, is widely believed to always hold true, but had not been subjected to significant experimental scrutiny. It has been suggested that some theories of quantum gravity might violate Born's rule, leading to interesting results for quantum complexity theory. To test the rule, IQC postdoctoral fellow Urbasi Sinha created a "triple-slit experiment," a variation on the famous double-slit experiment (known as an elegant demonstration of quantum effects). Because Sinha and collaborators did not see any violations of quantum mechanical predictions, it helped affirm quantum mechanics as a pillar of modern physics and opened new avenues for exploration.

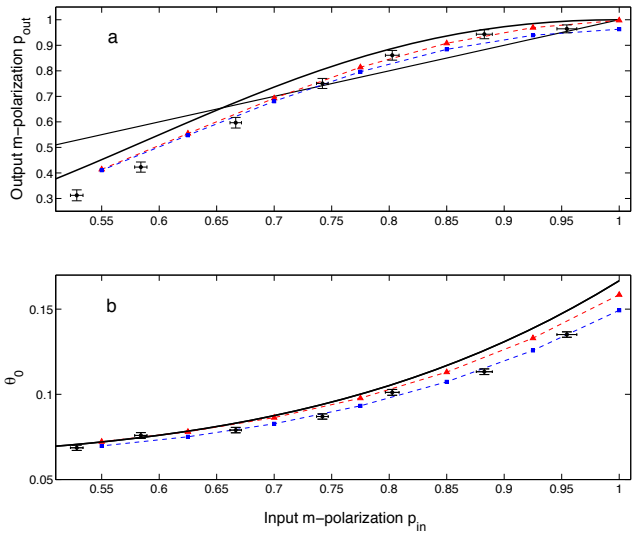
Team Advances Measurement-based Quantum Computing
Nature Physics, 6, 850–854 (2010)

Researchers made a significant step forward in measurement-based quantum computing in 2010. The experiment "capitalized on the fact that photonic states can simulate other quantum systems," summarized Jonathan Lavoie, a PhD student at IQC and co-author of the paper "Optical one-way quantum computing with a simulated valence-bond solid." *Nature Physics* 6, 850-845 (2010) published October 2010. The team experimentally achieved a result that had previously been theoretically considered as a resource for measurement-based (or "one-way") quantum computing. The researchers created and characterized, for the first time, a so-called AKLT (Affleck-Kennedy-Lieb-Tasaki) state, which can serve as a quantum processor. AKLT states are attractive for measurement-based quantum computing because they can be obtained simply by cooling the right solid-state system down to very low temperatures. The IQC researchers devised the means to simulate the AKLT state by using properties of photons, the fundamental particles of light. The experiment demonstrates the viability of quantum computation using AKLT states, and will inform future work in condensed matter physics.

"Our experiment is bridging the gap between condensed matter physics and quantum information," said Prof. Kevin Resch, an IQC faculty member and professor in the University of Waterloo's Physics & Astronomy department. "That's an important area to explore."

Error-Correction Advance
Nature Communications 2, 169 (2011)

One hurdle on the road to building quantum computers is that they are very vulnerable to errors caused by unintended interactions with the environment. Indeed, errors are unavoidable in any device used for quantum information processing. In January 2011, IQC researchers published the paper "Experimental magic state distillation for fault-tolerant quantum computing," in *Nature Communications*, explaining how they implemented a novel way to cope with errors inherent to quantum systems. A number of error-correcting and fault-tolerant methods have been developed in recent years to overcome quantum imperfections. In particular, some methods rely on the ability to prepare quantum bits (qubits) in a special high-purity state: the so-called "magic state."



Experimental results after the completion of magic state distillation. Output m-polarization of the faulty magic state (a) and the probability θ_0 (b) of finding this state in the mixture of possible outcomes as a function of the input m-polarization of the initial faulty magic state. The experimental data are represented by the filled circles and the error bars are estimated from the uncertainty of the fitting parameters. The point above the straight line in a shows success a distillation.

In the recent experiment, researchers implemented, for the first time, magic-state distillation. This quantum algorithm involves applying quantum operations to five imperfect magic states and distilling one with high purity. The research team implemented the distillation protocol with a seven-qubit quantum processor. In order to successfully realize their experiment, they had to achieve a high degree of control over their qubits. The result is an important building block in the implementation of quantum information processing.

Entanglement a Game-Changer in Communication
Physical Review Letters 106, 110505 (2011)

In March 2011, researchers at IQC demonstrated that quantum entanglement — the powerful correlation between particles — can significantly enhance the accuracy of communication between parties. Building upon work led the previous year by IQC postdoctoral fellow Will Matthews, the team experimentally demonstrated the use of entanglement for communication over a "noisy" classical channel. Other collaborators on the paper include R. Prevedel*, Y. Lu, R. Kaltenbaek, and K. J. Resch

While entanglement cannot itself be used to communicate, the IQC optics researchers demonstrated that one can transmit information over a certain channel with higher success when using entanglement than with the means available in classical physics. The team published their results in the paper "Entanglement-Enhanced Classical Communication Over a Noisy Classical Channel." In a commentary article on physics.aps.org, writer Mark Wilde explained the experiment in terms of a

game show, on which a pair of contestants named Alice and Bob play a game called "Guess That Button." To win a date with Alice at a nice restaurant, Bob must guess which button Alice has randomly pushed on a board with four coloured buttons.

While the board offers hints as to which button Alice pushed, ultimately Bob is clueless as to exactly which button Alice has pushed — unless, that is, the rules of the game are changed from classical to quantum. The IQC researchers demonstrated a scenario in which Alice and Bob stand a much greater chance of winning the game by sharing entangled photons in advance. The game show analogy illustrates a "noisy classical communication channel," over which communication between Alice and Bob is markedly improved by using entanglement. The experimental discovery, and the theoretical work that preceded it, were also highlighted in *Physics Today*.

QIP 2012 Conference

IQC was well represented at the 15th Workshop on Quantum Information Processing in Montreal. Some IQC contributions include:

- "Quantum query complexity of state conversation," by Ben Reichardt and collaborators
- "Hardness of approximation for quantum problems" by Sevag Gharibian and collaborators
- "A quantum information cost trade-off for the Augmented Index function," by Ashwin Nayak and collaborators
- "Discrete simulations of continuous-time query algorithms that are efficient with respect to queries, gates and space," by Richard Cleve, Dominic Berry and Sevag Gharibian
- "Parallel approximation of min-max problems with applications to classical and quantum zero-sum games," by Gus Gutoski
- "Hedging bets with correlated quantum strategies," by Abel Molina and John Watrous
- "Span programs for functions with constant-sized 1-certificates," by Aleksandrs Belovs

QIP2011 Conference

In January 2011, Andrew Childs gave an invited presentation at the QIP2011 conference in Singapore reporting on his work with elliptic curve isogenies. Cryptographers have since attempted to build new cryptosystems that are resilient to quantum attacks, an area of research called post-quantum cryptography. One of theses systems is based on elliptic curve isogenies. Childs and his collaborators, David Jao and Vladimir Soukharev, found a quantum algorithm that was significantly faster than the best-known classical algorithm, which suggests these cryptosystems may be susceptible to quantum attacks. This is an important result that cast doubts on the belief of post-quantum cryptography.

IQC was well represented at the 14th Workshop on Quantum Information Processing in Singapore. Contributions included:

- "Entanglement can increase asymptotic rates of zero-error classical communication over classical channels," by Debbie Leung, Laura Mancinska, William Matthews, Maris Ozols and Adian Roy
- "Quantum interactive proofs with weak error bounds," by Tsuyoshi Ito, John Watrous and collaborators
- "On the solution space of quantum 2-SAT problems," by Jianxin Chen, Bei Zeng and collaborators
- "Quantum query and complexity or minor-closed graph properties," by Andrew Childs and Robin Kothari
- "Finding is as easy as detecting for quantum walks," by Maris Ozols and collaborators
- "Constructing elliptic curve isogenies in quantum subexponential time," by Andrew Childs and collaborators

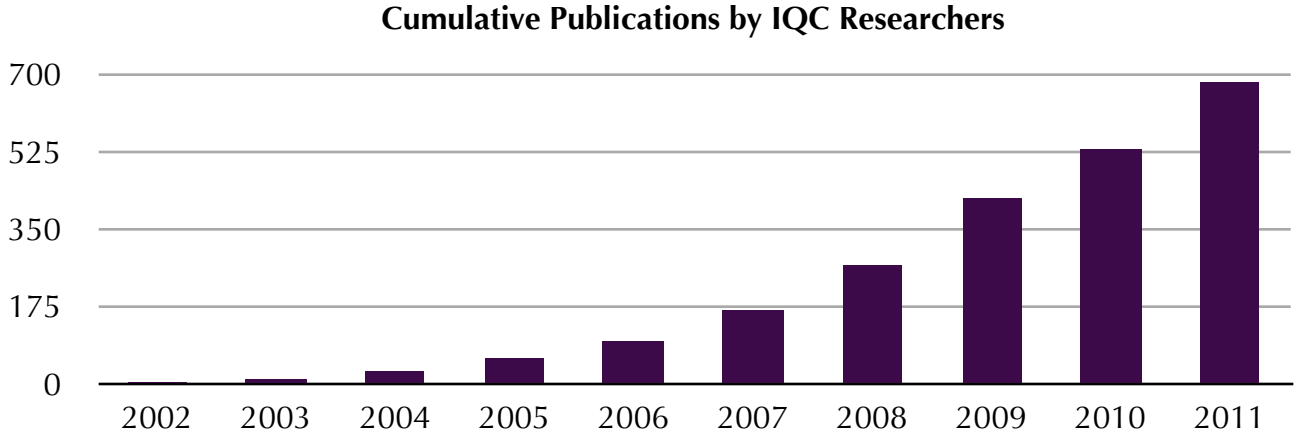
2.1.1.3 Publications by IQC Researchers

Publications are one of several indicators that IQC uses to demonstrate its research output. Since IQC is a relatively young organization, fluctuations are still occurring but the trend shows a strong record. Possibly more important than the number of publications is the quality of the journals in which these publications appear. Researchers from IQC have published in world leading journals such as those listed in the chart below. The chart shows the number of papers in selected publications since 2007.

IQC Research Published in Prominent Journals Since 2007

Publication	2007	2008	2009	2010	2011
Nature	3	2	1	3	1
Nature Photonics			1	1	1
Nature Physics	1	1	5	5	3
Nature Communications					1
Physical Review Letters	10	7	16	14	17
Science	2	1	1	1	2
STOC	1	2	1	2	
FOCS			3		1
Journal of Mathematical Physics		1	2	2	4

Below is a graph showing the number of cumulative publications by IQC researchers since 2002. This graph includes papers on arXiv.org and in other scientific publications.[1]



[1] Each one of IQC's publications has been counted only once, regardless of how many IQC researchers collaborated on it.

Below is a chart showing the total number of published papers by IQC researchers per year dating back to 2002.

All Publications by IQC Researchers Per Year

Calendar Year	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Publications	3	7	18	30	39	69	103	151	111	**152**

The data shown above is from information collected from the curriculum vitae and annual faculty reports of each researcher at the institute annually.[2]

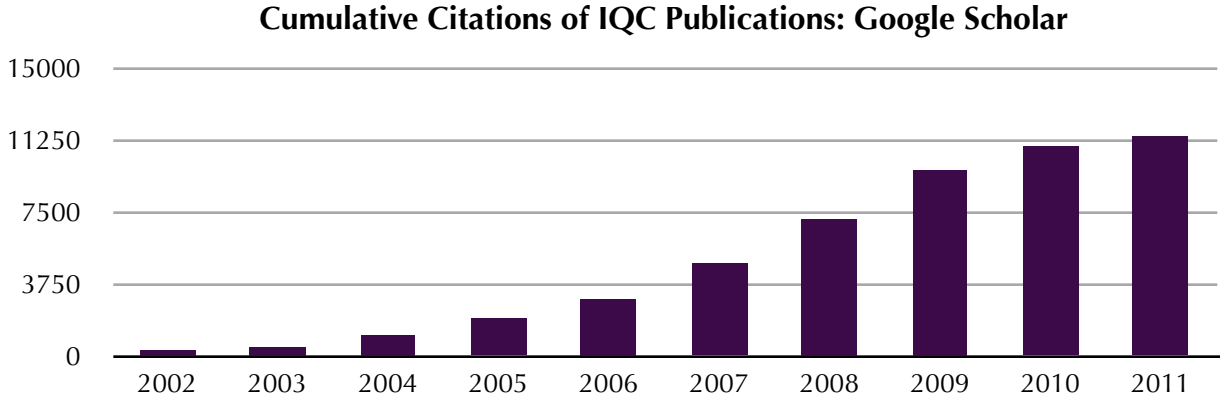
For a list of all publications by IQC researchers since 2007 see Appendix J or visit pubs.iqc.uwaterloo.ca to explore the institute's electronic database, the Quantum Library. The online repository stores, shares, and searches all of the institute's digital research material.

[2] IQC researchers include faculty, research assistant professors, IQC associate members, postdoctoral fellows, students and long-term visitors. A profile for each researcher was created in a repository and was populated with their respective IQC publications. The meta-data for each publication was imported from various research databases and electronic archives using the ISI Web of Science, Scopis, IEEE Xplore, arXiv, and Cryptography ePrint Archive.

2.1.1.4 Citations

Citations are another of the several indicators that IQC uses to demonstrate the authority of its research output.[3] These trends should be interpreted alongside other indicators that show IQC advancing research in quantum technology.

The graph below shows the cumulative number of citations of IQC publications as they were found on Google Scholar.[4]



The chart below illustrates the number of citations, per year, of publications with the designation "Institute for Quantum Computing" dating back to 2002.

Annual Distribution of Citations: Google Scholar

2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
377	134	633	840	1008	1865	2303	2577	1216	516

The chart above shows the citations, today, of all papers published in a given year. For example the papers published in the 2010 calendar year have garnered 1216 citations as of March 23, 2012.

[3] The citation numbers were collected from Google Scholar as of March 23, 2012. They include self-citations.

[4] A report for each year's list of publications was generated from IQC's publication repository. The repository is populated by importing metadata from ISI Web of Science, arXiv.org, SCOPUS, Spires, IEEE Xplore, etc.

Government Report

In a 2010 report on Quantum Capability by the Government of Canada, the University of Waterloo (Institute for Quantum Computing) was ranked fifth in the world for institutional affiliations in number of quantum computing papers and first in quantum algorithms literature.

"Canadian capacity in the area of quantum physics, and quantum computing/cryptography in particular, is superior. Strong government and corporate support of institutions such as Waterloo's Institute for Quantum Computing have led to that institution's rapid growth and enhanced its ability to attract star researchers."

2.1.1.5 Research Grants

As per the University of Waterloo, Office of Research:

Grants in Fiscal 2012

IQC received 73 new grants between May 1, 2011 and April 30, 2012. These new grants totaled $5,130,070 including $4,102,684 in government funding and $573,058 from industry partners. Additionally, IQC received $5 million from Industry Canada during this period.

Grants in Fiscal 2011

IQC received 80 new grants between May 1, 2010 and April 30, 2011. These new grants totaled $8,297,158. Additionally, IQC received $17 million from Industry Canada during this period.

Grants in Fiscal 2010

IQC received 75 new grants between May 1, 2009 and April 30, 2010. These grants totaled $7,379,979. Additionally, IQC received $16.5 from Industry Canada during this period.

A detailed breakdown of grants received since 2007 is available in Appendix I.

2.1.1.6 Faculty Awards

IQC faculty members have continued to set a global standard for excellence in quantum information research. The calibre of these scientists and their research is reinforced by the many awards and acknowledgements given to faculty members. The following list showcases a variety of the awards given to faculty members in in recent years.

Jonathan Baugh
- Early Researcher Award (2011)

Andrew Childs
- Early Researcher Award (2011)

Richard Cleve
- Appointed as Distinguished Scientist at the Centrum Wiskunde & Informatica (2011)
- Fellow of the Royal Society of Canada (2010)
- CAP-CRM Prize in Theoretical and Mathematical Physics (2008)
- Mike and Ophelia Lazaridis Chair in Quantum Computing, University of Waterloo (2004)

David Cory
- Canadian Excellence Research Chair (May 2010)

Joseph Emerson
- Early Researcher Award (2011)
- "40 Under 40" award from *The Waterloo Region Record* (2011)
- Scholar, Canadian Institute for Advanced Research (2008)

Thomas Jennewein
- Early Researcher Award (2011)

Raymond Laflamme
- American Association for the Advancement of Science, Fellow (2012)
- Fellow of the American Physical Society (2011)
- Canada Research Chair in Quantum Information (2009)
- Premier's Discovery Award in Natural Science and Engineering (2008)
- Fellow of the Royal Society of Canada (2008)
- Fellow of the American Association for the Advancement of Science (2005)
- Ivey Foundation Fellow at CIFAR (2005)

Debbie Leung
- Tier II Canada Research Chair (2007)

Adrian Lupascu
- Early Researcher Award (2011)
- Sloan Research Fellowship from the Alfred P. Sloan Foundation (2011)

Hamed Majedi
- Faculty of Engineering Distinguished Performance Award, University of Waterloo (2011)

Michele Mosca
- University Research Chair (2012)
- Canada's Top 40 Under 40, Globe and Mail (2011)
- CIFAR Fellow, QIP Program (2010)
- Waterloo Region 40 Under 40 (2010)
- Tier II Canada Research Chair (2002)

Ashwin Nayak
- NSERC Discovery Accelerator Supplement

Kevin Resch
- Outstanding Performance Award, University of Waterloo (January 2011)
- Early Research Award (2009)

John Watrous
- CIFAR, New Fellow
- Outstanding Performance Award, University of Waterloo (January 2011)

2.1.2 Recruiting New Researchers

The mission of IQC is to develop and harness quantum information science and technology at the highest international level through the collaboration of computer scientists, engineers, mathematicians and physicists. To this end, IQC must continue to build a team of theoretical and experimental researchers who are leaders in their respective disciplines. With such top researchers, IQC can achieve its strategic objectives of becoming a magnet for students and postdoctoral researchers, doing world-class science and becoming the authoritative source of insight, analysis and commentary on quantum information.

Objectives:

Fiscal 2012 Objectives:

- Recruit up to four new faculty members
- Recruit up to two new research assistant professors
- Recruit up to seven new postdoctoral fellows
- Leverage IQC's 10th anniversary celebrations, conferences and other outreach forums as recruitment opportunities

Highlighted Results from Fiscal 2012:

- Recruited three new research assistant professors
- Recruited ten new postdoctoral fellows
- IQC hosted six conferences and participated in eight graduate recruitment events

Fiscal 2011 Objectives:

- Recruit up to three new faculty members
- Recruit between six and 10 new postdoctoral fellows
- Recruit 20 new graduate students
- Leverage conferences and other outreach events as recruitment opportunities

Highlighted Results from Fiscal 2011:

- Recruited Prof. David Cory, Canada Excellence Research Chair in Quantum Information processing
- Recruited three new research assistant professors
- Recruited 18 new postdoctoral fellows
- IQC hosted six conferences and participated in seven graduate recruitment events

Fiscal 2010 Objectives:

- Recruit up to three additional faculty members
- Recruit six to ten postdoctoral fellows
- Recruit 20 new graduate students

Highlighted Results from Fiscal 2010:

- Recruited 2 new faculty members (Thomas Jennewein and Adrian Lupascu)

The following section of this report highlights the new faculty and research assistant professors that have joined IQC since the beginning of the Industry Canada grant. It also includes a summary of the

institute's membership, recruiting goals and the number of domestic and international researchers at the institute.

2.1.2.1 New Faculty & Research Assistant Professors since 2009

A key indicator of IQC's success is the stellar team of researchers that has been assembled over the past 10 years. An institute is only as strong as its membership, which is why IQC aims to recruit the world's top minds. This section highlights the top-calibre scientists IQC has attracted since the start of the Industry Canada grant, and some of their key research projects and breakthroughs.

"IQC seems to be a spectacularly successful effort, collecting top people in quantum computing and getting them to work together. It's very laudable."

Andrew Cleland, University of California, Santa Barbara

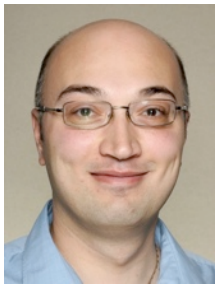
New Faculty Since 2009

David Cory

Prof. David Cory joined IQC in 2010 and is in the Department of Chemistry. Cory is the Canada Excellence Research Chair (CERC) in Quantum Information Processing bringing $10 million in funding with his appointment — he is one of only 19 recipients of the prestigious grant. Cory has also attracted another $4 million in funding from private sources. His state-of-the-art laboratory in the Research Advancement Centre II is outfitted with equipment for conducting experiments using nuclear spin, electron spin, superconducting qubits and quantum optics. Cory, who joins IQC from the Massachusetts Institute of Technology, leads experimental investigations into quantum sensors and actuators. Cory's research is expected to contribute to the world's first generation of practical quantum devices. These new technologies will have applications in the short-term in medicine, communications, biochemistry, physics and nanoscience.

Thomas Jennewein

Prof. Thomas Jennewein joined IQC in 2009 and is in the Department of Physics and Astronomy. His current research centres on the applications of quantum photonics and quantum optics, as well as the fundamental aspects of the quantum world. He is involved in the experimental design of devices based on quantum photonics suitable for communication and computing with photons, and the development of long-distance quantum communication systems using terrestrial and satellite-based systems. He is the leader of a multi-institutional collaboration working to implement quantum communications in space via satellite. Jennewein completed his PhD thesis in 2002 at the University of Vienna, focusing on quantum communication and teleportation experiments with entangled photon pairs.



Adrian Lupascu

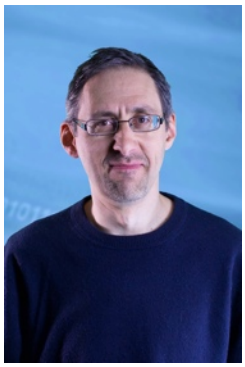
Prof. Adrian Lupascu joined IQC in 2009 and is in the Department of Physics and Astronomy. He studies superconducting atom-chips, Rydberg atoms and superconducting charged particle detectors. Lupascu worked as a postdoctoral researcher at Ecole Normale Superieure in Paris and at Delft University of Technology in the Netherlands where he conducted research on cold atoms and superconducting detectors. He completed his PhD at the Delft University, where his research involved experiments on dispersive measurement of superconducting qubits. Lupascu's work at IQC focuses on superconducting qubits and the interaction between artificial atoms and light at microwave frequencies.

New Research Assistant Professors Since 2009

IQC has recently begun to focus on attracting research assistant professors to help with the overall research impact of the institute. Currently, there are five research assistant professors at IQC hopes to recruit more in the coming year.

Vadim Makarov

Dr. Vadim Makarov joined the Institute for Quantum Computing in February 2012 following postdoctoral fellowships at the Norwegian University of Science and Technology and Korea's Pohang University of Science and Technology. A Russian native, Makarov earned his Master's in radiophysics from St. Petersburg State Polytechnical University before pursuing his PhD in Norway. His research is largely focused on looking for vulnerabilities in hardware implementations of quantum cryptography systems (essentially playing the part of "Eve" the eavesdropper in communications between "Alice" and "Bob") and recommending solutions.

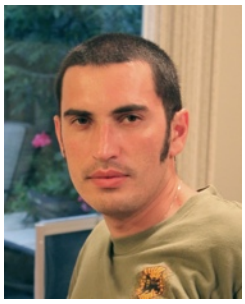


Radu Ionicioiu

Dr. Radu Ionicioiu joined IQC in June 2011 following postdoctoral fellowships at the Institute for Scientific Interchange in Torino, Macquarie University and the University of Cambridge's Engineering Department, as well as a research fellowship with the Quantum Information Processing Group at Hewlett-Packard Laboratories in Bristol. He earned his PhD from the University of Cambridge in 1999. His research interests span theoretical and experimental approaches to questions of quantum mechanics and foundations of mathematics and logic.

Guo-Xing Miao

Dr. Guo-Xing Miao joined the Institute for Quantum Computing in May 2011, and works primarily at the intersections of superconductivity, spin resonance and spintronics in the pursuit of practical quantum devices. Prior to joining IQC, he worked for five years as a research scientist at the Massachusetts Institute of Technology. He earned his PhD in Physics from Brown University in 2006.



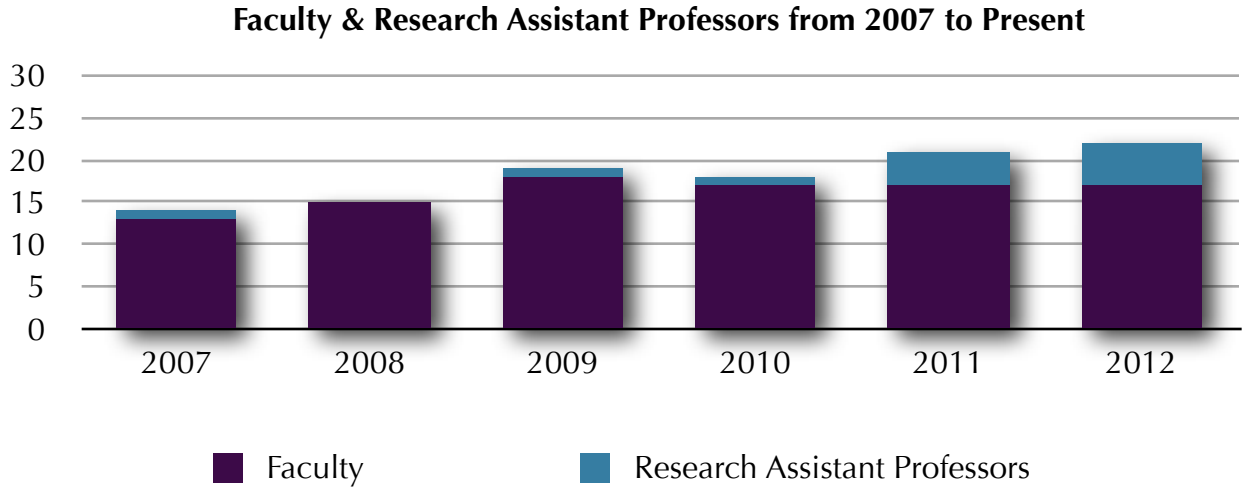
Dmitry Pushin

Dr. Dmitry Pushin joined IQC as a research assistant professor in September 2010 from the Massachusetts Institute of Technology, where he worked as a postdoctoral associate. Pushin is a specialist at the interface of neutron interferometry, condensed matter physics and quantum information. Pushin is working with the National Institute of Standards and Technology (NIST) to implement the "Power of one qubit" code that will make neutron interferometry measurements of magnetic cross-sections more robust. This has applications in material science, biology and nanotechnology.

Marco Piani

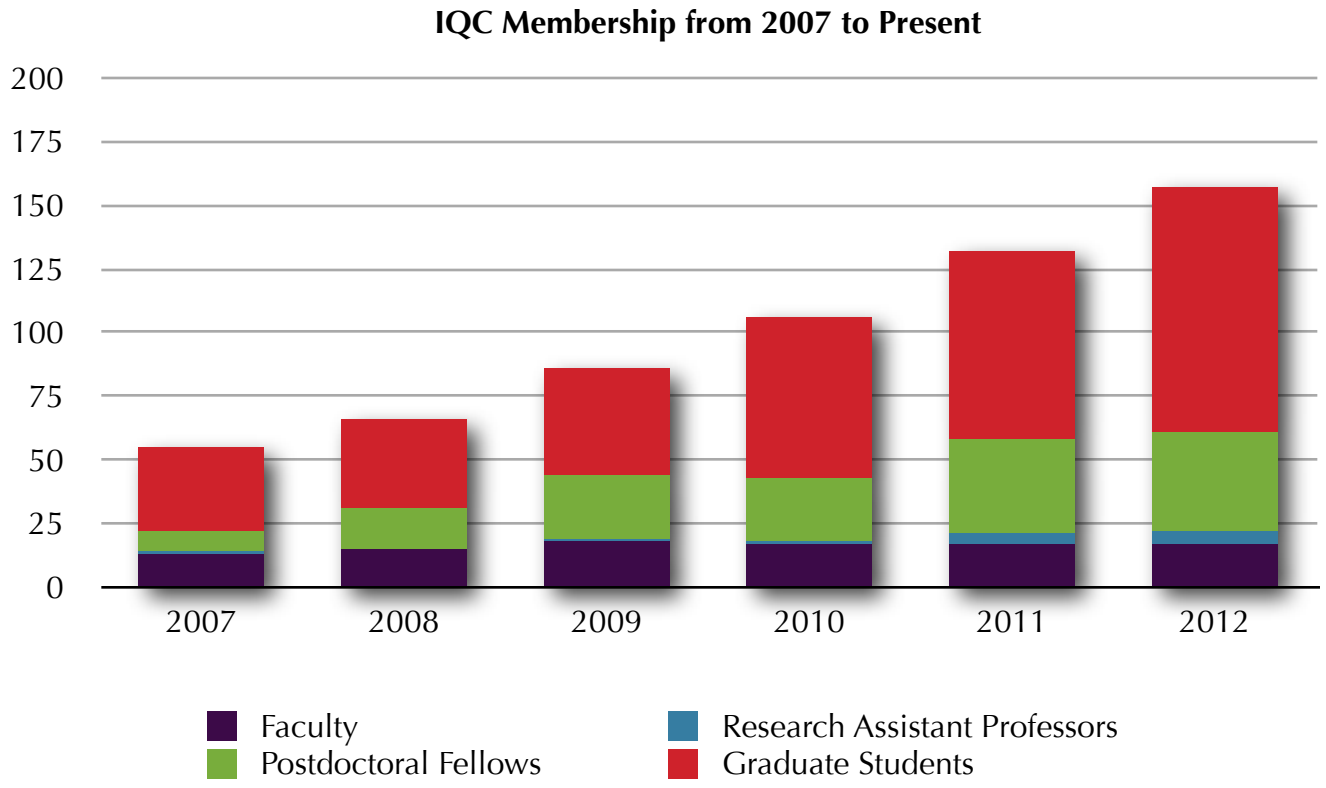
Dr. Marco Piani became a research assistant professor in September 2010 after having postdoctoral fellowships at IQC and Innsbruck. His interests lie mainly in the characterization, quantification, detection and exploitation of the non-classical features of correlations exhibited by distributed quantum systems.

Below is a graph showing the increase of faculty and research assistant professors over time. Since 2009, four IQC faculty members have left to return to their home country.



2.1.2.2 Researchers at IQC

Recruiting and retaining the world's top researchers is a high priority for the Institute for Quantum Computing. The graph below shows the growth of all IQC researchers from 2007 to fiscal 2012.



During the 2012 fiscal year IQC was home to 17 faculty members, 5 research assistant professors, 40 postdoctoral fellows, 96 graduate students, 36 research assistants, 21 long-term visitors and 6 technical specialists and 18 administrative, IT and communications staff.

Over the next few years, IQC plans to expand to 30 faculty, 50 postdoctoral fellows and 125 graduate students.

2.1.2.3 Recruitment

	Researchers Recruited in 2011	Researchers Recruited in 2012	Goal to Recruit in 2013
Faculty	1 - Canada Excellence Research Chair	2*	up to 5
Research Assistant Professors	3	3	up to 1
Postdoctoral Fellows	18	10	up to 15
Graduate Students	20	31	up to 25

* Two new faculty members will be joining the institute in September.

2.1.2.4 Domestic v. International Researchers

IQC continues to attract high-quality personnel from around the world. Below is a chart showing the citizenship of IQC's faculty, research assistant professors, postdoctoral fellows and graduate students.

	Canadian	Dual Citizenship	International
Faculty	6	5	6
Research Assistant Professors			5
Postdoctoral Fellows	9	2	29
Graduate Students	53		43

2.1.3 Collaborating with Other Researchers

The field of quantum information processing spans many disciplines — physics, chemistry, computer science, mathematics and more. Breakthroughs in quantum information will come from collaborations between researchers in a variety of fields. IQC's strategy for success is to encourage interdisciplinary research between the various groups at IQC and national and international collaborators.

Objectives:

Fiscal 2012 Objectives:

- Be a catalyst for collaborations of quantum information scientists though networks such as the NSERC Nano-Qubits Network (NNQ), the Canadian Institute for Advanced Research (CIFAR) Quantum Information program and the Natural Sciences and Engineering Research Council of Canada (NSERC) Strategic Networks
- Promote collaborations through participation in national and international conferences
- Produce internationally recognized, high-calibre publications co-authored by IQC researchers
- Organize at least three conferences that involve multi-disciplinary participants
- Continue, enhance and increase visits to IQC by international scientists and academics from around the world

Highlighted Results from Fiscal 2012:

- IQC researchers published 50 papers with external collaborators
- Researchers collaborated with 126 scientists from 69 organizations from more than 20 countries
- IQC continued to pursue strategic relationships with other institution and partners in government and industry
- IQC hosted 6 conferences

2011 Fiscal Objectives:

- IQC to be a catalyst to facilitate collaborations of quantum information scientists through networks such as QuantumWorks, Canadian Institute for Advanced Research (CIFAR) Quantum Information program and the Natural Sciences and Engineering Research Council of Canada (NSERC) Strategic Networks
- Researchers will attend international conferences on quantum information processing to build networks and connections
- Increased number of publications co-authored by IQC researchers and external collaborators
- Organize three conferences that involve multi-disciplinary participants
- Continue, enhance and increase visits to IQC by researchers from around the world

Highlighted Results from Fiscal 2011:

- IQC researchers have collaborated with 166 collaborators in 96 institutes from 20 countries
- IQC continued to pursue strategic relationships with other institution and partners in government and industry
- Faculty members presented talks at a total of 50 international events
- Organized six conferences
- Hosted 138 researchers from around the world for scientific visits

Fiscal 2010 Objectives:

- IQC will host the 4th Workshop on Theory of Quantum Computation, Communication and Cryptography; Undergraduate School on Experimental Quantum Information Processing; Quantum Cryptography School for Young Students; Fields Institute Workshop (Mathematics in Experimental Quantum InformationProcessing); Annual Tony Leggett Lecture Series

Highlighted Results from Fiscal 2010:

- IQC hosted the 4th Workshop on Theory of Quantum Computation, Communication and Cryptography; Undergraduate School on Experimental Quantum Information Processing; Quantum Cryptography School for Young Students; Fields Institute Workshop (Mathematics in Experimental Quantum InformationProcessing); Annual Tony Leggett Lecture Series
- IQC published 41 joint publications with 141 external collaborators in 61 institutes

This section includes a review of IQC's collaborative research projects since the start of the Industry Canada grant. Additionally, it reviews IQC's involvement in research networks, signed memoranda of understanding and other important strategic relationships. Additionally the section includes a look at the scientific visitors that have come to the institute since the start of the grant.

2.1.3.1 Collaborative Research Projects

Quantum information science is multidisciplinary and brings together researchers from many areas of expertise. IQC researchers consider collaborative research a catalyst for discovery. Therefore, scientists at the institute often work closely with peers from organizations around the globe to publish and present results. The institute's international network is expanding and the institute is laying the groundwork for exciting developments in the future.

Collaborative research projects involve IQC researchers networking with scientists around the world conducting joint research and publishing their results together. IQC has been collecting information on collaborations for the past three years. The chart below shows the numbers of collaborations, co-authors and organizations with whom IQC collaborates.

Collaborative Research Projects - Three Years

	2009	2010	2011
Papers co-authored by IQC faculty and other non-IQC researchers	41	56	50
Number of non-IQC co-authors on publications	141	166	126
Institutes whose researchers have collaborated with IQC faculty	61	96	69

IQC researchers participated in collaborative research projects with institutes from more than 20 countries around the globe including:

- University of Erlangen-Nuremberg
- Massachusetts Institute of Technology
- National University of Singapore
- University of Queensland
- University of Bristol
- Austrian Academy of Science
- Griffith University
- University of Innsbruck
- Macquarie University
- University of Oxford
- Yale University
- University of Vienna
- Caltech
- Los Alamos National Laboratory

The following map shows connections between IQC and the countries of collaborating institutes. Dark purple regions show areas with a higher number of collaborating institutions.

.

In 2011, IQC collaborated with 126 collaborators from 69 institutions in more than 20 countries. For a complete review of IQC's 2011 collaborations see Appendix K.

2.1.3.2 Research Networks

CIFAR (Quantum Information Program)

IQC's Executive Director, Raymond Laflamme, has served as the director of CIFAR's Quantum Information Processing research program since 2002. CIFAR (Canadian Institute for Advanced Research) aims to lead the world in framing and answering complex questions at the frontiers of understanding. Their vision is to create knowledge that enriches human life, improves understanding of the world, and advances the research community in Canada. The Quantum Information Processing program was founded in 2002 and renewed in 2007. There are 35 members total (10 of these are IQC researchers). CIFAR's QIP program has representatives from computer science, mathematics, and theoretical and experimental quantum physics. In the last budget on March 29, CIFAR's federal funding was renewed for an additional two years and the Quantum Information Program was highlighted.

The Canadian Institute for Advanced Research (CIFAR) is a private, non-profit organization linking Canadian researchers with the top minds from around the world. Its main priority is to establish and maintain global networks of top researchers and students, enabling Canadians to participate in and lead groundbreaking work on the international stage. To enhance the organization's activities and allow it to continue to link Canadian researchers to the world, Economic Action Plan 2012 proposes $10 million over two years to CIFAR.

Through its research programs, CIFAR identifies areas where significant new knowledge can be created by bringing together leading Canadian and international researchers to focus on "big questions." For example: Nanoelectronics aims to understand the power of materials at the nanometre (one billionth of a metre) scale, which holds the potential to create computer circuits orders of magnitude smaller than those found on today's microchips. Quantum information processing unites computer scientists and physicists in an effort to harness the unique properties of the quantum world, with the aim of building quantum computers.

- Federal Budget, March 2012

QuantumWorks

QuantumWorks, Canada's research network in quantum information processing, is based at the Institute for Quantum Computing. The network was established as an NSERC Innovation Platform in 2006. The network served as an umbrella organization, allowing for collaboration across diverse fields within quantum information in Canada. It also connected with stakeholders from the public and private sector, including the Communications Security Establishment Canada and the European Telecommunications Standards Institute (ETSI). QuantumWorks' mission is to have Canada be the world leader in the development and implementation of quantum information technologies. By encouraging collaboration, QuantumWorks' research programs will strengthen and build on established national expertise to promote and protect "made in Canada" breakthroughs, as well as promote them to both private and public sectors.

2.1.3.3 Memoranda of Understanding

IQC has a total of six official agreements to date. Generally, these constitute an agreement between parties that can help to facilitate collaborative research projects, joint research and the pursuit of common scientific interests. These official relationships offer scientists at both organizations a chance to visit, exchange ideas and collaborate with a new circle of researchers.

National Research Council (NRC)— Memorandum of Understanding (May 2010)
National University of Singapore— Memorandum of Understanding (March, 2010)
International Business Machines (IBM) – Software License Agreement (January, 2010)
National Science Council of Taiwan— Statement of Understanding (December, 2009)
Indian Institute of Technology, Kanpur – Memorandum of Understanding (April, 2006)
National Institute of Informatics, Japan – Memorandum of Understanding (December, 2005)

2.1.3.4 Other Important Strategic Relationships

In addition to the official agreements, IQC has established strong collaborative partnerships with several research organizations, government agencies and industry partners to ensure the successful pursuit of innovative, multi-disciplinary research.

Perimeter Institute for Theoretical Physics
Perimeter Institute (PI), in Waterloo is an independent, resident-based research institute devoted to foundational issues in theoretical physics. PI was instrumental in the creation and early development of IQC, and was essential in bringing IQC's Executive Director, Raymond Laflamme, back to Canada. PI also played a crucial role in the recruitment of Professors Ashwin Nayak, Richard Cleve and David Cory, Canada Excellence Research Chair in Quantum Information Processing. PI and IQC have collaborated on many scientific, outreach and recruitment efforts.

University of Guelph
IQC has developed a relationship with the University of Guelph — in particular with the mathematics department. Two faculty members at Guelph are Associates at IQC — David Kribs, head of the department researching algebra and operator theory, and Bei Zeng who conducts research in the area of quantum error correction. The collaboration has also resulted in interactions with postdoctoral fellows and students.

COM DEV, Canadian Space Agency & Institut National d'Optique
These three organizations are part of a multi-institutional collaboration working with researchers at the Institute for Quantum Computing to create international quantum communications networks. COM DEV is an Ontario-based designer and manufacturer of space-qualified equipment, and is committed to the prospective Quantum Encryption and Science Satellite (QEYSSAT) project. INO is a technological design and development firm for optic and photons solutions, working with IQC on technology for the prospective QYESSAT mission. The CSA is committed to the logistical operations of launching the prospective mission.

European Commission's Directorate General for Education and Culture and Human Resources and Social Development Canada (HDRC):
IQC is a participating institution in a program called "The Collaborative Student Training in Quantum Information Processing Project" — a part of the EU-Canada Programme for Cooperation in Higher Education, Training and Youth. The project is aimed at giving graduate students in Canada and the EU opportunities to study areas of Quantum Information Processing (QIP) that lie outside of the expertise of their local research groups. IQC's participation in the program is led by Ashwin Nayak, Raymond Laflamme and Norbert Lütkenhaus.

National Institute for Science & Technology (NIST), USA
IQC faculty member David Cory and research assistant professor Dmitry Pushin maintain a laboratory at NIST in Gaithersburg, MD, to perform experiments in neutron interferometry and sensing. Lab funding, and support for students and postdoctoral fellows carrying out research there, is provided by NIST. Cory, Pushin and colleagues have used principles of quantum error correction to achieve breakthroughs in sensing with neutron interferometry at NIST. Previously, neutron interferometry experiments needed to be shielded from "noise" inside a massive blockhouse, roughly the size of a garage. But Pushin and Cory, working alongside NIST researchers, developed a new type of neutron interferometer that is vastly more robust against noise and can be housed inside an apparatus roughly

the size of a barbecue. The innovation is expected to greatly advance neutron interferometry as a technique for probing and characterizing materials.

Communications Establishment Security Canada
A number of IQC faculty members including Raymond Laflamme, Michele Mosca and Norbert Lütkenhaus have been supported by CSEC over the past five years to provide the organization with reports about advances in quantum computing and quantum cryptography. These faculty members serve as authoritative sources of information on the field for CSEC.

Research In Motion & Certicom
A number of IQC researchers meet with representatives from RIM (and its wholly owned subsidiary Certicom Corp.) at least one day per term to discuss quantum cryptography, quantum computing, and potential applications of these fields in information security and cryptography. RIM gains exposure to the latest advancements and highly qualified personnel in the area, and IQC gains insight into the interests and needs of industry in this important area of research.

2.1.3.5 Scientific Visitors

IQC has developed a global reputation for excellence in quantum information processing. The institute has hosted the world's top scientists to conduct research, give talks, and meet with IQC's researchers and students.

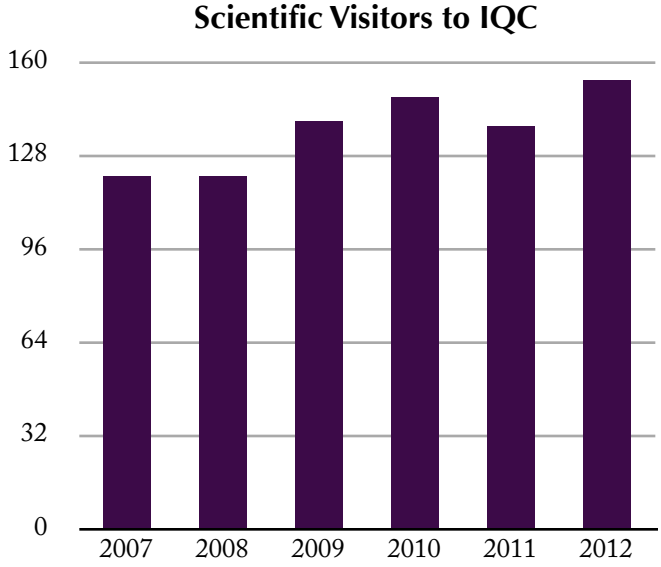
For a full list of IQC's scientific visitors and their institutes, see Appendix L.

The following list shows a sample of the institutions that these visitors have come from:

Academy of Mathematics and Systems Science Chinese Academy of Sciences
AT&T Labs
California Institute of Technology
Canadian Foundation for Innovation
Canadian Space Agency
Carleton University
CEA-Saclay
Centre for Quantum Technologies
Chalmers University of Technology
Columbia University
Commissariat à l'énergie atomique-Saclay
Dartmouth College
Ecole normale supérieure Cachan
Griffith University
Harvard
idQuantique, Genève
Imperial College London
Indiana University
Institute for Advanced Study, Princeton University
Institute for Molecular Manufacturing
Institute for Quantum Information (IQI), Caltech
Institute for Theoretical Physics Zurich
Instituto de Fisica Fundamental
Kyoto University
Laboratoire Aimé Cotton
Los Alamos National Laboratory
Macquarie University
Massachusetts Institute of Technology
McGill University
MITRE Corporation
National Institute of Standards and Technology
Nippon Telegraph and Telephone (NTT)
Northwestern University
Ohio State University
Perimeter Institute
Pohang University of Science & Technology
Potsdam University
Princeton University
Queen's University Belfast
Research Institute for Molecular Pathology

Rutgers University
Sabinci University
Spanish National Research Council
Stanford University
Stockholm University
Stony Brook University
Tata Institute of Fundamental Research
Technical University of Munich
Texas A&M University
The Chinese University of Hong Kong
The Hebrew University of Jerusalem
The University of Hong Kong
The University of Nottingham
Tornado Medical Systems
Tsinghua University
Tufts University
Universidad Complutense de Madrid,
Université de Sherbrooke
Universität Ulm
Université Autònoma de Barcelona
Universität Dortmund
Universität Innsbruck
Université de Montréal
Université Paul Sabatier
University of Alberta
University of British Columbia
University of Calgary
University of California
University of Illinois
University of Innsbruck
University of Maryland
University of Michigan
University of New Mexico
University of North Carolina
University of Ottawa
University of Oxford
University of Padova
University of Queensland
University of Rochester
University of Science and Technology of China
Universität of Stuttgart
University of the Basque Country Universidad del País Vasco
University of Toronto
University of Washington
Wayne State University
Wellesley College

Below is a chart showing the trend in IQC's academic visitors over the past six years.



Fiscal Year	# of Visitors
2012	**154**
2011	138
2010	148
2009	140
2008	121
2007	121

2.1.3.6 Patents & Spin-Offs

Research is a pipeline for ideas that occasionally sprout into useful applications for generating wealth, which in turn helps to support more investment in discovery. This process has been examined to death but is unpredictable by its very nature. All we can do is ensure that the best quality is achieved at every level, and that we do not inadvertently limit the resources and ideas of those who practice this bizarre but essential driver of progress.

Jim Woodgett *Nature* 467, 400 sept 23rd 2010

Though most of IQC's research is fundamental in nature — from exploring quantum systems to developing algorithms — it is already spawning the first wave of quantum technologies and intellectual property. The ultimate outcome of IQC's Strategic Framework (created in 2009) is the development and widespread use of practical quantum information processing devices. Although this stage is still years away, IQC is preparing by tracking new patent applications. Researchers at IQC continue to submit their own patent applications for new practical applications and devices. In 2011, IQC assembled a database of patents related to quantum information science. This project was initiated as part of the institute's third strategic objective, to help track new patents and major players in the field of quantum information science.

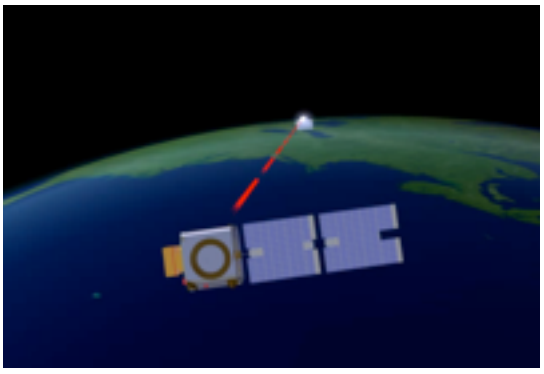
The following IQC members are patent holders or have patents pending approval:

- Prof. Richard Cleve
- Prof. David Cory
- Prof. Thomas Jennewein
- Prof. Norbert Lütkenhaus
- Prof. Kevin Resch
- Prof. John Watrous
- Dr. Anne Broadbent
- Dr. Rolf Horn

Research at IQC has sparked the creation of two nascent start-up companies.

Satellite Quantum Communication

An exciting collaborative project spearheaded by the institute is the effort to establish a secure global quantum communication network. Such a network would allow for the testing of some fundamental concepts in physics, and open the possibility of a worldwide system for quantum key distribution. A research team led by Thomas Jennewein, Norbert Lütkenhaus and Raymond Laflamme is developing the theory and technology necessary to establish such a global network in collaboration with industry/government



Schematic of QKD via Satellite

partners COM DEV (global designer and manufacturer of space hardware), the Institut National d'Optique and the Canadian Space Agency, along with academic partners Perimeter Institute, and the universities of Cambridge, Calgary, and Toronto.
Such work on quantum key distribution and other facets of quantum optics has resulted in IQC's first spin-off company: Universal Quantum Devices Incorporated (UQD).

Universal Quantum Devices Incorporated
The company aims to provide instrumentation for use in sophisticated quantum optics laboratories around the world. UQD will provide optical instruments — some of which are made exclusively by UQD, having been originally created for use in optics laboratories at the Institute for Quantum Computing. UQD will also be the North American distributor of specialized quantum optics instruments produced overseas. The initial flagship instrument is the IQCLogic Unit (shown above) was designed and built in cooperation with DotFast Consulting. The unit combines a timing analyzer, a coincidence logic unit and counters for 16 input channels on one device — a useful instrument for an array of research in quantum optics. “It’s a high-level product for photon experiments that outperforms anything previously available,” said Thomas Jennewein, UQD co-founder and IQC faculty member. UQD is in the process of making its first sale. Visit uqdevices.com for more information.

QuSpin
Postdoctoral fellows Rolf Horn and Chris Erven have launched QuSpin, a company specializing in free-space quantum key distribution. The small company was originally formed to support research and development of a chip-based source of polarization entangled photons. That project has since been acquired by the Waterloo Commercialization office, and is being further developed at IQC. Presently, QuSpin provides services related to the commercialization of quantum technology, but will be pursuing and supporting new ideas in the future.

2.1.4 Building, Facilities & Laboratory Support

Having the proper infrastructure to support world-class research is critical to the success of the institute. IQC is currently based in two buildings on the uWaterloo north campus in the Research Advancement Centre I & II (RAC I & RAC II). These two facilities have laboratories for research in optics, superconducting qubits, quantum dots, nuclear and electron magnetic resonance, single photon detectors and quantum sensors. Additionally, a successful interim cleanroom was constructed to service the needs of researchers until the fabrication facility in the Mike & Ophelia Lazaridis Quantum-Nano Centre is ready. The Industry Canada funding was essential to the completion of the RACI cleanroom, an important step in enhancing IQC's international competitiveness.

Objectives:

Fiscal 2012 Objectives:

- Ensure the Mike & Ophelia Lazaridis Quantum-Nano Centre is completed per specifications, on time and on budget
- Complete commissioning phase and move into the Mike & Ophelia Lazaridis Quantum-Nano Centre beginning in early 2012

Highlighted Results from Fiscal 2012:

- Expansion into the Mike & Ophelia Lazaridis Quantum-Nano Centre was deferred due to construction delays — preliminary planning for the move was paused when construction delays became clear

Fiscal 2011 Objectives:

- Proceed with the construction of the Mike & Ophelia Lazaridis Quantum-Nano Centre and ensure that the building is constructed per specifications, on time and on budget
- Establish a new 10,000 sq. ft. laboratory in the Research Advancement Centre II building with research focused on quantum sensors and actuators in June 2010
- Prepare equipment and other resources for expansion into to the QNC — building construction will be complete in July 2011
- Continue acquisition and maintenance of equipment for RACI laboratories

Highlighted Results from Fiscal 2011:

- The 10,000 sq. ft. laboratory in the Research Advancement Centre II opened in June 2010
- Continued to acquire new equipment for RAC1 laboratories

Fiscal 2010 Objectives:

- Ensure the building is constructed per specifications, on time and on budget
- Purchase equipment and outfit laboratories including the nano-fabrication facility
- Forming of ground floor slab 2nd to 5th floor slabs, superstructure, and building envelope completion

Highlighted Results from Fiscal 2010:

- Began the outfit of the RACI Cleanroom with: e-beam evaporator; ICP RIE for etching metals such as Al, Cr and Nb; Deep RIE for etching of silicon or mix gas processes; oxygen removal system; atomic layer disposition system with plasma-enhanced chemical vapour; and an electrical probe station

The following section reviews IQC's facilities and equipment that are necessary to perform research at the highest international level. The institute's facilities offer ideal research conditions, promote collaboration research between disciplines and serve as a magnet for the world's top minds. IQC has experienced tremendous expansion since its inception a decade ago. The chart below shows how IQC has grown in terms of lab space on the University of Waterloo campus.

Square Footage: IQC Lab Space by Year

Time Period	Buildings	Square Footage
2001 - 2004	Physics and Chemistry	2,625 sq. ft.
2004 - 2008	BFG, Physics and Chemistry	6, 694 sq. ft.
2008 - 2010	RACI, Chemistry	11,983 sq. ft.
2010 - 2012	RACI, RACII and Chemistry	25,132 sq. ft.
2012	RACI, RACII, Chemistry and QNC	51,832 sq. ft.

The following chart shows IQC's lab space by building:

Square Footage: Lab Space by Building

Physics	777 sq. ft.
Chemistry	1,848 sq. ft.
BFG	4,069 sq. ft.
RACI	10,135 sq. ft.
RACII	13,149 sq. ft.
QNC	26,700 sq. ft. 6,700 sq. ft, Cleanroom 20,000 sq. ft. Lab space

B.F. Goodrich Building

In 2004, the fast-growing institute moved into the B.F. Goodrich (BFG) building on Columbia Street, on the north edge of the university's main campus. The BFG facility housed laboratories specializing in quantum optics and nuclear magnetic resonance. IQC faculty members at the time included professors Raymond Laflamme, Michele Mosca, Kevin Resch, Gregor Weihs and Norbert Lütkenhaus.

Research Advancement Centres I & II

In 2008, IQC moved into its current headquarters, the Research Advancement Centre I (RACI), a 10,000-square-foot building with a 1,650-square-foot cleanroom/ fabrication facility.

In 2010, the Research Advancement Centre II (RACII) opened as the research base for the newly recruited Prof. David Cory (Canada Excellence Research Chair in Quantum Information Processing) and his team.

These adjacent three-storey buildings currently house all of IQC's laboratories and operations, and some of IQC's research will continue in these buildings on the north campus after the institute expands into its new headquarters, the Mike & Ophelia Lazaridis Quantum-Nano Centre.

RACI

RACI houses eight experimental labs and a cleanroom/fabrication facility:

Nuclear Magnetic Resonance (NMR) Laboratory

The spin properties of nuclei are great candidates for qubits, and nuclear magnetic resonance (NMR) is a technique by which the spins are controlled and measured. NMR is one of the best test-beds for quantum computing research. A research collaboration between IQC and MIT resulted in a long-standing world record for the largest number of well-characterized qubits harnessed for computation (12).

Electron Spin Resonance (ESR) Laboratory

A natural extension of nuclear magnetic resonance is to use electron spins to control nuclear spins; this allows for faster operation while keeping the inherent robustness of the nuclear spins. These two systems demonstrate a high degree of control and make a good test-bed for quantum computer prototypes.

Coherent Spintronics Laboratory

Although nuclear magnetic resonance (NMR) and electron spin resonance (ESR) can achieve good quantum control, it is challenging to add more qubits to those systems. Thanks to advances in semiconductor fabrication technologies, researchers can build extremely small "quantum dots"

that can hold a single electron. The qubits are the electron spins confined using charged electrodes on nanowires.

Integrated Quantum Optoelectronics Laboratory

IQOL aims to develop a unique test-bed for the characterization of superconducting and photonic quantum devices and circuits. IQOL is equipped with a custom-designed optical/microwave cryogenic probe system.

Superconducting Qubits Laboratory

Harnessing quantum systems at the mesoscopic scale is possible by defining qubits using superconducting nano-devices embedded in electrical circuits (namely Josephson junctions, which offer a scalable way to perform quantum computation). Scientists in this lab explore the interaction between light and these qubits.

Quantum Photonics Laboratory

A key goal pursued in this lab is to develop technologies that enable applications of quantum information and communication on a global scale. Researchers are developing technologies for quantum cryptography transmitted through optical fibres and free space to satellites. They are also engineering novel and high-quality states of entangled photons and applying them to quantum communication protocols and fundamental quantum physics experiments.

Quantum Optics & Quantum Information Laboratory

Particles of light (photons) generated using lasers can be used as qubits for quantum computation. Because photons interact very little with their surrounding environment, they are resistant to decoherence. Research in this lab focuses on experimental quantum optics, nonlinear optics, state reconstruction and measurement, and interferometry.

Quantum Hacking Lab (new in 2012)

The quantum hacking lab aims to identify weaknesses and vulnerabilities in commercial quantum cryptography systems. Although quantum cryptography is perfectly secure in principle, hardware implementations of it — such as commercially available quantum key distribution (QKD) setups — can have unforeseen loopholes. Research in the quantum hacking lab ensures these loopholes are discovered and remedied in future hardware systems.

RACI Cleanroom

The fabrication cleanroom in Research Advancement Centre I is certified Class-1000, meaning that one cubic foot contains less than 1,000 particles (as opposed to the 105 million in typical outdoor air). Such conditions enable the use of e-beam lithography (for patterning designs with dimensions as small as 20 billionths of a metre), along with atomic layer deposition and optical lithography, which allow for the engineering of nanoscale devices.

RACII

The RACII laboratories are centered around spin-based approaches to quantum research, with emphasis on the development and engineering of sensitive and robust quantum sensors, actuators and transducers, with the long-term goal of engineering practical quantum devices.

The RAC II laboratory is fully functioning with the following equipment:

- Seven nuclear magnetic spin resonance spectrometers Made by Bruker BioSpin in the following strengths: 600 MHz, 400 MHz, 300 MHz, 142 MHz and 100MHz

- One optically detected nuclear magnetic resonance setup
- One electrically detected nuclear magnetic resonance setup
- One dilution refrigerator
- One helium3 system
- One probe station
- One continuos wave x-band electron spin resonance spectrometer
- One pulsed x-band with endor-electron spin resonance spectrometer
- One q-band pulsed electron spin resonance system
- One s-band pulsed electron spin resonance system
- One v-band electron spin resonance system
- One atomic force microscopy system
- One nuclear quadrupole resonance spectrometer
- One micro-CT scanner

New Equipment in 2012:

- 2-axis superconducting magnet system --- Leiden Cryogenics
- Plasma-Enhanced Chemical Vapour Deposition System for Single Crystal Diamond Growth --- Seki Technotron
- Powder X-Ray Diffraction system and Raman Microscope --- Bruker ASX
- Dilution Refrigerator --- Leiden Crygenics
- Gas cabinets --- Applied Energy Systems
- Fume hoods --- Mottlab
- Copper Electroplating system --- Vital Presentation Concepts

The Mike & Ophelia Lazaridis Quantum-Nano Centre

This year will be an exciting milestone for IQC and the University of Waterloo. After several years of construction, the Mike & Ophelia Lazaridis Quantum-Nano Centre is nearing completion. IQC will expand to occupy a total of 51,832 sq. ft. of lab space on campus.

The centre will be home to a 6,700 sq. ft. fabrication and metrology facility, and be shared with the Waterloo Institute for Nanotechnology (WIN). The building will foster cross-disciplinary collaboration in its many common areas, lounges and meeting rooms. The Quantum-Nano Centre will allow IQC to continue its aggressive growth, as it expands to 30 faculty, 50 postdoctoral fellows and 125 graduate students.

Designers of the facility were guided by three principles:

1. It must be functional, i.e. meet the highest scientific standards for temperature, vibration, humidity and electromagnetic radiation control
2. It must encourage interaction and collaboration between researchers and students
3. It should attract top scientists to Waterloo

Fabrication & Metrology Facility

The new cleanroom and metrology lab will be shared between IQC, WIN and the University of Waterloo.

- Class-100 cleanroom (less than 100 particles per cubic foot of air)
- Stray magnetic fields of less than 0.1 uTesla
- Minimization of EMI interference with fibreglass rebar in 1-metre thick concrete floor
- Vibration isolation of all electrical and mechanical systems fastened to ceilings
- Floor vibration: displacement of less than 2um peak-to-peak
- AdvanceTEC Inter 6,700 ft^2 mediate ceiling grid installed
- Maintained temperature of 20C (+/- 1) and relative humidity of 35% (max 40)

Laboratories and Technical Specifications:

1. Superconducting Qubits (solid-state and low temperature)
2. Atomic & Ion-trapping Quantum Information Processing
3. Quantum Optics
4. NMR/Spin-Based Quantum Information Processing
5. Quantum Communication/Cryptography

The laboratories are equipped with the following technical specifications:

- Temperature Control: +/- 1 C
- Humidity Range: 80 – 30 %
- Vibration Rating: VC-E
- RFI/EMI Shielding 3mG

As of April 30, 2012 the Mike & Ophelia Lazaridis Quantum-Nano Centre was 98 per cent complete. There is currently no experimental equipment in the facility. Construction is on budget.

Industry Canada funding for building construction created 126 jobs in fiscal 2010 and 123 jobs in fiscal 2011.

2.2 Becoming a Magnet for Highly Qualified Personnel in the Field of Quantum Information

IQC's second strategic objective — to become a magnet for highly qualified personnel in the field of quantum information — is realized through attracting, educating and training students and young researchers. By recruiting top scientists, IQC achieves its foremost goal of conducting world-class science — and this research, in turn, attracts more exemplary scientists. IQC aims to fuel this cycle of research and recruitment by providing scientists with the best possible facilities, collaborative opportunities and the intellectual freedom needed to be leaders in their field. IQC understands that the future of this cutting-edge branch of research will be pioneered by the outstanding students who work with and learn from IQC faculty. Today's young researchers will form the first quantum-ready workforce as quantum devices become pervasive in society.

The following section provides indicators to assess IQC's achievements and results related to the institute's second strategic objective, including: information on the number and growth of IQC researchers over the past five years; a review of IQC's postdoctoral fellowship program including information on recruitment, the mentorship program, and profiles of several outstanding postdoctoral fellows; highlights of the collaborative graduate program on quantum information and profiles of several outstanding students; information on student alumni and the quality of students recruited by IQC; and statistics about applications to IQC programs

2.2.1 Attracting, Educating and Training Highly Qualified Personnel

The path toward the realization and commercialization of practical quantum information technologies will be forged by the current generation of students. Seeking out prospective students, recruiting them to IQC and providing them with the necessary resources and guidance is critical to the long-term mission and vision of IQC.

Objectives:

Fiscal 2012 Objectives:

- Attend at least four graduate fairs to connect with prospective students
- Field at least 240 applications to the uWaterloo/IQC graduate studies program
- Expand connections made with undergraduate programs at Ontario and Canadian universities
- Take part in at least two international outreach or recruitment events

Highlighted Results from Fiscal 2012:

- Attended eight graduate fairs to connect with prospective students
- Fielded 185 applications for the uWaterloo/IQC graduate studies program[5]

[5] The estimate of 240 applications (a 23% increase) was in the context of a unexpectedly high increase from 104 to 195 applications for quantum information studies (an 88% increase) from 2010 to 2011, and general increases across the 6 participating units ranging from roughly 10-60%. The 2012 figures across the 6 participating units ranged from drops of roughly 10-25%, while the total quantum information numbers dropped 5%, and the applications specifically for the quantum information collaborative program rose to 121 from 117. From 2010-2012, the total quantum information numbers rose 78%, in the context of increases as high as 40% (to a drop of 20%) across the 6 participating units .

- Attended the American Association for the Advancement of Science and interacted with many international scientists and science journalists

Fiscal 2011 Objectives:

- Roll-out the graduate program
- Establish an open house event for graduate students to attract prospective applicants
- Enhance prominence and content of graduate studies program on the IQC website (including background information, course materials, etc.)
- Attend at least four graduate fairs to connect with prospective students
- Field at least 120 applications to the UW/IQC graduate studies program (a 20 per cent increase over applications in 2009/2010)
- Host an information session for University of Waterloo students

Highlighted Results from Fiscal 2011:

- The graduate studies section on iqc.uwaterloo.ca/welcome/graduate is now home to detailed program and course information. For information on IQC's website see section
- IQC attended seven graduate recruitment events
- Field at least 120 applications to the uWaterloo/IQC graduate studies program
- There were 195 applications. For more information on program applications
- Two students from the PSI program joined IQC for the fall and winter terms and three students have been offered positions to join in fall 2011
- IQC held tours for potential graduate students from the University of Waterloo, Wilfrid Laurier University, Laurentian University and the University of Guelph. Students from the Perimeter Scholars International (PSI) program were invited for a second year of study at IQC

Fiscal 2010 Objectives:

- Implement a collaborative graduate program in quantum information at the University of Waterloo to foster the next generation of quantum information scientists

Highlighted Results from Fiscal 2010:

- The Ontario Council for Graduate Studies approved the new collaborative graduate program in January 2010 and began in September 2010

This section of the report includes information on IQC's activities in recruitment as well as the postdoctoral fellow and graduate programs.

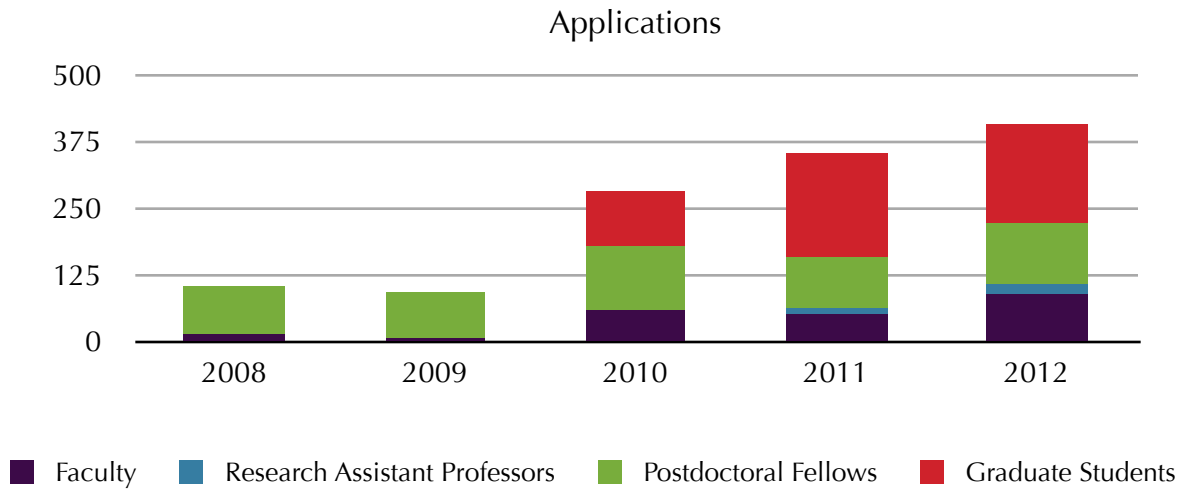
2.2.1.1 Applications to IQC Programs

In order to maintain its position as a world-class centre for research, IQC must continue to attract the best and brightest faculty within the field of quantum information science.

IQC accepts applications year-round for new faculty, research assistant professor and postdoctoral fellow positions.

There are four faculty hiring committees representing Engineering, Science (Physics and Chemistry) and Mathematics. Each has the mandate to proactively identify candidates, advertise, and recommend candidates for faculty roles at IQC. Committee members coordinate with the respective departments and oversee the logistics of the hiring process. Student applications are accepted via the University of Waterloo's OnBase system.

The chart below shows trends in application numbers from 2008 to present[6].



Applications for the graduate program include both students indicating an interest in quantum information (64) and those applying directly to the quantum information graduate program (121).

	2008	2009	2010	2011	2012
Faculty	14	7	60	53	**90**
Research Assistant Professors	N/A	N/A	N/A	10	**17**
Postdoctoral Fellows	91	87	119	96	**116**
Graduate Students	N/A	N/A	104	195	**185**

[6] Although IQC had graduate students prior to 2010, the figures listed here account only for applications to the Collaborative Graduate Studies program that was launched in 2010

2.2.1.2 Postdoctoral Fellow Recruitment

Today at IQC, there are 40 postdoctoral fellows working alongside IQC's faculty and students. These young scientists have expertise and innovative approaches to research that enrich the institute's scientific landscape. They contribute to every aspect of IQC's mission, spanning research, publications, teaching and outreach. They represent the next wave of leaders in quantum information science.

The following is a list of some of the organizations from which that these postdoctoral researchers were recruited.

- CEA Saclay, France
- Chinese Academy of Sciences, China
- Concordia University, Canada
- Dartmouth College, USA
- Dortmund University, Germany
- Griffith University, Australia
- Harvard University, USA
- Kinki University, Japan
- Leiden University, Netherlands
- Macquarie University, Australia
- Massachusetts Institute of Technology, USA
- McGill University, Canada
- Michigan State University, USA
- National University of Singapore, Singapore
- Nicolaus Copernicus University, Poland
- Perimeter Institute, Canada
- University of London, UK
- Rutgers University, USA
- University of Toronto, Canada
- University of Alberta, Canada
- University of Bristol, UK
- University of Calgary, Canada
- University of California, USA
- University of Cambridge, UK
- University of Connecticut, USA
- University of Georgia, USA
- University of Guelph, Canada
- University of Innsbruck, Austria
- University of Montreal, Canada
- University of New Jersey, USA
- University of New Mexico, USA
- University of Southern California, USA
- University of Vienna, Austria

2.2.1.3 Postdoctoral Fellow Profiles

Below is a sample of some of the outstanding postdoctoral fellows who have conducted research at IQC since 2009.

Anne Broadbent

IQC postdoctoral fellow Dr. Anne Broadbent explores theoretical questions of quantum cryptography, and in 2012 co-authored a *Science* paper about secure quantum computing in a "cloud" scenario. She earned her PhD at Université de Montréal under quantum cryptography pioneers Gilles Brassard and Alain Tapp. In 2011 she co-ordinated the inaugural Women in Physics Canada conference, which brought more than 60 female scientists to Waterloo. IQC recruited Broadbent from the Université de Montréal.

Bill Coish

Former IQC postdoctoral fellow Dr. Bill Coish is currently an assistant professor of physics at McGill, specializing in quantum condensed matter theory. He is a scholar in the CIFAR Quantum Information Processing and Nanoelectronics program and is a member of McGill's Centre for the Physics of Materials. IQC recruited Coish from the University of Basel.

Jay Gambetta
Former IQC postdoctoral fellow Dr. Jay Gambetta is currently a Research Staff Member in the quantum computing group at IBM's TJ Watson Research Center. He was a CIFAR Junior Fellow from July 2009 to June 2010. Originally from Australia, he completed his PhD in 2004 at Griffith University near Brisbane. IQC recruited Gambetta from Yale University.

Krister Shalm
Dr. Krister Shalm is a postdoctoral fellow at the Institute for Quantum Computing specializing in experimental quantum optics. He earned his PhD in physics from the University of Toronto in 2010; one of the research projects he completed at University of Toronto was named Breakthrough of the Year by *Physics World* in 2011. He is dedicated to scientific communication, and has spearheaded several public outreach events while at IQC — including the popular "Harry Potter and Quantum Physics" event in 2011, and a TEDxWaterloo talk in 2012 explaining quantum science through swing dancing. IQC recruited Shalm from the University of Toronto.

Urbasi Sinha
Former IQC postdoctoral fellow Dr. Urbasi Sinha is currently an associate professor at Raman Research Institute in Bangalore, India. Her research at IQC focused on quantum optics experiments, which led to the publication of a paper in *Science* explaining how she and her team tested the fundamental Born's Rule for probabilities in quantum mechanics. She earned her PhD in materials science and her Master's degree at the University of Cambridge. IQC recruited Sinha from the University of Cambridge.

2.2.1.4 Postdoctoral Fellow Mentorship Program

To enhance the postdoctoral fellowship experience, IQC implemented a formal mentorship program with guidelines for faculty supervisors. The program is monitored by a faculty member and aims to help guide postdoctoral fellows through their current research, career plans, job search, work environment, and more. The main purpose of the program is to help young researchers develop research and career goals, formulate a plan, and to track their progress towards these goals. The faculty mentors draw on their own experience and expertise to help the young researcher succeed. Mentors and postdoctoral fellows meet shortly after the postdoc arrives and then at least once per term for mentoring activities. Topics of discussion include frequency of meetings, research interactions, charting out directions for research, career plans, job search, work environment, conflicts, etc. At the end of the tenure of the postdoctoral fellow, IQC conducts an exit interview.

2.2.1.5 Collaborative Graduate Program: Update

The University of Waterloo offers students a comprehensive and collaborative approach to graduate studies in quantum information leading to a MMath, MSc, MASc or PhD degrees. Courses for the quantum information graduate program began in early 2010. The program exposes students to a wide range of advanced research projects and courses on the foundations, applications and implementations of quantum information processing. One particularly special feature of the new graduate program is its scope and breadth, encompassing both experimental and theoretical aspects of quantum information. The collaborative program in quantum information helps to provide new opportunities for students to learn and apply new knowledge.

The program is offered jointly by the Faculties of Mathematics, Science and Engineering with the departments of Applied Mathematics, Combinatorics and Optimization, Chemistry, Physics and Astronomy, Electrical and Computer Engineering, and the David R. Cheriton School of Computer Science.

To promote the collaborative graduate program, IQC attends several graduate fairs annually including those at the University of Waterloo, McGill University, the University of Alberta, the University of Western Ontario, the University of British Columbia, and the Canadian Undergraduate Physics Conference. In addition, the University of Waterloo's Graduate Studies Office promotes the program at international graduate fairs.

Current Student Information:

- 52 students currently enrolled in the collaborative program
- 28 Canadian students, 24 international students
- 26 Master's students, 26 PhD students
- Home departments: Applied Mathematics (3), Combinatorics & Optimization (5), Chemistry (1), Computer Science (3), Electrical and Computer Engineering (3), Physics (37)
- Home countries: Australia (1), Cameroon (1), Canada (28), China (2), Colombia (1), Estonia (1), India (1), Iran (4), Japan (1), Latvia (2), Poland (2), Russia (1), Singapore (1), South Korea (1), Turkey (1), Ukraine (1), USA (3)
- 16 students previously or currently hold an internal IQC scholarship (Mike and Ophelia Lazaridis Fellowship, IQC Entrance Award, IQC Achievement Award, IQC David Johnston Award for Scientific Outreach, Bell Family Fund)

Supervisor information:

There are 33 approved quantum information supervisors and 17 supervise or co-supervise at least 1 graduate student in the collaborative program.

Key Activities and Accomplishments:

The collaborative graduate program in quantum information was successfully launched in the fall of 2010. Since then, more than 10 courses have been taught. The program has been advertised through IQC and uWaterloo's websites, updated brochures and posters. Information was mailed to relevant departments and individuals across North America, Asia and Europe. Several awards for students were established including the IQC Entrance Award, the IQC Achievement Award, and the IQC David Johnston Award for Scientific Outreach. Mechanisms to enhance the graduate student experience have also been implemented including a new welcome package, orientation events, social

gatherings, and matching students with a peer in a different area of study. Additionally, the IQC Graduate Students' Association was launched in 2011.

2.2.1.6 Quantum Information Courses

The following courses have been offered at IQC since the start of the collaborative graduate program in September 2010.

Fall 2010

QIC 710 Quantum Information Processing
An investigation into 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
Goals of the course are to understand the context of QKD what does it achieve, and what not; understand the principles that allow to realize QKD; understand the principles of formal security proofs and its elements; understand quantum optical implementations of QKD; understand open problems in QKD research.

Winter 2011

QIC 750 Implementation of QIP
This course gives an introduction to physical implementations of quantum computers with an emphasis on common and connecting themes.

QIC 890 Spin-based Implementation
The course is intended to provide an in-depth introduction to quantum information processing (QIP) implementations based on nuclear and electron spin. It will describe how such implementations are advancing the state of the art for quantum devices, and are feeding back to improve metrology, spectroscopy, and enabling other potential real-world applications of use in Chemistry and many other fields.

QIC 885 Quantum Electronics and Photonics
This course is designed for engineers who are interested to learn applied quantum mechanics to study quantum behaviors of electron, photon and their interaction. The course content is a mix of topics usually covered in more conventional courses such as quantum electronics and quantum optics to invite a wide range of audiences who are working on areas such as engineering electromagnetics, solid state electronics, nanotechnology, applied quantum optics and quantum devices for classical and quantum information processing.

QIC 845 Open Quantum Systems
Experimental capabilities have advanced to the point where individual quantum systems can now be measured and controlled with very high precision, enabling exacting tests of foundational aspects of quantum theory and the prospect of new technological capabilities, such as quantum computing and quantum communication. From both the experimental and theoretical viewpoints, it has become abundantly clear that quantum systems are very sensitive to the effects of residual interactions with their unobserved environment, known as decoherence, and from imprecise control.

QIC 823 Quantum Algorithms
An investigation of algorithms that allow quantum computers to solve problems faster than classical computers. The quantum circuit model. Quantum Fourier transform, phase estimation, computing discrete logarithms, and quantum algorithms for number fields. The hidden subgroup framework and the nonabelian hidden subgroup problem. Quantum search, amplitude amplification, and quantum walk algorithms. Limitations on the power of quantum computers. Selected current topics in quantum algorithms.

Spring 2011
QIC 890 Implementations of Quantum Communication
Investigation of the experimental issues of realizing quantum communication schemes. The relevant experimental concepts and principles for quantum communication will be studied, leading to the "real world" possibilities and limitations of the most prominent quantum communication protocols.

QIC 891 Foundations of Quantum Mechanics and Quantum Information
This course discusses topics in the foundations of quantum mechanics, including: what exactly does Bell's theorem plus the experiments exclude, approaches to the quantum realization ("measurement") paradox, time (a)symmetry in QM, the role and limitations of "weak measurement", tests of QM versus macrorealism and versus "nonlocal HV" theories

QIC 890/891 Selected Advanced Topics in Quantum Information
This course consists of several short independent modules introducing a selection of interesting advanced topics in quantum information. Module topics include: Semi-definite Programming in Quantum Information, Quantum State Discrimination, Representation Theory in Quantum Information, Quantum Entrepreneurship, Tensor Network States, Bell's Theorem and the Connection to Cryptography, Quantum Computational Models and the Roles of Entanglement

Fall 2011
QIC 710 Quantum Information Processing
Quantum Information Processing (also known as "quantum computing") seeks to harness the strange power of quantum mechanics to provide a qualitatively different and more powerful way of processing information than "classical" physics seems to allow. The objective of this course is to introduce this multidisciplinary subject at the graduate level.

QIC 880 Nanoelectronics for Quantum Information Processing
Electrodynamics of superconductors, BCS theory and tunnel junctions, the Josephson effect, flux and fluxoid quantization, quantization of electric circuits, the basic types of superconducting qubits, decoherence in the solid state, circuit quantum electrodynamics, readout of nanoscale qubits, fabrication of qubit devices, measurement techniques.

QIC 820 Theory of Quantum Information
This course presents a mathematical treatment of the theory of quantum information, with a focus on the development of concepts and methods that are fundamental to a broad range of studies in quantum algorithms and complexity, quantum cryptography, and quantum Shannon theory.

QIC 890 Design in Quantum Systems
This course is addressed to students who are interested in learning to integrate quantum information processing into design of quantum devices. The course will teach design principles

in the context of quantum devices. The course emphasizes the role of quantum information processing and its applicability to designing devices that perform beyond their classical counterparts

Winter 2012

QIC 750 Implementations of Quantum Information Processing

The course will explore selected physical implementations of quantum processors and introduce the basic experiments used for characterizing their performance. The descriptions will be in the language of open quantum systems and we will connect to quantum information science and the requirements for a quantum computer.

QIC 890 Optical and Atomic Implementations

This course covers topics related to the quantized electromagnetic field, its properties, and its interaction with matter. Topics may include: field quantization, quantum states of light, coherence and interference, quasi-probability representations, nonlinear optics, light sources, tomography, measurement of light, continuous variable quantum information protocols, cavity QED.

QIC 890 Quantum Error Correction and Fault-Tolerance

This course focuses on how reliable quantum computation can be performed using unreliable primitives -- how quantum error correcting codes can be used to correct for a continuum of possible quantum errors, and how quantum error correction can still be effective when the encoding and decoding operations are also imperfect.

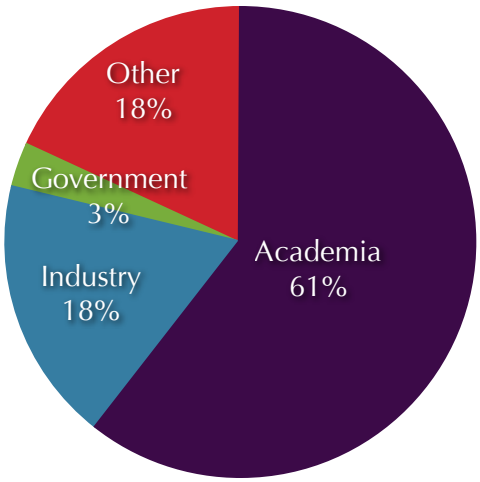
QIC 890 Applied Quantum Cryptography

The goal of the course is to familiarize the students with the cryptographic context of quantum key distribution (QKD), the basic ideas of QKD protocols, their optical implementation and their security analysis.

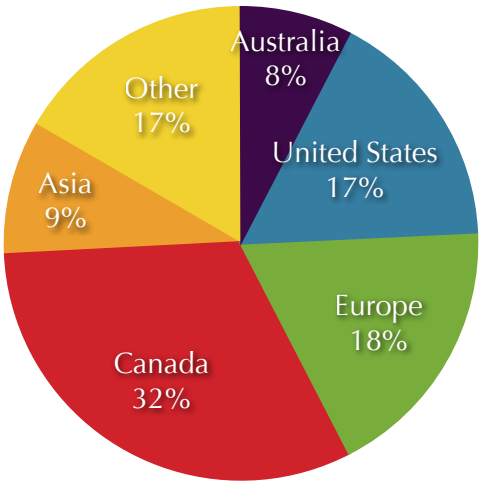
2.2.1.7 Student Alumni: Where are they now?

The institute tracks where its former students go after IQC. The following graphs show the current locations of the IQC's 66 past students and the sectors in which they are working[7].

Student Alumni: Field of Employment



Student Alumni: Where They Are Now



2.2.1.8 Student Alumni Profiles

Highlighted below are some of the outstanding student alumni who have come through IQC. These profiles show the high calibre of IQC's students.

Chris Erven

Dr. Chris Erven completed his PhD at the Institute for Quantum Computing in early 2012 under the supervision of Gregor Weihs. He also completed his Master's degree in physics at the University of Waterloo. His research has focused on free-space approaches to quantum key distribution (QKD). He has overseen the QKD experiment that exchanges encrypted keys between "Alice" (a receiver at IQC) and "Bob" (a receiver at Perimeter Institute). In his spare time he has worked as head coach of the University of Waterloo's badminton team.

Phil Kaye

Dr. Phil Kaye did his undergraduate degree in Systems Design Engineering and his Master's degree in Combinatorics and Optimization, both at the University of Waterloo. He was awarded the George Dufault Medal for Excellence in Communication at his engineering convocation. For his PhD studies, was awarded an NSERC Postgraduate Scholarship. He co-authored the text "An Introduction to Quantum Computing" with Raymond Laflamme and Michele Mosca.

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[7] IQC students since inception, 2002.

Gina Passante
Dr. Gina Passante completed her PhD at the Institute for Quantum Computing in early 2012 under the supervision of Raymond Laflamme. Her work at IQC focused on experimental spin-based approaches to quantum information processing — particularly nuclear magnetic resonance. She completed her undergraduate degree in physics at the University of Winnipeg in 2006. After being awarded a Commonwealth Scholarship she studied Part III of the Mathematical Tripos at the University of Cambridge. In fall 2012 she will begin her postdoctoral studies at the University of Washington in Seattle. Gina was the winner of the NSERC Vanier Graduate Scholarship in 2010.

David Poulin
Dr. David Poulin is an associate professor of physics at Université de Sherbrooke in Quebec. He earned his doctorate at the Institute for Quantum Computing under the direction of Raymond Laflamme in 2005. His main interests are quantum error correction, quantum algorithms for the simulation of physical systems, and the interplay between information science and fundamental physics including quantum gravity and the quantum-classical transition.

Lana Sheridan
Dr. Lana Sheridan completed her PhD at the Institute for Quantum Computing under the co-supervision of Michele Mosca and Raymond Laflamme, and is now a Research Fellow at the National University of Singapore's Centre for Quantum Technologies. Her research focuses on theoretical approaches to quantum information science, particularly quantum key distribution and other forms of quantum cryptography.

2.2.1.9 Students from Top Undergraduate Schools Internationally

The Times Higher Education World University Rankings judge educational institutions based on peer-review, academic polls, teacher-to-student ratios, internationalization rate and number of research citations.

Over the past few years, IQC students have come from one or more of the following top ranked institutions:

California Institute of Technology
Dartmouth College
École Normale Supérieure
Indian Institute of Technology
Massachusetts Institute of Technology
McMaster University
McGill University
National University of Singapore
Nanjing University
Peking University
Queens University
Tufts University
Tsinghua University
University of Alberta
University of Basel
University of Calgary
University of Cambridge
University of Oxford
University of Queensland
University of Toronto
University of Waterloo

For more information on the Times Higher Education World University Rankings visit:
http://www.timeshighereducation.co.uk/world-university-rankings/

2.2.1.10 Students with a High Grade Point Average

In the 2012 fiscal year, 96 students were registered in graduate programs at IQC. Of those, 60 per cent had a grade point average of 90 per cent or more. Additionally, 88 per cent of students had a grade point average of 85 per cent or higher.

In 2011, 62 per cent of students had a GPA of 90 per cent or higher, and 75 per cent had a GPA of 85 per cent or higher.

In 2010, 61 per cent of students had a GPA of 90 per cent or higher, and 85 per cent had a GPA of 85 per cent or higher.

2.2.1.11 Transatlantic Exchange Partnership

The Collaborative Student Training in Quantum Information Processing project is part of the European Union-Canada Programme for Cooperation in Higher Education, Training and Youth. The project is meant to give graduate students in Canada and the European Union exposure to study quantum information processing abroad.

Each year, the 36 students involved in the program participate in an internship with a faculty supervisor and course work in the relevant topics at the host institution. Students study QIP, its sub-disciplines and allied subjects including: algorithms and complexity, error-correction, cryptography, communication, information theory, experimental implementations of QIP devices, communication and practical cryptography.

Students involved in the EU-Exchange program during the 2011 fiscal year:

- Agnes Ferenczi (From IQC visiting the Institute of Optics, Information and Photonics, University of Erlangen)
- Thomas Gunthner (Visiting IQC from University of Innsbruck, Austria)
- Bettina Heim (Visiting IQC from Institute of Optics, Information and Photonics, University of Erlangen)
- Christian Konrad (Visiting IQC from Université Paris-Sud)

2.2.1.12 Postdoctoral Fellow Awards

The Institute for Quantum Computing strives to recruit the world's best young minds — the generation who will turn the discoveries of today into the technologies of tomorrow. This is a chief motivation behind IQC's strong and ever-growing Postdoctoral Fellowships program. The high calibre of postdoctoral researchers at IQC is evidenced by the many awards and acknowledgements these early-career scientists have earned. The following list summarizes some of the many academic awards and scholarships earned by IQC's postdoctoral fellows in recent years.

Anne Broadbent
- CIFAR Junior Fellow (August 2011)
- John Charles Polanyi Prize (November 2010)
- NSERC Doctoral Prize (January 2009)
- NSERC Postdoctoral Fellowship (2008)

Bill Coish
- CIFAR Junior Fellow (2009)

Brendon Higgins
- Banting Postdoctoral Fellowship (April 2011)

Jay Gambetta
- CIFAR Junior Fellow, 2009

Robert Prevedel
- MRI Award (October 2009)
- Erwin-Schrödinger-Fellowship (November 2009)

Aidan Roy
- University of Waterloo Fields Scholarship (August 2010)

Krister Shalm
- CIFAR Fellowship (October 2010)

Eduardo Martin-Martinez
- Banting Postdoctoral Fellowship (April 2012)

2.2.1.13 Student Scholarships and Fellowships

Bell Family Fund for Quantum Computing
- Chris Erven
- Chris Ferrie
- Peter Groszkowski
- Sarvagya Upadhyay
- Robin Kothari
- Jonathan Lavoie
- Pierre-Luc Dallaire-Demers
- Evan Meyer-Scott
- Jean-Luc Orgiazzi

David R. Cheriton Graduate Scholarship
- Sevag Gharibian
- Sarvagya Upadhyay
- Abel Molina Prieto
- Matthew Amy
- Robin Kothari
- Ansis Rosmanis
- Stacey Jeffery

IQC Achievement Award
- Felix Motzoi
- Farzad Qassemi
- Sarvagya Upadhyay
- Evan Meyer-Scott
- Maris Ozols
- Easwar Magesan
- Sevag Gharibian

IQC David Johnston Award for Scientific Outreach
- Chris Erven
- Jean-Luc Orgiazzi
- Gina Passante

IQC Entrance Award
- Kent Fisher
- Luke Govia
- Tomas Jochym-O'Connor
- Nickolay Gigov
- Christopher Wood
- Matthew Graydon
- Holger Haas
- Chris Pugh
- Denis-Alexandre Trottier

Mike and Ophelia Lazaridis Fellowship
- Yingkai Ouyang
- Farzad Qassemi
- Iman Marvian
- Amin Eftekharian
- Ansis Rosmanis
- Abel Molina Prieto
- Sarvagya Upadhyay
- Juan Miguel Arrazola
- Joshua Geller
- Adam Paetznick
- Antonio Scotland

NSERC Alexander Graham Bell Canada Graduate Scholarship - Doctoral
- Easwar Magesan
- Jonathan Lavoie
- Sevag Gharibian
- Farzad Qassemi
- Matthew Graydon
- Stacey Jeffery
- Evan Meyer-Scott

NSERC Alexander Graham Bell Canada Graduate Scholarship - Masters
- Cozmin Ududec
- Chris Ferrie
- Easwar Magesan
- Gina Passante
- Deny Hamel
- Daniel Criger
- Pierre-Luc Dallaire-Demers
- Robin Kothari
- Evan Meyer-Scott
- Stacey Jeffery
- Kent Fisher
- Luke Govia
- Tomas Jochym-O'Connor
- Nickolay Gigov
- Chris Pugh
- Joseph Rebstock
- Jamie Smith

NSERC Postgraduate Scholarship - Doctoral
Chris Erven
Chris Ferrie
Jamie Sikora
Jamie Smith
Felix Motzoi
Robin Kothari

NSERC Postgraduate Scholarship - Master's Extension
Cozmin Ududec
Gina Passante
Jamie Smith
Deny Hamel

NSERC Vanier Canada Graduate Scholarship
Gina Passante
Deny Hamel
Kent Fisher

Ontario Graduate Scholarship
Jamie Sikora
Hamid Mohebbi
Cozmin Ududec
Kurt Schreiter
Thomas McConkey
Nathan Killoran
Fatin Haque
Evan Meyer-Scott
Jean Philippe Bourgoin
Kent Fisher
Luke Govia
Victor Veitch

Ontario Graduate Scholarship in Science and Technology
Sevag Gharibian
Jamie Sikora
Felix Motzoi
Chunqing Deng
Peter Groszkowski
Thomas McConkey
David Pitkanen

Ontario Trillium Scholarship
Zak Webb

President's Graduate Scholarship
Jamie Sikora
Cozmin Ududec
Chris Ferrie
Easwar Magesan
Gina Passante
Jamie Smith
Chris Erven
Hamid Mohebbi
Deny Hamel
Kurt Schreiter
Daniel Criger
Pierre-Luc Dallaire-Demers
Robin Kothari
Jonathan Lavoie
Thomas McConkey
Evan Meyer-Scott
Sevag Gharibian
Stacey Jeffery
Nathan Killoran
Felix Motzoi
Farzad Qassemi
Kent Fisher
Luke Govia
Fatin Haque
Tomas Jochym-O'Connor
Jean Philippe Bourgoin
Nickolay Gigov
Matthew Graydon
Chris Pugh
Joseph Rebstock
Victor Veitch

Queen Elizabeth II Graduate Scholarship in Science and Technology
Agnes Ferenczi
Alexandre Laplante
Yuval Sanders

2.3 Establishing IQC as the Authoritative Source of Insight, Analysis and Commentary on Quantum Information

To turn IQC's vision into reality, the institute's research cannot remain within the confines of its walls. It must reach a broad audience that includes government, industry and the general public. Not only is this critical to adopt quantum devices in the long term, it supports the institute's first two strategic objectives. The scientific reputation of IQC relies on the quality of its research and it is enhanced through effective communication to all its stakeholders.

Achieving IQC's third strategic objective starts with researchers providing analyses, commentaries and reviews to the scientific community — but this is only a start. It is reinforced beyond the global scientific network by communicating with a much larger community.

Educating broader audiences about quantum research and its fundamental importance will inspire the next generation of quantum scientists, who will build on the foundational work being done today. Educating the first quantum-informed workforce will pave the way for productive partnerships with industry. Raising awareness about the role quantum science will play in our future, reinforces the importance of the major investment being made in quantum research at IQC and will secure the future of that investment.

This section of the report reviews how the institute achieves its third strategic objective through the dissemination of scientific knowledge, and through varied communications and outreach.

2.3.1 Disseminating Scientific Knowledge

Meetings, workshops, conferences and outreach activities are organized annually to complement the research that is happening at IQC. These events range from general interest lectures to highly specialized conferences. IQC launched a new website that will help with outreach and knowledge dissemination in the future.

Objectives:

Fiscal 2012 Objectives:

- Develop and implement a year-long plan of communications, outreach events and other activities linked to IQC's 10th anniversary celebrations
- Increase interest in camps, workshops, conferences and programs through targeted marketing and increase the scale of the events with technology
- Reflect IQC's outreach priorities and programs on the web
- Host at least five conferences with three distinct target audiences
- Increase external media coverage, especially international media coverage

Highlighted Results from Fiscal 2012:

- Began the activities related to IQC's 10th anniversary and continued planning for activities related to the opening of the Mike & Ophelia Lazaridis Quantum-Nano Centre in September 2012
- Offered many lectures for the Undergraduate Experimental School on Quantum Information Processing (USEQIP) and the Quantum Cryptography School for Young Students (QCSYS) online via the YouTube channel
- Hosted six conferences

Fiscal 2011 Objectives:

- Host five conferences at IQC with three distinct target audiences including researchers, undergraduate students and high school students
- Complete website redesign project and launch new web presence
- Compile a database of the publications by IQC researchers on RefBase
- Increase external media coverage

Highlighted Results from Fiscal 2011:

- IQC hosted six conferences
- The institute's new website was launched in September 2010
- "The Quantum Library"— IQC's publications database— was launched in April 2011
- IQC was featured in local, national and international media 86 times— including prominent stories in the Globe and Mail, New York Times, Telegraph (India) and Scientific American

Fiscal 2010 Objectives:

- IQC will engage in outreach events that include: the 4th Workshop on Theory of Quantum Computation, Communication and Cryptography; Undergraduate School on Experimental Quantum Information Processing; Quantum Cryptography School for Young Students; Fields Institute Workshop (Mathematics in Experimental Quantum InformationProcessing); Annual Tony Leggett Lecture Series

Highlighted Results from Fiscal 2010:

- IQC attended or helped to organize 8 outreach events and helped to organize five workshops or conferences including the 4th Workshop on Theory of Quantum Computation, Communication and Cryptography; Undergraduate School on Experimental Quantum Information Processing; Quantum Cryptography School for Young Students; Fields Institute Workshop (Mathematics in Experimental Quantum InformationProcessing); Annual Tony Leggett Lecture Series

The following section includes information on IQC's contributions to commentary and analysis on the subject of quantum information science, a review of the conferences, workshops and schools organized and hosted by the institute in recent years.

2.3.1.1 Commentary & Analysis

IQC aims not only to conduct world-class research at the forefront of quantum information science, but also to share its results with the world. This is the motivation behind IQC's third strategic objective — to be the authoritative source of insight, analysis and commentary in the field of quantum information. IQC utilizes a number of avenues to achieve this objective, from publications to videos to events and conferences. Naturally, the scientific advances and breakthroughs achieved by IQC researchers are published in renowned academic journals, including *Science*, *Nature* and *Physical Review Letters*. IQC scientists also contribute to such journals with commentary and analysis articles about research conducted elsewhere. Because IQC researchers come from a variety of backgrounds — mathematics, computer science, engineering and more — they are able to provide insight on a wide range of areas in both general and highly specific publications. Public and academic lectures also provide an important venue for communicating results and sparking new ideas. Several IQC researchers including David Cory, Joseph Emerson, Raymond Laflamme and Michele Mosca have

delivered talks as part of the Perimeter Institute Public Lectures series. Faculty members often present their work at conferences and workshops around the world. The institute also has a large and ever-growing video library that allows viewers from around the world to watch lectures, explanatory clips, interviews and more. Prof. John Watrous, for example, filmed a five-minute video explaining his theoretical breakthrough "QIP=PSPACE," which brings IQC success to a broader audience. IQC has also produced a series of interviews with quantum information science leaders from around the world including David Wineland, Seth Lloyd, Gilles Brassard and many more. Academic lectures at IQC are often filmed, including the entire slate of introductory lectures for 2011 Undergraduate School on Quantum Information Processing (USEQIP). These and all other IQC videos are available on the institute's YouTube channel, www.youtube.com/quantumiqc. For a list of videos see Appendix T. For a list of other articles, lectures and videos, see Appendix P.

IQC has also produced a report analyzing the funding of quantum information research in Canada in the past 10 years. It can be used as a tool both for researchers and policy makers. The report can be found at http://iqc.uwaterloo.ca/resources/reports/QIP_Funding_in_Canada_2011.pdf A second research project, to be released shortly, will include a detailed analysis of patents in quantum information science and technology.

IQC postdoctoral fellow Rolf Horn has also produced a Quantum Intellectual Property database, an attempt at assessing the landscape of quantum information science from an intellectual property perspective. Questions that drove the creation of the database were "Who's patenting?, How many patents are there? and What is being patented? The database consists of patents related to quantum information science that were obtained by searching the main European patent database ESPACENET (http://www.epo.org/searching/free/espacenet.html) and the US Patent and Trademark Office (http://www.uspto.gov/). In addition to the standard information (Patent classification, Inventor, Applicant, Title, Abstract), each patent was briefly assessed and placed into a customized category that seemed most relevant to the patent content. The database will continue to be expanded to answer different questions as they arise.

2.3.1.2 Schools, Conferences & Workshops

IQC organizes annual meetings, workshops, conferences, and outreach activities to complement the research at the institute. These events range from general interest lectures to highly specialized scientific conferences. A full list of the conferences, schools and workshops held at IQC since 2007 is available in Appendix M.

IQC often hosts rotating scientific conferences that visit different Canadian or international organizations on an annual basis. These conferences bring world-leading researchers to Waterloo and encourage collaborative research projects between IQC members and visiting scientists. The number of scientific conferences varies between two to six per year. As well, each year the institute hosts two student focused summer schools: the Undergraduate School for Experimental Quantum Information Processing (USEQIP) and the Quantum Cryptography School for Young Students (QCSYS). USEQIP is a two-week program on the theory and experimental study of quantum information processors aimed primarily at students completing their junior year. The program is designed to introduce students to the field of quantum information processing. The lectures are geared to students in engineering, physics, chemistry and math. QCSYS is an exciting week-long program offered to students in Grades 11 and 12. Students are given a first-hand look into one of the most exciting topics in contemporary science — quantum cryptography. Not only will students be exposed to cutting-edge topics like quantum physics and cryptography — they will have the opportunity to meet some of the most

renowned researchers the field has to offer. In addition, students also tour quantum computing and quantum cryptography labs. These two summer schools aim to attract young students to Waterloo and into quantum information science in general.

Nanostructured Single & Entangled Photon Sources for Quantum Information Processing
April 28-29, 2011
Number of Participants: 26

Undergraduate School on Experimental Quantum Information Processing
May 30-June 10, 2011
Number of Participants: 19

Quantum Key Distribution Summer School
July 25-29, 2011
Number of Participants: 47

Quantum Cryptography School for Young Students
August 8-12, 2011
Number of Participants: 42

General Quantumness of Correlations Workshop
February 23-24, 2012
Number of Participants: 18

Recent Progress in Quantum Algorithms
April 11-13
Number of Participants: 46

2.3.1.3 Sponsored Conferences & Events

Conceptual Foundations and Foils for Quantum Information Processing
May 9-12, 2011
www.perimeterinstitute.ca/Events/Conceptual_Foundations_and_Foils_for_Quantum_Information_Processing
"It should be a very good conference scientifically, the topic is of interest to IQC researchers, and IQC members will be involved as speakers and possibly in the poster session."

Women in Physics Canada
July 19-21, 2011
www.perimeterinstitute.ca/Events/Women_in_Physics_Canada
"The conference is broadly targeted, to all areas in physics. But given its location, its organizers, and some of the planned agenda, it is clear that quantum will have a special place. Since the conference is targeted partly at undergraduates, it could draw applications in to IQC. This is a good outreach opportunity for IQC."

First Annual Conference of Quantum Cryptography (QCRYPT)
www.qcrypt2011.ethz.ch
September 12-16, 2011
"This should be a fine conference, and it is well-aligned with IQC's research."

Canada-America-Mexico Graduate Student Physics Conference (CAM2011)
www.cap.ca/en/cam2011
September 29-October 31, 2011
"The focus is not on quantum information but many areas represented are related to QI research."

TEDxUW
www.tedxuw.ca
November 12, 2011
TED event held on campus at the University of Waterloo.

Second International Conference on Quantum Error Correction
qserver.usc.edu/qec11/
December 5-9, 2011

Quantum Information Processing (QIP)
conference.iiis.tsinghua.edu.cn/QIP2013/index.html
December 12-16, 2011

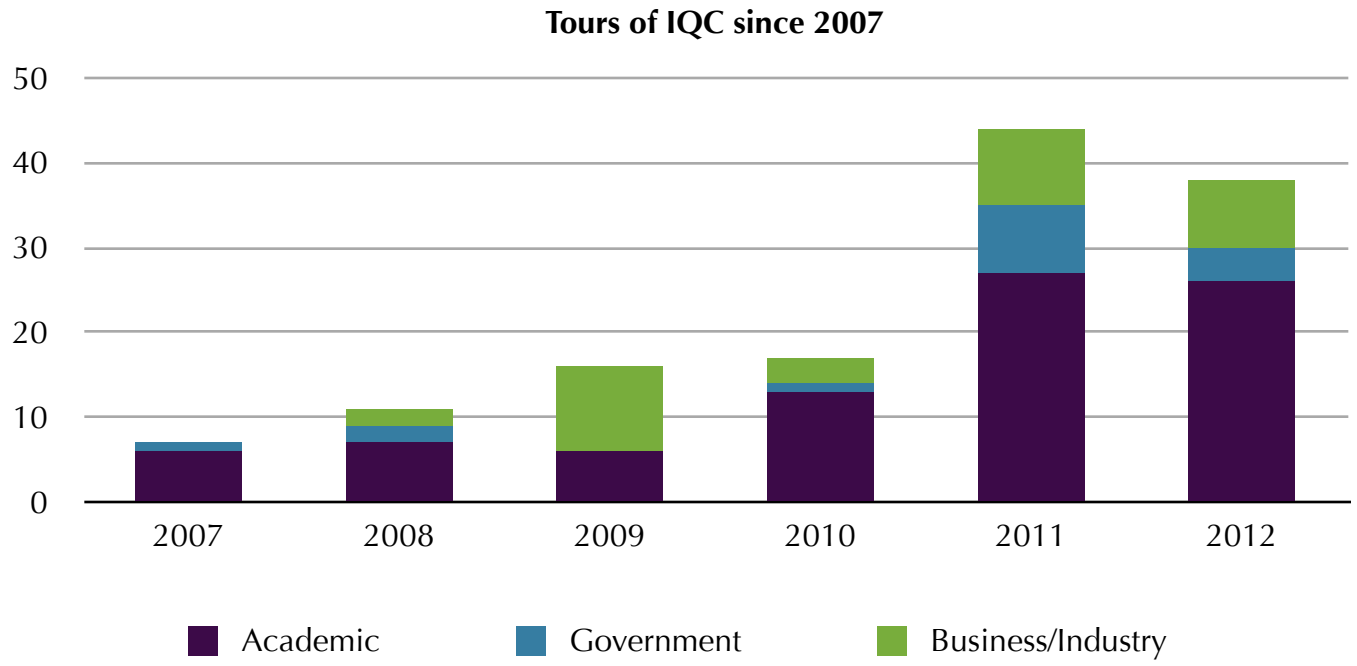
TEDxWaterloo
www.tedxwaterloo.com
March 21, 2012

Business & Education Partnership: Science Superheroes
www.bus-edpartnership.org
The program is designed to help instill the excitement of discovery and invention in today's youth and to increase enrollments in science, technology, engineering and mathematics programs by sharing the real-life stories of our own "science superheroes."

Business & Education Partnership: ZOOM Career Days
www.bus-edpartnership.org
This program is a series of one-day 'sector-specific' career exploration days for Specialist High Skills Major students and other interested senior high school students in Waterloo Region.

2.3.1.4 Tours of IQC Facilities

IQC offers tours of RAC I and RAC II at varying levels of technical complexity. Researchers at the institute help guide tours for high school students, government officials, industry of businesspeople and members of the community. Sharing quantum research with the society that will benefit from it is a central mandate of IQC, which is why the institute's doors are always open to those wishing to explore the quantum frontier.



Below find a breakdown and highlights from each of the categories of tour participants for the past three years. For a full list of tours see Appendix U.

Government Tours
In fiscal 2012, IQC hosted 4 government tours. Highlights include: Yaprak Baltacioglu (Deputy Minister at Transport Canada), and Sir Peter Gluckman (Science Advisor to the Prime Minister of New Zealand).

In fiscal 2011, IQC hosted 8 government tours. Highlights include: David C. Onley (Ontario Lieutenant Governor), Glen Murray (Minister of Research and Innovation), Jim Flaherty (Minister of Finance), Peter Braid (MP, Kitchener-Waterloo), Stephen Woodworth (MP, Kitchener Centre), Masuo Aizawa (Council for Science and Technology Policy Cabinet Office, Japan).

In fiscal 2010, IQC hosted 1 government tour.

Business/Industry Tours
In fiscal 2012, IQC hosted 8 tours for industry or businesspeople. Highlights include: Kevin Michaluk (Crackberry.com), Michael Kearney (IBM), and the iCanada Delegation.

In fiscal 2011, IQC hosted 9 tours for industry or businesspeople. Highlights include: Royal Bank of Canada (Ontario-based executives), Research in Motion, Moloney Electric Inc., Lockheed Martin Aeronautics Company, Michael Goodkin (Capital Investor).

In fiscal 2010, IQC hosted 3 tours for industry or businesspeople.

Academic Tours

Academic tours are perhaps the most popular tour that comes to IQC. These tours, typically for high school classes or undergraduate students, can be for anywhere from five to 30 or 40 students at once.

In fiscal 2012, IQC hosted 26 academic tours. Highlights include: Freeman Dyson (Institute for Advanced Study), Einstein Plus Teachers (PI Program), Laurentian University/Science North program.

In fiscal 2011, IQC hosted 27 academic tours. Highlights include: Gerald Sussman and the University of Waterloo Computer Science Club, University of Waterloo Physics Alumni, Senior science students from Uxbridge Secondary School, Perimeter Scholars International, Wilfrid Laurier Physics and Computer Science students.

In fiscal 2010, IQC hosted 13 academic tours.

"On behalf of the first-year physics and photonics students, I must say that we were thoroughly impressed and tremendously enjoyed the visit. Many of the tour participants commented on the excellent guided tour. Special thanks to Martin [Laforest] for his unique way of explaining the beauty of IQC and the impressive laboratories with state-of-the-art equipment and cutting-edge research."

Prof. Hasan Shodiev
Lab Coordinator, Departments of Physics and Computer Science
Wilfrid Laurier University

2.3.1.5 Invited Talks

IQC faculty and research assistant professors presented a total of 109 times during the 2011 calendar year. Of these, 57 were in Canada and 52 were at international events or organizations.

For a full list of invited talks see Appendix N.

2.3.2 Communications and Outreach

Communications and outreach have been central to IQC's mission since the inception of the institute. In IQC's initial stages, these efforts were largely focused on establishing the institute's presence in the scientific community, through newsletters, conferences, workshops and more. The institute also reaches out to the broader public through open houses, public lectures and the media, to convey the importance to quantum science to the people who will ultimately benefit from its discoveries. The support provided by the Industry Canada grant allowed IQC to intensify these activities and develop a more robust, multi-layered communications and outreach program. Initiatives spearheaded by the Communications and Outreach team are guided by IQC's three strategic objectives — particularly the goal of establishing IQC as the world's authoritative source of insight and analysis on quantum information science. This involves many activities aimed at the full spectrum of IQC's audiences and stakeholders through multiple channels such as: website content, media relations, social media, video production, publications, events, conferences, tours and more.

Ultimately, communications and outreach activities aim to share IQC's story — world-class science, exceptional researchers and discoveries with important social applications — with everyone from fellow scientists and government leaders to the merely quantum-curious.

Objectives:

Fiscal 2012 Objectives:

- Develop a year-long plan of communications, outreach, events and other activities linked to IQC's 10th anniversary
- Hold an Open House in mid-2012 in partnership with the University of Waterloo main campus to celebrate IQC's move into the Mike & Ophelia Lazaridis Quantum-Nano Centre
- Continue and develop the research and creative work that will result in key messages per stakeholder group, consistent and compelling brand identity for IQC to help convey world-class science as broadly as possible
- Continue with website development to showcase IQC's scientific achievements and intensify the outreach activities

Highlighted Results from Fiscal 2012:

- Developed a plan to mark IQC's 10th anniversary including special outreach events, grand opening events, a community open house, and special communication materials
- Continued planning for the community open house, scheduled for September 29, 2012
- Continued to develop and refine key messages and brand identity for IQC communications that help to convey the world-class science as broadly as possible
- Continued to develop and improve the website with increased interactivity and usability

Fiscal 2011 Objectives:

- Assemble the full communications and outreach team by August 2010
- Lay IQC branding groundwork, including market research, focus groups, interviews/surveys with stakeholders — beginning summer 2010
- Complete website redesign to increase IQC's web presence, interactivity and outreach scope
- Develop key messages and themes for IQC communications
- Targeted outreach to highlight IQC's scientific strengths and attract researchers to the institute

- Planning for IQC's 10th anniversary and the expansion into the new Mike & Ophelia Lazaridis Quantum-Nano Centre

Highlighted Results from Fiscal 2011:

- The full communications and outreach team was in place by June 2010 — including the addition of the Associate Director, Communications and Outreach and Manager of Scientific Outreach
- Initial branding research and groundwork was completed; decision was made to postpone further branding work
- Website redesign project was completed at iqc.uwaterloo.ca in September 2010
- Initial key messages were drafted for specific stakeholder groups, a standard graphic identity was implemented for all IQC communications
- Initial planning for IQC's 10th Anniversary began

Fiscal 2010 Objectives:

- Communications to include building a team that will create a roadmap and budget for IQC key messages, tools and branding strategies
- IQC will engage in outreach activities that will help with recruitment of graduate students and postdoctoral fellows

Highlighted Results from Fiscal 2010:

- Expanded the communications and outreach team by adding two communications specialists
- Began work creating key messages, stories and a consistent look and feel for all IQC communications
- IQC attended or helped to organize 8 outreach events including Quantum to Cosmos, TEDxWaterloo and the University of Waterloo's Open House Day

This section includes IQC's key messages, information on IQC's publications and online resources (website, social media, video, etc), and highlights of prominent media coverage of IQC.

2.3.2.1 Key Messages

IQC communications materials are focused on four key messages:

1. IQC a leader in the quantum revolution internationally
2. IQC significantly contributes to Canada's high ranking in international science
3. IQC is sparking quantum curiosity and deepening understanding
4. IQC is developing the quantum-enabled workforce of the future
5. IQC is attracting and nurturing the scientific excellence that will turn breakthroughs into benefits for society

2.3.2.2 Publications

IQC's Communications and Outreach team produces as number of publications aimed at a variety of the institute's target audiences. The institute has produced two annual reports, both of which have been recognized with awards from the League of American Communications Professionals (LACP). Other publications — such as the semesterly IQC Newsletter and a variety of brochures and posters — are vital components of IQC's communications and outreach strategy.

Name	Publication Cycle
Annual Report	Yearly; 2011, 2012
"NewBit" Newsletter	Semesterly; January, May, September
IQC "one pager"	Yearly
Graduate Brochure/Poster	Yearly
USEQIP/QCSYS Brochure/Poster	Yearly
Industry Canada Annual Reports	Yearly; 2010, 2011, 2012

2.3.2.3 Stakeholder Relations

IQC is continually working to strengthen existing relationships — and develop fruitful new ones — with its full spectrum of stakeholders, from donors and industrial partners to governmental policy-makers and the general public. A government relations team was created in early 2012 to meet with representatives from the provincial and federal governments and keep quantum research at the forefront of policy planning. Donor relations initiatives strive to honour the visionary supporters whose generosity has enabled world-class research at IQC. As always, researchers at the institute continue to forge relationships within the academic/research world, as quantum information science is a truly collaborative field. The institute has continued to broaden its networks with other top research centres, and is developing new partnerships with India's Raman Research Institute and China's Tsinghua University. IQC is also building upon its strong connections within the University of Waterloo community, particularly in planning and executing the upcoming Grand Opening of the

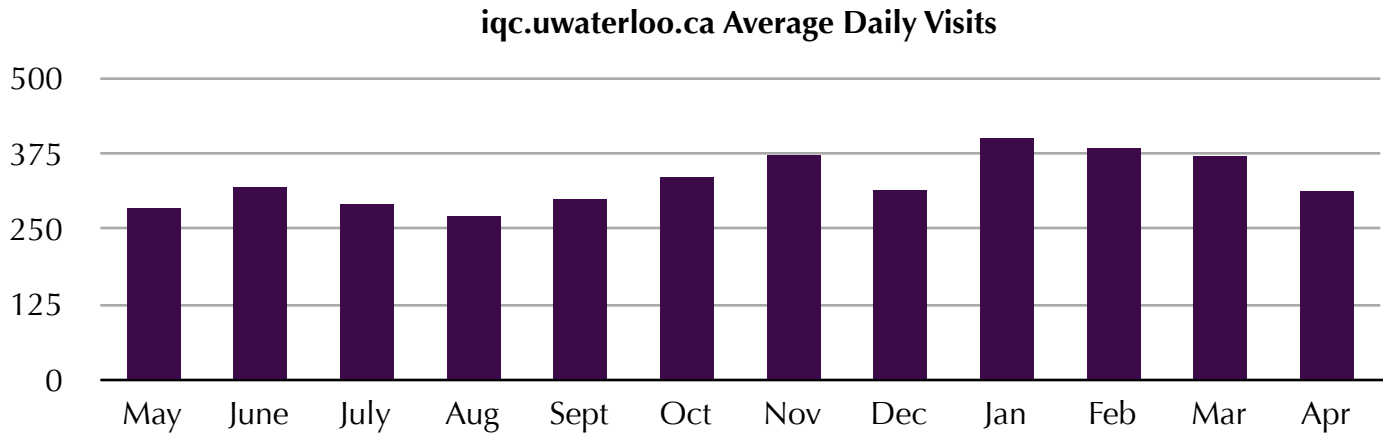
Mike & Ophelia Lazaridis Quantum-Nano Centre in the fall of 2012. Communicating quantum science with the general public remains a cornerstone objective of IQC, fueling a broad variety of activities encompassing outreach, media relations, social media, e-communications and more.

2.3.2.4 Website

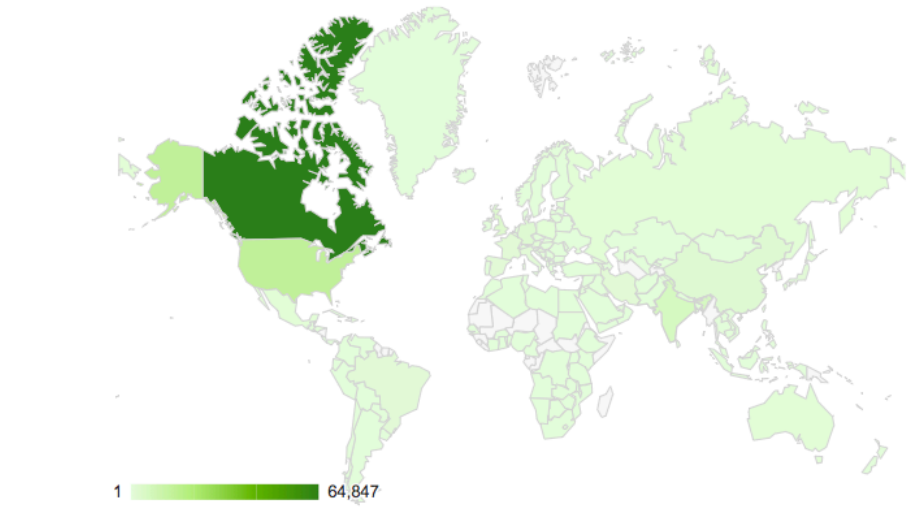
The IQC website is in many ways the outward face of the institute on a global scale. It is home to all of the information and resources relevant to all of IQC's target audiences — from prospective students and faculty to government and the general public.

IQC's website has changed substantially since 2007. Within the last two years, IQC has launched a new website platform and with a revamped look and new content. The website has enhanced interactivity, audience-specific features, expanded scientific information, and greater use of social media platforms. The website serves as a news source, recruiting tool, learning resource and a gateway to IQC social media.

In the next year and beyond, the communications and outreach team will continue to strengthen IQC's web presence to convey quantum information broadly and attract people to IQC. Plans include continuing to enhance interactivity, usability and content. Creating an expanded Quantum Library of publications, videos, commentary, analysis and more is high on IQC's web priority list. The institute will also continue to refine the presentation of its website as online styles and conventions evolve.



Below is a map from Google Analytics showing where the highest concentrations of visitors to IQC's website are located. Seventy countries/territories are shown to have at least one visitor coming to the site. Canada, the United States, China and India have the highest number of visitors respectively.



2.3.2.5 Social Media

Social media has become the dominant means for communicating in an increasingly online world. IQC has adapted its communications strategies in pace with the global shift from traditional news outlets to online and new media. The institute's social media channels such as Facebook and Twitter have seen an explosion in usage and popularity in the past several years. They are vital channels for communicating IQC's messages to its target audiences — particularly the young generation of researchers IQC seeks to recruit. The institute has produced more than 100 online videos which have been watched by more than 100,000 viewers. IQC uses social media not only to convey its messages, but to generate interest and spark conversation about quantum information science on a global scale.

YouTube Channel

IQC's YouTube channel hosts more than 100 scientific talks, distinguished lectures and interviews with world-leading scientists. It can be found at youtube.com/QuantumIQC. It is a vital component in achieving IQC's third strategic objective of becoming the authoritative source of insight, analysis and commentary on quantum information. It is a repository of expertise from dozens of top researchers, and is available free of charge to anyone around the world. As IQC's video library continues to grow, it will become even more widely known as a go-to source for information on quantum science. The channel has had 104,059 views to date with more every day.[8] The chart below shows the most popular videos on the QuantumIQC channel, which provides a reliable gauge of the topics of most interest to our target audiences. Such information helps to guide the direction of future video projects.

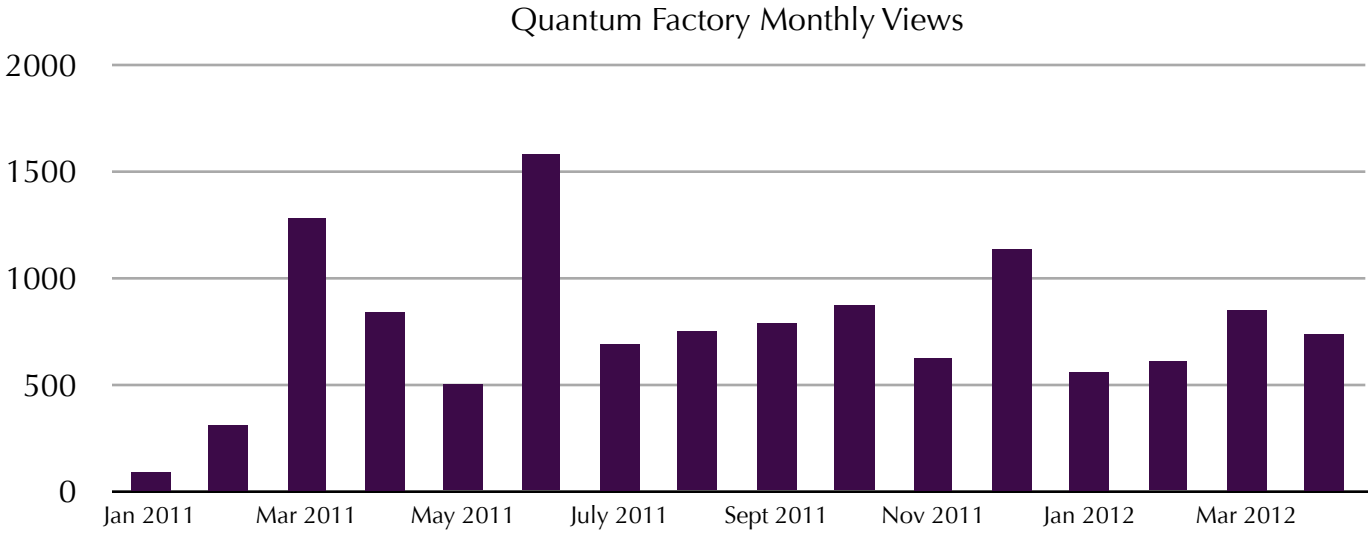
[8] As of April 1, 2012

Top 10 Videos & Views

Video	Views
The Quantum Mechanics of Time Travel	30,037
Quantum Computing 101	7,197
Intro to Quantum Computing - Michele Mosca USEQIP 2011	4,623
Born to Rule - Dr. Urbasi Sinha	4,289
Seth Lloyd on the Universe as a Quantum Computer	3,983
Quantum Physics & Harry Potter	3,976
Casimir Effects: Peter Milonni's lecture at the Institute for Quantum Computing	3,699
Quantum Computing Breakthrough: QIP=PSPACE	3,638
Introduction to the Institute for Quantum Computing	2,756
Quantum Key Distribution Animation	2,574

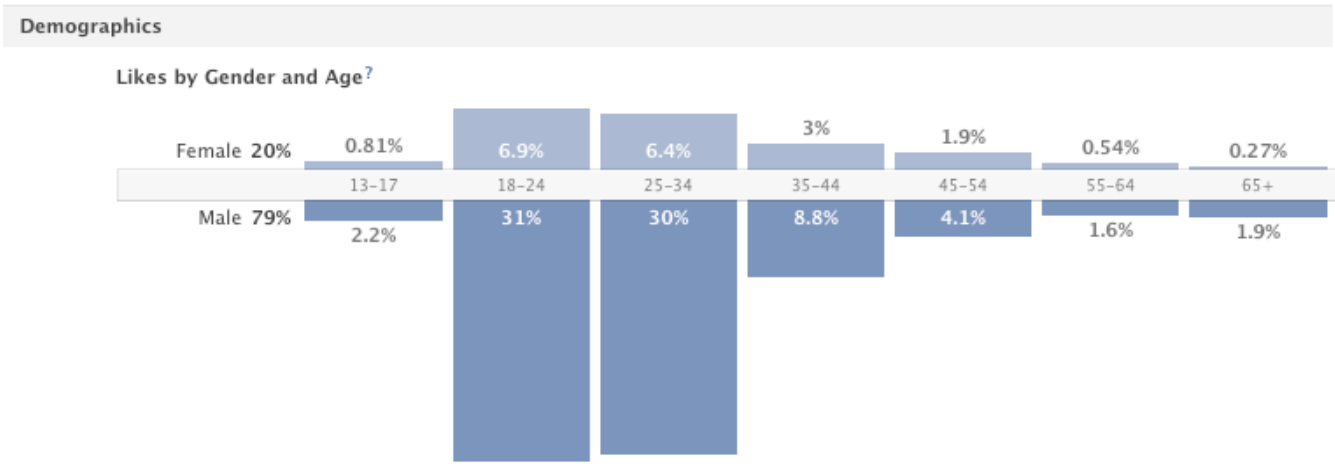
The Quantum Factory Blog
quantumfactory.wordpress.com

Launched January 2011, the Quantum Factory is a fun and informative blog spearheaded by IQC's communications and outreach team. Like other forms of social media, blogging has become a pervasive and legitimate alternative to traditional media. Blogs are intended to start conversations and engage readers in a form of online community. The QuantumFactory blog is home to a variety of diverse posts including video interviews, news articles, travelogues and a photo gallery of the new Mike & Ophelia Lazaridis Quantum-Nano Centre construction site. By April 2012, the blog had 12,443 all time views.



Facebook

Facebook is the world's most popular and widely used social media channel, and has become one of IQC's primary means of spreading news and views about the institute. IQC's Facebook group page can be found at facebook.com/QuantumIQC. Currently, 809 people "like" IQC's Facebook page. The chart below demonstrates that IQC's Facebook page is most effective at reaching the 18-34 demographic, which is a key target audience for the institute's recruitment and outreach efforts.



Twitter

IQC's social media strategy is enhanced by the use of Twitter, which allows instantaneous and interactive communication and online conversation. IQC's Twitter account has seen a drastic increase in followers over the past year and has directly resulted in media coverage, event attendance and other measurable successes. The account can be found at @QuantumIQC.

Year	Twitter Followers
2010	195
2011	649
2012	1,747

IQC's other social media avenues include LinkedIN (which connects IQC members with each other and the broader quantum science community), Picasa and FlickR (which increase the scope and visibility of IQC events, people and facilities through freely accessible photo galleries).

2.3.2.6 Outreach & Community Events

IQC is committed to conducting outreach activities aimed at all its target audiences, from the lay public to prospective students and potential faculty members. Such activities are integral to establishing IQC as the authoritative source for insight and expertise on the field of quantum information, and in attracting the world's best researchers to the institute. These events and activities are spearheaded by the institute's Communications and Outreach team. Members of this team have travelled the globe in targeted and strategic efforts to share IQC's research with the world — and to bring the world to IQC.

Representatives from IQC attend the Annual Meeting of the American Association for the Advancement of Science (AAAS) — the largest scientific gathering in the world with 12,500 participants in 2012. This event is an opportunity for IQC to meet with many key science journalists from Canada and around the world. In 2012, IQC faculty members including Raymond Laflamme, David Cory and Thomas Jennewein participated in panel discussions with international colleagues. Thousands of people visited the IQC booth in the AAAS exhibition hall, where IQC members talked with dozens of media representatives, fellow scientists and the interested public. The IQC booth was also part of “Family Science Day” one of the most well-attended events of the conference. IQC’s participation in the 2012 AAAS Annual Meeting resulted in immediate high-profile media coverage in outlets including The Economist, Space.com, ABC Australia, Physics World and more.

As well, representatives from IQC attended the 2011 World Conference of Science Journalists in Doha, Qatar. Raymond Laflamme delivered a talk at the event, which resulted in media attention and connections with journalists and fellow scientists worldwide. IQC's Manager of Scientific Outreach, Dr. Martin Laforest, frequently travels to graduate fairs and other recruitment-focused events. In 2010, Laforest participated in the PhD Workshop China at the prominent Beijing Normal University, and spoke at several Chinese institutions.

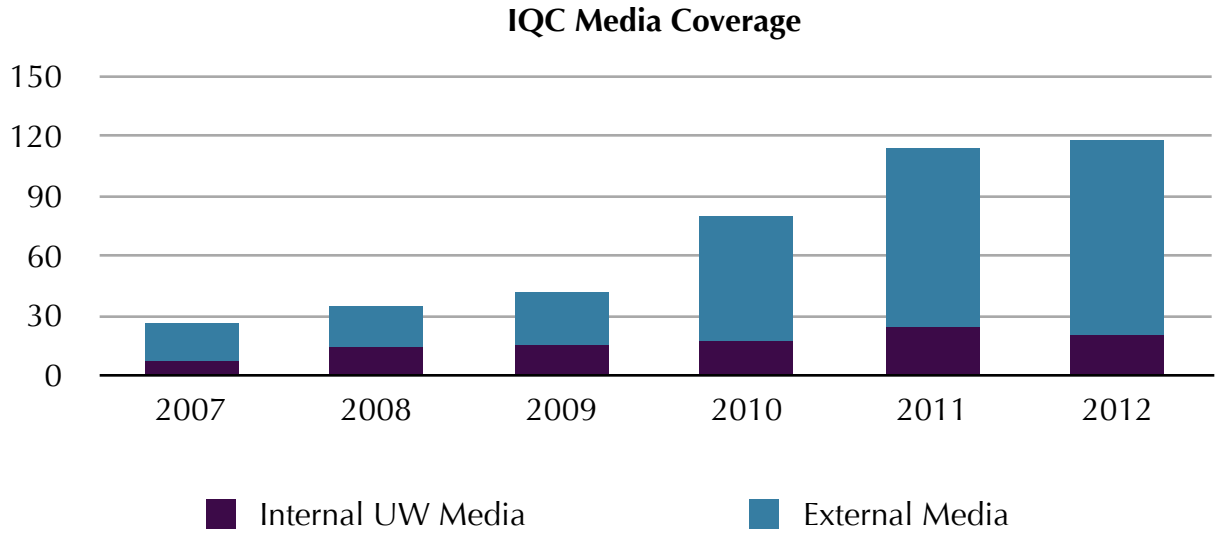
IQC also spearheads outreach activities in Waterloo. The Quantum Frontiers Distinguished Lecture Series features talks by visiting scientists who are working at the nexus of quantum information and nanotechnology. Held roughly once per term, these talks are recorded in their entirety and posted on IQC's YouTube channel, where they have been viewed by thousands. IQC researchers have delivered public lectures at a variety of other venues, such as the Royal Canadian Institute (Joseph Emerson), the Perimeter Institute (David Cory, Raymond Laflamme, Michele Mosca and Joseph Emerson), the Canadian Undergraduate Mathematics Conference (Michele Mosca) and elsewhere.

IQC is also committed to outreach activities aimed at inspiring and informing the general public about the power of quantum science. The institute hosts regular tours and open houses for the public and school groups. IQC participated in the Cirque de Science event in 2011, which saw 250 young students try hands-on demonstrations of quantum science. In an event that bridged science and the arts, IQC teamed up with the Kitchener-Waterloo Symphony for "Quantum: Music at the Frontier of Science" — two sold-out and well-received concerts held in February 2012. Additionally, IQC faculty members Raymond Laflamme and Joseph Emerson were scientific advisors for the award-winning documentary *The Quantum Tamers: Revealing Our Weird & Wired Future,* produced by Perimeter Institute in 2009. IQC has also participated in all three installments of TEDxWaterloo — Raymond Laflamme was a featured speaker at the inaugural event in 2010 — as well as the popular Quantum to Cosmos Festival hosted by Perimeter Institute. Building a strong and respected public profile — both locally and among the international scientific community — remains a vital aspect of IQC's communications and outreach strategy.

2.3.2.7 Media Coverage

IQC has received increasing coverage from national and international media outlets — print, online and broadcast — in recent years. Such coverage re-inforces IQC's status as a leader in quantum information science and an authoritative source of insight, commentary and analysis on the field. Some notable coverage in recent years has included:

- The Economist, several articles about quantum computing, February 2012
- ABC Australia Online "Quantum Security Looks Beyond the Skies," February 2012
- Al Jazeera News, "The best information is Quantum Information," by IQC faculty member Joseph Emerson, Feb. 2012
- The Guardian UK "Stephen Hawking at 70," featuring Raymond Laflamme, January 2012
- BBC News, "Quantum Computing could head to the 'cloud', Feb. 2012
- New York Times, "Billions of Entangled Particles Advance Quantum Computing," January 2011
- BBC Documentary "Codebreakers," featuring IQC Deputy Director Michele Mosca, October 2011
- CBC.ca, "Waterloo Institute seeks to Unlock Secrets of Subatomic World," February 2009
- Nature, "Quantum Potential," November 2009
- Nature News and Views, "A shift in spectroscopy by Frank Wilhelm" September 2008
- CBC.ca, "Quantum Computing," April 2007



"IQC will place Waterloo at the forefront of a new frontier of knowledge."

Governor General of Canada, David Johnston
Former President, University of Waterloo

"The drive that moves researchers here is to develop this beautiful vision of bringing quantum into our daily lives."

Tommaso Calarco
University of Ulm, Germany

2.4 Administrative Support

A full administrative team is necessitated by the ever-growing number of researchers and students at IQC. The institute plans to continue its growth to reach 30 faculty, 50 postdoctoral fellows and 125 graduate students within the next few years. The following section of this report reviews IQC's laboratory teams, the communications and outreach mandate, the information technology team and the administrative team functions.

Objectives:

Fiscal 2012 Objectives:

- Plan for the expansion into the Mike & Ophelia Lazaridis Quantum Nano Centre, including the commissioning of the labs (scheduled for early 2012), facilities and equipment
- Implement in the fall semester an information management repository that provides intuitive retrieval and administration of the institute's business, including practices and procedures, financial reports, metrics, governance framework (e.g. committee terms of reference), and other information that facilitates the successful operation of the institute
- Implement software for the fabrication facility (cleanroom) during the winter semester to provide for equipment scheduling (including assurance that users are trained), billing to end-users and maintenance planning
- Establish a funding mechanism for the ongoing operating costs (utilities and maintenance) for the QNC prior to the winter semester
- Develop a stakeholder relations plan

Highlighted Results from Fiscal 2012:

- Designed and delivered the foundational elements of the information management repository including enhancements to the visitor tracking system, improved publication tracking, an enhanced members directory, a new grant management system and extended the "HUB" file sharing system
- Provided ongoing support for the operation of the of qncfab.uwaterloo.ca website, implemented a solution for isolating the cleanroom tool equipment systems from software virus contamination, integrated existing booking data into a invoicing system for the cost recovery of the NanoFab operations
- The mechanism for ongoing operating costs (utilities and maintenance) of the QNC prior to the winter semester did not occur because construction on the building was delayed
- Expansion into the Mike & Ophelia Lazaridis Quantum Nano Centre was deferred due to construction delays
- An effort to build, grow and rationalize stakeholder relations on all fronts is currently underway — see section 2.3.2.3 for more on IQC's stakeholder relations

Fiscal 2011 Objectives:

- Documenting and standardizing processes, jobs and back-ups in a rapidly expanding institute
- Establishing a grant life cycle process for standardizing and tracking sources of funding
- Developing desktop and other software/hardware tools and techniques
- Developing tools and processes for a new website

Highlighted Results from Fiscal 2011:

- Terms of reference have been developed for each of IQC's committees including researcher recruitment, the graduate program, scholarly visitor and colloquium committees — the terms of reference highlight the mandate, roles and responsibilities, process and reporting for each committee
- Practices and procedures related to internal controls for financial transactions have been documented
- Job descriptions have been rewritten, job procedures written and cross-training has taken place for administrative roles. The institute prepared its first budget and is now reporting actuals relative to this benchmark
- The admin team was trained to help researchers with grants including: finding the grant opportunity, applying for the grant, reporting and managing budget
- Documentation includes clearly defined roles and responsibilities between faculty and staff, background information for use when preparing grants and standard templates for reporting
- The institute moved its desktop and BlackBerry email service to the central campus "Connect" services
- An antivirus protocol for the fabrication facility in RAC1 was implemented
- To improve the effectiveness of technology support within the Operations Team, a common desktop platform was implemented
- Instant messaging, common file sharing and centralized backup were all implemented
- The technology support for the institute's new website includes new internally developed software to aid in the recruitment of faculty and post doctorate fellows. Also, new software was developed to record and communicate visiting scholars

Fiscal 2010 Objectives:

- Document funding requirements for completion of the building, to equip the facility and support IQC's strategic objectives
- Prepare a 10-year financial plan circuit

2.4.1 IQC Laboratories

A team of specialized staff works in the facilities and research labs at the institute. This group builds and operates the world-class Quantum NanoFabrication facility, for the combined benefit of the University of Waterloo's stakeholders, researchers and collaborators. The group maintains infrastructure and ensures that key lab equipment performs optimally and consistently. Technical laboratory support is critical to the ongoing continuity of experimental research at the institute and to fulfill its strategic objectives — in particular the first objective of performing world-class research. The team includes: Director of Operations, Quantum NanoFab; NMR Facility Manager; Lab Instructor, Senior Fabrication Equipment Technologist; Senior Equipment Technologist; NanoFabrication Process Engineer; Laboratory Technician; Electronics and Instrumentation Technologist.

2.4.2 Communications and Outreach

IQC understands that great science should not and cannot happen in isolation. It is vital to share the results and discoveries of IQC's research with the scientific community, with the governments that support it, and with the public that will benefit from it. IQC's Communication and Outreach team

plays a crucial role in developing the international reputation of the institute by showcasing its researchers and their work. This is done through a strategy that includes publications, media relations, the IQC website, government relations, events and conferences, e-communications and social media, video production and more. Such activities raise IQC's visibility and international renown, aiding in the recruitment of top faculty, postdoctoral fellows, students and visiting researchers. IQC's Communications and Outreach team includes: Associate Director, Communications & Outreach; Manager, Scientific Outreach; Senior Communications Officer, Media & Writing; Communications Officer, Publications and e-Communications; Web and e-Communications Officer; and Coordinator of Events, Outreach and Communication.

2.4.3 Information Technology

Information technology is integral to IQC's success and its support ranges from enabling administrative functions to supporting scientific research and online outreach. IQC's information technology strategy encompasses infrastructure, information/transaction management and stakeholder support. An information management repository provides intuitive retrieval and administration of the institute's business, including practices and procedures, financial reports, performance indicators, governance framework (eg. committee terms of reference), and other information that facilitates the successful operation of the institute.) IQC's Information Technology team includes a Manager, Information Technology and a Client Support Specialist.

2.4.4 Finance and Administration

The fundamental function of IQC's administrative team is to provide IQC researchers and students with the professional support needed to pursue leading-edge research in quantum information. They work collaboratively with University of Waterloo's central finance administration office and the many departments throughout campus. IQC's current 11-member Finance and Administration team is made up of the following roles: Assistant Director, Administration; Financial Officer; Administrative Officer; Visitor Coordinator; Graduate Program Coordinator and Recruitment Assistant; Administrative Coordinator/Financial Assistant; Administrative Assistants (2); Administrative Assistant / Reception; and Administrative Support.

3. Objectives for Fiscal 2013

3.1 Conducting Research in Quantum Information

The research at IQC will produce new knowledge that will lead to publications and presentations at conferences. This knowledge will include a better understanding of quantum information processors and laboratory demonstrations of their control, and the development of technologies based on these processors. Ultimately it will lead to new technologies and applications.

Objectives for 2013:

- Continue leading-edge investigation of theoretical approaches to quantum information processing in order to better understand the impact of quantum mechanics for information processing and to investigate new potential applications
- Continue developing approaches to quantum information using photonic, nuclear and electron spins, quantum dots, superconducting technologies and proceed with studying the requirements needed to design earth-to-satellite quantum cryptography systems

3.2 Recruiting Researchers

Assembling a critical mass of theoretical and experimental researchers, exploring a broad range of approaches to quantum information processing, will establish IQC at the forefront of the field. The ongoing recruitment of top-tier faculty to IQC will further enhance the institute's fundamental objective of pursuing quantum information research at the highest international level. This, in turn, will fuel the institute's objectives of being a magnet for top students and being the authoritative source for information and analysis on the field. Fulfilling all these objectives will put IQC, and therefore Canada, at the forefront of the international pursuit of quantum information technologies.

Objectives for 2013:

- Recruit up to five new faculty members
- Recruit up to one new research assistant professors
- Recruit up to 15 new postdoctoral fellows
- Continue to leverage IQC's 10th anniversary celebrations, conferences and other outreach forums as recruitment opportunities

The chart above illustrates the areas of research that IQC will focus its attention for future faculty hiring. Of course, if an outstanding opportunity arises that falls outside the precise scope below, IQC will act to take advantage of it.

3.3 Collaborating with Other Researchers

Strategic collaborations with key researchers from across disciplines will enhance IQC's international reputation, draw highly qualified personnel to IQC, and increase the probability of experimental and theoretical breakthroughs. By fostering such collaboration, IQC will continue to build its reputation as a world-class centre for research and development of quantum information technologies.

Objectives for 2013:

- Be a catalyst for collaborations of quantum information scientists though networks such as the Canadian Institute for Advanced Research (CIFAR) Quantum Information program and the Natural Sciences and Engineering Research Council of Canada (NSERC) Strategic Networks
- Promote collaborations through participation in national and international conferences
- Produce internationally recognized, high-calibre publications co-authored by IQC researchers
- Organize at least four conferences that involve multi-disciplinary participants
- Continue, enhance and increase visits to IQC by international scientists and academics from around the world

3.4 Building, Facilities and Laboratory Support

This activity will result in the Mike & Ophelia Lazaridis Quantum-Nano Centre building being completed and operational on schedule. Additionally, the RAC I & II laboratories will be operational and fully functional.

Objectives for 2013:

- Migrate some of IQC's researchers, labs and staff into the Mike & Ophelia Lazaridis Quantum-Nano Centre before the September 2012 grand opening
- Host a ribbon cutting ceremony in September 2012 to mark the grand opening of the building
- Commence the QNC NanoFab fit-out in October 2012. Including: the installation of the multiple services required by the ensemble of lab equipment purchased to date as well as equipment which is on order. These services include the high purity water loop, acid waste neutralization system, high purity process gas lines, process chilled water lines, exhaust drops from the main ducts, compressed air & nitrogen lines, as well as power panels and equipment disconnects. Fit out is expected to take from three to five months to complete.

3.5 Attracting, Educating and Training Highly Qualified Personnel

Student targeted outreach will lead to an increased number of applications to the graduate studies program, providing a larger pool of prospective applicants from which IQC can recruit the best. Training students in quantum information research is vital since they will be the decision makers in 10 to 15 years when quantum information devices become more widespread. IQC prides itself in ensuring that students have the right knowledge to make wise decisions in the future.

Objectives for 2013:

- Attend at least four graduate fairs to connect with prospective students
- Field at least 200 applications to the uWaterloo/IQC graduate studies program
- Expand connections made with undergraduate programs at Ontario and Canadian universities
- Take part in at least two international outreach or recruitment events

3.6 Disseminating Knowledge

The increase in outreach and knowledge dissemination will help to achieve the strategic objective of establishing IQC as the authoritative source of information, analysis and commentary on quantum information. It will also help to promote IQC and Canada as a world-class centre of research in quantum technologies and their applications.

Objectives for 2013:

- Plan and manage the events related to the 10th anniversary and grand opening celebrations of the Mike & Ophelia Lazaridis Quantum-Nano Centre
- Increase interest in camps, workshops, conferences and programs through targeted marketing and increase the scale of the events with technology
- Reflect IQC's outreach priorities and programs on the web
- Host at least four conferences with three distinct target audiences
- Increase external media coverage, especially international media coverage

3.7 Communications and Outreach Strategy

The year-long plan for events and activities linked to the 10th anniversary as an institute will ramp up IQC's profile and support its three strategic objectives. Branding work should help to showcase the world-leading science as broadly as possible. Continued work with the website should allow for world-class presentation of key scientific information that will build and reinforce IQC's identity as the authoritative source of insight, analysis and commentary on quantum information around the world. The branding project will be founded on the strategic aspirations of IQC with the recognition that IQC is part of a global community who share many of the same goals.

Objectives

- Plan and manage the events related to the 10th anniversary and grand opening celebrations of the Mike & Ophelia Lazaridis Quantum-Nano Centre
- Hold an Open House in September 2012 in partnership with the University of Waterloo's main campus and the Waterloo Institute for Nanotechnology to mark IQC's expansion into the Mike & Ophelia Lazaridis Quantum-Nano Centre
- Continue and develop the research and creative work that will result in key messages per stakeholder group, consistent and compelling brand identity for IQC to help convey world-class science as broadly as possible
- Continue with website development to showcase IQC's scientific achievements and intensify the outreach activities
- Continue with government and stakeholder relations

3.8 Administrative Support

A seamless transition to the QNC and the related commissioning of equipment will minimize research disruptions. An information management repository will provide an effective resource to access research and business information of the institute including governance, practices and procedures, and providing ready access to management information and performance metrics. Software support for the operations of the fabrication facility will streamline workflows and aid in providing for higher quality assurance on equipment. A stakeholder development plan will be prepared with a view to ensuring the institute's main stakeholders are kept informed of our mission, strategic objectives and our accomplishments.

Objectives for 2013:

- Execute the expansion into the Mike & Ophelia Lazaridis Quantum Nano Centre, including the commissioning of the labs, facilities and equipment
- Participate in the fit-out of the new QNC facility including specifying the furniture; co-ordinating with central campus IT teams on the fit-out of networking and audio/visual infrastructure; migration of the IQC computing infrastructure to the new facility; plan (and execute) of the physical move of individual computing equipment of designated members; deliver a system solution to manage the scheduling of research meeting spaces for IQC in QNC

4. Risk Assessment & Mitigation Strategies

Impact	Likelihood: Low	Likelihood: Med	Likelihood: High
High	6	8	9
Med	3	5	7
Low	1	2	4

Risk Factor	Impact Score	Likelihood Score	Risk Rating	Explanation of Score	Mitigation Measures
1) IQC may not be able to attract high quality researchers	High	Medium	8	The market for world-class researchers is highly competitive, and IQC is still building brand awareness. However, researchers are the cornerstone on which institutional reputation is built	•Pursue recruits from a wide breadth of areas of research •Offer competitive job offers/package. •Adequately promote the world class researchers and the cutting-edge facilities/ equipment at IQC
2) Key staff may defect from IQC	High	Medium	8	IQC's research and recruitment efforts are largely the responsibility of a few key individuals. These individuals would be difficult to replace	•Diversify the nature of staff members' work •Provide a challenging work environment •Ensure adequate technical and administrative support •Ensure world-class facilities and equipment •Provide a stimulating environment •Provide attractive benefits and employee/spousal programs.

Risk Factor	Impact Score	Likelihood Score	Risk Rating	Explanation of Score	Mitigation Measures
3) Transformational technologies may render current research less relevant	High	Low	6	If IQC research is rendered less relevant, HQP and data seekers will go elsewhere	•Ensure a wide breadth of research to investigate (this would differentiate IQC from its competitors) •Continue applications for research funds to support leading edge equipment
4) Graduate program may not be approved or may suffer delays	Medium	Low	3	Delays may hinder IQC's recruitment efforts	•Ensure high-quality graduate program application
5) IQC may not be able to recruit enough HQPs	High	Low	6	Many international HQP come from potentially politically unstable countries (top three are Iran, China, India)	•Promote IQC sufficiently •Ensure excellent research •Diversify markets/ countries from which students are recruited
6) Lack of financial information (regarding endowment) impedes long-term planning	High	Low	6	Sustainability/ source of funds (other than IC) is largely unknown	•Prepare a 10-year financial plan for ongoing operations
7) Operating constraints limit IQC's efforts to brand itself	High	Low	6	Operating constraints include limited resources (including staff), degree of flexibility	•Recruit the right people/talent/skills •Develop and deliver a branding project plan •Foster close working relationships with appropriate units within the university
8) Construction costs may exceed budget	Low	Medium	2	The IC grant amount is fixed. University has committed to compensate for shortfall.	N/A

Risk Factor	Impact Score	Likelihood Score	Risk Rating	Explanation of Score	Mitigation Measures
9) Construction schedule may be delayed	Medium	Low	3	Outcomes would be delayed, but not changed	N/A

Appendix

A. Industry Canada Grant Agreement
B. Industry Canada Page Reference Guide
C. IQC Members: Fiscal 2012
D. Governance
E. IQC Executive Committee Biographies
F. IQC Board of Directors Biographies
G. Scientific Advisory Committee Biographies
H. Financial Supporters
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J. Publications
K. Collaborations
L. Scientific Visitors
M. Conferences
N. Invited Talks
O. Times Higher Education Rankings 2012
P. Commentary & Analysis
Q. Outreach Activities
R. News Releases and Web Updates
S. Media Coverage
T. YouTube Video Library
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A. Industry Canada Grant Agreement

This report focuses on two main evaluation issues (consistent with the new Treasury Board Policy on Evaluation effective April 1, 2009): relevance and performance. Within these two categories, the evaluation will consider:

- Appropriateness and effectiveness of the design and delivery of the research conducted by IQC
- Results achieved to date:
  - Outputs and immediate outcomes
  - Intermediate outcomes, such as the establishment of a world-class facility for QI (quantum information) research and training

According to the Grant Agreement, the University of Waterloo's Board of Governors must approve IQC's annual report to Industry Canada.

IQC's annual report will include:

1. A statement of the institute's objectives for that year and a statement on the extent to which the institute met those objectives
2. A list of activities undertaken with the grant
3. A statement of the institute's objectives for the next year and the foreseeable future
4. A description of the proposed activities for the next year to be undertaken within the context of this agreement, and a description of how the institute intends to implement them
5. A proposed schedule for the implementation of the activities for the next year
6. The anticipated results of those activities
7. Results achieved in the past year in accordance with a performance measurement strategy developed by Industry Canada
8. Risk assessment and mitigation strategies and ongoing performance monitoring strategies

The five-year grant from Industry Canada will enable the establishment of a new world-class research facility, which will support the government's science and technology strategy aimed at building a strong Canadian economy via knowledge and innovation. In the long-term, Industry Canada expects four key outcomes as a result of this grant:

1. Increased knowledge in quantum information
2. New opportunities for students to learn and apply new knowledge
3. Canada branded as a place to conduct research in quantum technologies
4. Canada positioned to take advantage of economic and social benefits of research

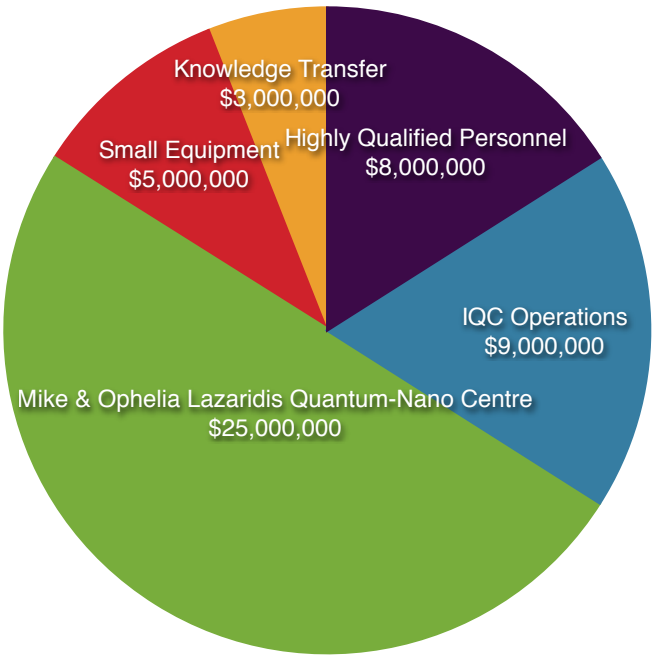
This chart illustrates the distribution of Industry Canada funds over five years:

Fiscal Year	Funding Amount ($ in Millions)
2010	$16.5
2011	$17.0
2012	$5.0
2013	$5.5
2014	$6.0
Total	$50.0

With the aim of supporting IQC in its pursuit of these expected results, Industry Canada has allotted $25 million over two years to the construction of the new Mike & Ophelia Lazaridis Quantum-Nano Centre, $5 million over five years for the purchase of small equipment and $20 million over five years to the following four activities:

1. Recruiting and retaining highly qualified personnel
2. Transferring knowledge
3. Supporting administrative and technical staff members
4. Purchasing materials and supplies (other than small equipment)

Industry Canada Funding Alottment



B. Industry Canada Page Reference Guide

Section	Metric	Page #
Future Objectives	Conducting research in quantum information	92
	Recruiting new researchers	92
	Collaborating with other researchers	92
	Building, facility and laboratory support	93
	Attracting, educating and training highly qualified personnel	93
	Disseminating scientific knowledge	94
	Communications and outreach	94
	Administrative support	95
Past Objectives	Conducting research in quantum information	12
	Recruiting new researchers	37
	Collaborating with other researchers	43
	Building, facility and laboratory support	52
	Attracting, educating and training highly qualified personnel	58
	Disseminating scientific knowledge	73
	Communications and outreach	80
	Administrative support	89
Results		
Activity 1: Building facility and equipment	Per cent of construction that is complete	57
	Per cent of equipment is in place/labs finished	57
	Degree to which construction is on budget	57
	Degree to which construction is on schedule	52
	Number of jobs created (construction)	57
	Number of requests to visit the facility	78

Section	Metric	Page #
Activity 2: Collaborating with Other Researchers	Number of new grants	35
	Number of collaborations (between two or more researchers)	44
	Type of collaborations	44
	Number of collaborators	44
	Number of citations	33
	Number of peer reviewed publications	31
	Number of spinoffs, disclosures, patents, etc.	50
	MOUs with other universities or organizations	46
	Number of faculty awards	35
	$ investment by government and industry	35
Activity 3: Recruiting Researchers/Conducting Research in QI	Number of citations	33
	Number of peer reviewed publications	31
	Number of spinoffs, disclosures, patents, etc.	50
Activity 4: Attracting, Educating and Training HQPs	Number and type of new courses and labs	64
	Documented establishment of graduate program	63
	Type of practical opportunities for graduates	67
	Number of scholarships/fellowships/awards received by IQC HQP	71
	Per cent of graduates working in the QI field in Canada	67
	Number of books/chapters authored by IQC researchers	31
	Per cent of IQC HQPs from top undergraduate/graduate schools (as ranked by the FT)	68
	Per cent of IQC HQPs with high GPAs	69

Section	Metric	Page #
	Number of domestic/international HQPs at IQC/jobs created	42
Activity 5: Disseminating Knowledge	Number of workshops held	75
	Number of visitors to IQC	48
	Number of presentations at conferences made by IQC HQP	79
	Number of applications to IQC (faculty and postdocs)	60
	Number of visits to the IQC website	83
	Type of content on the IQC website	83
	Number and type of outreach activities (including number of participants)	87
	Number of press releases by/articles written on IQC	88
	Number and type of researchers at IQC	41
Activity 6: Communications and Outreach Strategy	Documented communications/branding plan, roadmap	73
	Number and type of outreach activities (including number of participants)	87
Risks	Situational assessment	96
	Mitigation strategies	96
	Ongoing performance monitoring strategies	96

C. IQC Members: Fiscal 2012

Faculty

1. Jonathan Baugh
2. Andrew Childs
3. Richard Cleve
4. David Cory
5. Joseph Emerson
6. Thomas Jennewien
7. Raymond Laflamme
8. Debbie Leung
9. Adrian Lupascu
10. Norbert Lütkenhaus
11. Hamed Majedi
12. Michele Mosca
13. Ashwin Nayak
14. Ben Reichardt (resigned December 2011)
15. Kevin Resch
16. John Watrous
17. Frank Wilhelm

Research Assistant Professors

1. Radu Ionicioiu
2. Vadim Makarov
3. Guo-Xing Miao
4. Marco Piani
5. Dmitry Pushin

Postdoctoral Fellows

1. Gorgan Alagic
2. Mohammad Ansari
3. Mustafa Bal
4. Olaf Benningshof
5. Dominic Berry
6. Anne Broadbent
7. Jianxin Chen
8. Lin Chen
9. Chris Erven
10. Motohisa Fukuda
11. Silvano Garnerone
12. Oleg Gittsovich
13. David Gosset
14. Patryk Gumann
15. Gus Gutoski
16. Brendon Higgins
17. Rolf Horn
18. Tsuyoshi Ito
19. Zhengfeng Ji
20. Piotr Kolenderski
21. Eduardo Martin-Martinez
22. William Matthews
23. Seth Merkel
24. Rajat Mittal
25. Hamid Mohebbi
26. Osama Moussa
27. Mustafa Muhammad
28. Florian Ong
29. Robert Prevedel
30. Emily Pritchett
31. Robabeh Rahimi Darabad
32. Aiden Roy
33. Krister Shalm
34. Urbasi Sinha
35. Yipu Song
36. Jon Tyson
37. Nathan Wiebe
38. Zizhong Yan
39. Bei Zeng
40. Jingfu Zhang

Graduate Students

1. Jean-Philippe Bourgoin
2. Alessandro Cosentino
3. Daniel Criger
4. Pierre-Luc Dallaire-Demers
5. Chunqing Deng
6. Amin Eftekharian
7. Chris Erven
8. Agnes Ferenczi
9. Chris Ferrie
10. MirMotjaba Gharibi
11. Sevag Gharibian
12. Peter Groszkowski
13. Deny Hamel
14. Tyler Holden
15. Stacey Jeffery
16. Mohsen Keshavarz
17. Botan Khani
18. Milad Khoshnegar Shahrestani
19. Nathan Killoran
20. Robin Kothari
21. Jonathan Lavoie
22. Nicholas LeCompte
23. Easwar Magesan
24. Laura Mancinska
25. Iman Marvian
26. Thomas McConkey
27. Evan Meyer-Scott
28. Hamid Mohebbi
29. Felix Motzoi
30. Varun Narasimhachar
31. Jean-Luc Orgiazzi
32. Yingkai Ouyang
33. Maris Ozols
34. Adam Paetznick
35. Gina Passante
36. David Pitkanen
37. Farzad Qassemi
38. Ansis Rosmanis
39. Amir Jafari Salim
40. Kurt Schreiter

41. Jamie Sikora
42. Jamie Smith
43. Gelo Noel Tabia
44. Cozmin Ududec
45. Sarvagya Upadhyay
46. Rui Xian
47. Razeih Annabestani
48. Kent Fisher
49. Luke Govia
50. Christopher Granade
51. Nupur Gupta
52. Fatin Haque
53. Catherine Holloway
54. Tomas Jochym-O'Connor
55. Artem Kaznatcheev
56. Xian Ma
57. Sergei Mikheev
58. Abel Molina Prieto
59. Mohamad Niknam
60. Kyungdeock Park
61. Om Patange
62. Wenling Qiao
63. Nickolay Gigov
64. Yuval Sanders
65. Christopher Wood
66. Michael Mazurek
67. Grant Cleary
68. Victor Veitch
69. Ian Hincks
70. Marcin Kotowski
71. Michal Kotowski
72. Jeremy Kroeker
73. Alexandre Laplante
74. Vadym Kliuchnikov
75. Matthew Amy
76. Antonio Scotland
77. Feyruz Kitapli
78. Juan Miguel Arrazola
79. John Donohue
80. Aimee Heinrichs
81. Gregory Holloway
82. Joseph Rebstock
83. Denis-Alexandre Trottier
84. Zak Webb
85. Chris Pugh
86. Takafumi Nakano
87. Joshua Geller
88. Steven Casagrande
89. Joachim Nsofini
90. Kaveh Gharavi
91. Matthew Graydon
92. Holger Haas
93. Sadegh Raeisi
94. Elena Anisimova
95. Daniel Puzzuoli
96. Naimeh Ghafarian

Research Assistants

1. Tessa Alexanian
2. Srinivasan Arunachalam
3. Steven Casagrande
4. Artur Czerwinski
5. Miriam Diamond
6. Julian Glaessel
7. Ian Hincks
8. Daryl Chulho Hyun
9. Dmitri Iouchtchenko
10. Erika Janitz
11. Nidhi Juthani
12. Andrew Kowalczyszyn
13. Madelaine Liddy
14. Nhat Ly
15. Jean Maillard
16. Andrew McMullen
17. Martin Otto
18. Alex Parent
19. Jacob Parker
20. David Pomaranski
21. Philip Reinhold
22. Laura Richards
23. Dusan Sarenac
24. Tapash J. Sarkar
25. Shaun Sawyer
26. Shitikanth
27. Daryoush Shrii
28. Fil Simovic
29. Marilyne Thibault
30. Tian Tian
31. Matthew Volpini
32. Marcel van Helden
33. Logan Wright
34. Yingjie Zhang
35. Tong Zhao
36. Jonathan Zung

Long-Term Visitors

1. Vikram Sharad Athalye
2. Amin Baumeler
3. Aleksandrs Belovs
4. Troy Borneman
5. Guanru Feng
6. Thomas Guenthner
7. Bettina Heim
8. Won-Young Hwang
9. Shelby Kimmel
10. Antti Karlsson
11. Yusuke Kondo
12. Christian Konrad
13. Kevin Krsulich
14. Jun Li
15. Thomas Lutz
16. Laura Piispanen

17. Carmelo Scarcella
18. Hou Shiyao
19. Sarah Sheldon
20. Virginia Villanueva
21. Yafei Yu

Administrative Staff

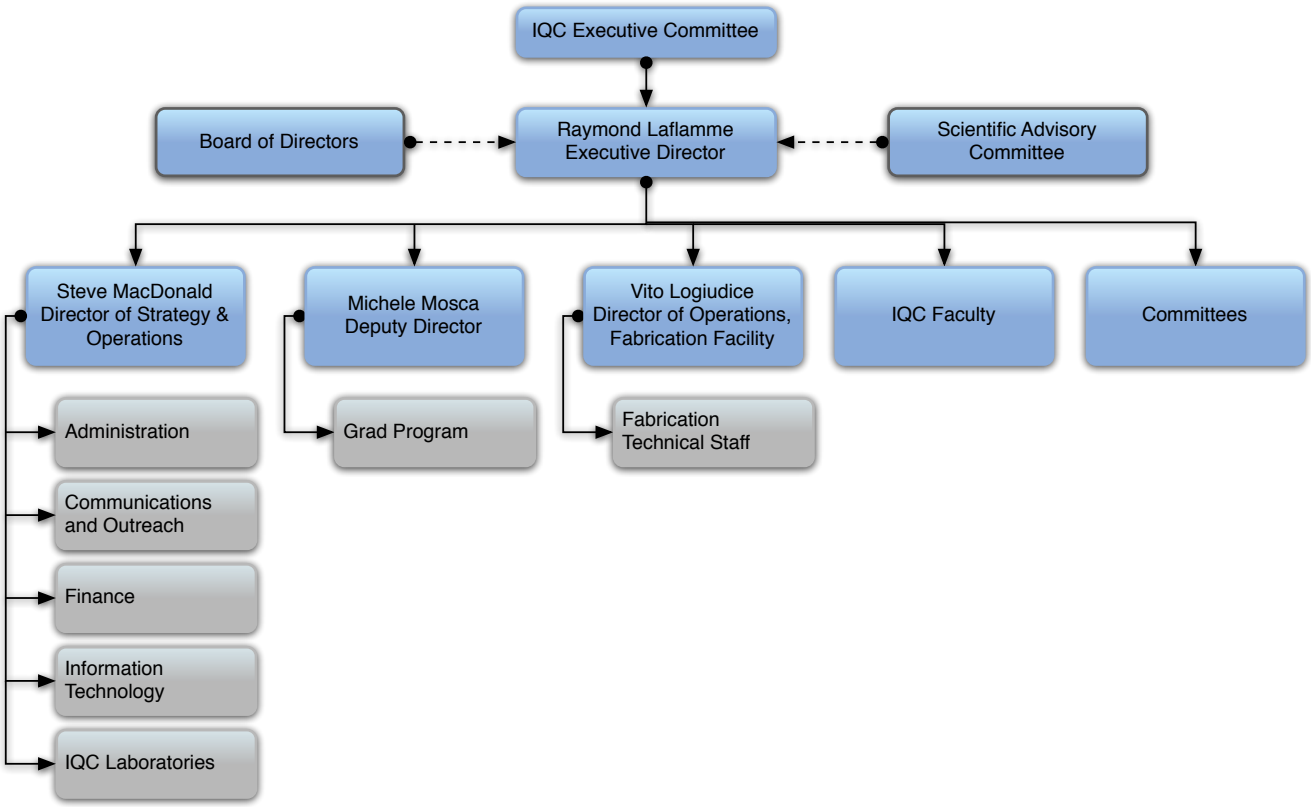
1. Matthew Cooper
2. Andrew Dale
3. Lisa David
4. Monica Dey
5. Melissa Floyd
6. Matthew Fries
7. Jaymis Goertz
8. Jasmine Graham
9. Katharin Harkins
10. Colin Hunter
11. Lorna Kropf
12. Martin Laforest
13. Steve MacDonald
14. Mary Lyn Payerl
15. Wendy Reibel
16. Kimberly Simmermaker
17. Marta Szepietowski
18. Carly Turnbull
19. Steve Weiss

Technical Staff

1. Brian Goddard
2. Vito Logiudice
3. Nathan Nelson-Fitzpatrick
4. Roberto Romero
5. Rodello Salandanan
6. Ivar Taminiau

D. Governance

This section outlines IQC's governance structure. The following chart depicts IQC's current organizational makeup.



IQC's collaborative and interdisciplinary research goes beyond the scope of one single department. Therefore, faculty members are appointed across six departments that span the University of Waterloo's faculties of Engineering, Math and Science. Departments include: Combinatorics and Optimization, Physics and Astronomy, The David R. Cheriton School of Computer Science, Electrical and Computer Engineering, Applied Mathematics, and Chemistry.

Executive Committee

IQC's Executive Committee is made up of senior administrators from the University of Waterloo who provide guidance to IQC's Executive Director and senior management team.[9] The committee meets twice per year.

George Dixon, Vice-president, Chair, University Research, University of Waterloo (Chair)
Ian Goulden, Dean, Faculty of Mathematics, University of Waterloo
Raymond Laflamme, Executive Director, Institute for Quantum Computing
Steve MacDonald, Director of Strategy and Operations, Institute for Quantum Computing
Terry McMahon, Dean, Faculty of Science, University of Waterloo
Michele Mosca, Deputy Director, Institute for Quantum Computing
Adel S. Sedra, Dean, Faculty of Engineering, University of Waterloo

Board of Directors

IQC's Board of Directors is made up of internationally recognized leaders from academia, business and government.[10] The Board provides advisory strategic advice on all aspects of management including finances, planning, commercialization and outreach. The Board of Directors includes:

Douglas Barber, Distinguished Professor-in-Residence, McMaster University
Tom Brzustowski (Board Chair), RBC Professor, Telfer School of Management, University of Ottawa
Paul Corkum, University of Ottawa and National Research Council
George Dixon, Vice-president, University Research, University of Waterloo
Cosimo Fiorenza, Vice-president and General Counsel, Infinite Potential Group
David Fransen, Consul General, Canadian Consulate General in Los Angeles
Peter Hackett, Executive Professor, School of Business at the University of Alberta & Fellow, National Institute for Nanotechnology
Raymond Laflamme, Executive Director, Institute for Quantum Computing
Mike Lazaridis, Co-Founder of Research In Motion
Steve MacDonald, Chief Operating Officer, Institute for Quantum Computing
Michele Mosca, Deputy Director, Institute for Quantum Computing
Peter Nicholson, Retired President, Council of Canadian Academies
William R. Pulleyblank, Professor of Operations Research, United States Military Academy, West Point

[9] Biographies for the Executive Committee can be found in Appendix E

[10] Biographies for the Board of Directors can be found in Appendix F

Scientific Advisory Committee

IQC's Scientific Advisory Committee is made up of leading international scientists.[11] The committee meets annually to assess IQC's progress toward fulfilling its mission and achieving its strategic goals. The committee advises the Executive Director on areas of strength and opportunity in the institute's scientific endeavours to ensure the success of IQC. Members of the Scientific Advisory Committee include:

Prof. Harry Buhrman, Centrum voor Wiskunde en Informatica
Prof. Anthony J. Leggett, University of Illinois at Urbana-Champaign
Prof. Gerard Milburn, University of Queensland
Prof. Christopher Monroe, University of Maryland
Prof. Umesh Vazirani, University of California, Berkley
Prof. Anton Zeilinger, University of Vienna
Prof. Wojciech Hubert Zurek, Laboratory Fellow, Los Alamos National Laboratory and Santa Fe Institute

The Scientific Advisory Committee released a formal review report on IQC's progress in 2011. The review is available in section 5.2 of this report. IQC was also reviewed by NSERC in 2009 as a part of the submission for funding from the federal government. The review can also be found in Section 5.2 of this report.

Internal Governance

Faculty members at IQC hold appointments in departments at the University of Waterloo and as such, are governed by the University's policies on appointment, promotion and tenure. All faculty participate in annual evaluations conducted by their home departments. The Executive Director of IQC gives input to the heads of departments about the contributions of each member. In addition, the institute tracks information on research, outreach and other contributions to IQC for its own membership renewal process. Members are elected to IQC for a period of five years.

IQC holds monthly faculty meetings to discuss issues arising issues related to faculty and postdoctoral fellow hiring, visiting scientists, the graduate program, upcoming colloquia and seminars, scholarships and others as they arise.

[11] Biographies for the Scientific Advisory Committee can be found in Appendix G

E. IQC Executive Committee Biographies

George Dixon, Vice-president, University Research, University of Waterloo (Chair)
Dr. George Dixon, an expert in aquatic toxicology and environmental risk assessment, has received both the Award of Excellence in Research and the Distinguished Teaching Award from the University of Waterloo.

Ian Goulden, Dean, Faculty of Mathematics, University of Waterloo
Dr. Ian Goulden is a an algebraic combinatorialist who has had a profound effect on an area of mathematics that deals with structures central to many other parts of mathematics. Much of his research has now entered into standard use within the discipline itself, as well as in applications to the mathematical sciences.

Raymond Laflamme, Executive Director, Institute for Quantum Computing
Dr. Raymond Laflamme is the founding executive director of IQC, as well as a founding member of Perimeter Institute and the founding director of QuantumWorks, the Canadian consortium of quantum research. He is a pioneer in quantum information research — particularly spin-based quantum computing and quantum error correction.

Steve MacDonald, Director Strategy and Operations, Institute for Quantum Computing
Steve MacDonald has a track record of developing and implementing corporate-wide initiatives, whose background ranges from finance to not-for-profit work. Prior to IQC, he held prominent positions at CIBC Mellon, Clarica Life Insurance and kidsLINK.

Michele Mosca, Deputy Director, Institute for Quantum Computing
Dr. Michele Mosca is a co-founder of the Institute for Quantum Computing and a professor in the University of Waterloo's Department of Combinatorics and Optimization, as well as the departments of Computer Science and Physics and Astronomy. Also a founding member of the Perimeter Institute, he is an expert in quantum algorithms and cryptography.

Terry McMahon, Dean, Faculty of Science, University of Waterloo
Dr. Terry McMahon's research in physical chemistry is directed toward the investigation of structure, energetics and reaction dynamics of gaseous ions and cluster ions. To carry out this research, he and his team use high pressure mass spectrometry and Fourier transform ion cyclotron resonance (FTICR) spectrometers.

Adel S. Sedra, Dean, Faculty of Engineering, University of Waterloo
Dr. Adel Sedra specializes in the area of microelectronics. He has co-authored about 150 papers and three textbooks, including Microelectronic Circuits, which is now in its fifth edition and in 10 languages. He currently serves on the Research Council of the Canadian Institute of Advanced Research (CIFAR).

F. IQC Board of Directors Biographies

Tom Brzustowski, Chair of the Board

Tom Brzustowski graduated with a B.A.Sc. in Engineering Physics from the University of Toronto in 1958, and a PhD in Aeronautical Engineering from Princeton in 1963. He was a professor in the Department of Mechanical Engineering at the University of Waterloo from 1962 to 1987. He served as Chair of Mechanical Engineering from 1967 to 1970 and as Vice-President, Academic of the university from 1975 to 1987. He served as deputy minister in the Government of Ontario from 1987 to 1995. He was appointed President of NSERC in October 1995, and reappointed in 2000. He is an Officer of the Order of Canada and a fellow of the Canadian Academy of Engineering and of the Royal Society of Canada.

H. Douglas Barber

H. Douglas was an Athlone Fellow and NATO Scholar and received his PhD from Imperial College, University of London in 1965. In 1973 he was a founder of Linear Technology Inc., (now known as Gennum Corporation) which manufactures and markets microcircuits. He was President and CEO of Gennum when he retired in 2000 and he continues in his position as a director. He was a part-time Engineering Physics Professor at McMaster University from 1968 to 1994 and in 2001 he was appointed Distinguished Professor-in-Residence. Dr. Barber's honours include the APEO Engineering Medal, the Professional Engineers of Ontario Gold Medal and Engineer of the Year Award of the Hamilton Engineering Institute. He has received an Honorary Doctorate of Engineering from the University of Waterloo, an Honorary Doctorate of Science from McMaster University, and in 1999 was named Ontario's Technology Entrepreneur of the Year and received the National Citation for Innovation & Technology. Most recently, Dr. Barber was named to the Order of Canada.

-

Paul Corkum

Dr. Paul Corkum earned his PhD in physics at Lehigh University in 1972. After a year at Lehigh as a postdoctoral researcher, he moved to the National Research Council in Ottawa. In 1990 he formed the Femtosecond Science Group within NRC's Steacie Institute for Molecular Sciences. In 2008 he was named a Canada Research Chair of Attosecond Photonics at the University of Ottawa and appointed Director of the Joint NRC/University of Ottawa Laboratory for Attosecond Science. He is a member of the Royal Societies of Canada (1995) and London (2005). He has been the recipient of the Gold Medal for Lifetime Achievement in Physics from the Canadian Association of Physicists (1996), the Einstein Award of the Society for Optical and Quantum Electronics (1999), the Golden Jubilee Medal of Her Majesty

Queen Elizabeth II (2003), the Tory Medal of the Royal Society of Canada (2003), the Quantum Electronics Award of the Institute of Electrical and Electronics Engineers (IEEE, 2005), the Killam Prize for Physical Sciences (2006), and the Arthur Schawlow Prize for Quantum Electronics from the American Physical Society (2006).

George Dixon

Dr. D. George Dixon is Vice-President, University Research and Professor of Biology at the University of Waterloo.
Dr. Dixon has received both the Award for Excellence in Research and the Distinguished Teaching Award from the university. He has over 25 years experience in aquatic toxicology and environmental risk assessment and management. He maintains an active research program, which is focused methods for environmental effects monitoring, methods of assessing the environmental risks associated with exposure of aquatic organisms to metal mixtures, and on the aquatic environmental effects of oil sands extraction in Alberta. He is Associate Editor of three scientific journals, including the Canadian Journal of Fisheries and Aquatic Sciences.

Cosimo Fiorenza

Cosimo Fiorenza is the Vice-President and General Counsel of the Infinite Potential Group. He is actively involved at several public and private non-profit and charitable institutions in addition to Institute for Quantum Computing, including the Perimeter Institute, the Law Society of Upper Canada, the Centre for International Governance Innovation, the Institute for Quantum Computing, and several private family foundations. Mr. Fiorenza holds a degree in Business Administration from Lakehead University and a law degree from the University of Ottawa.

David Fransen

David Fransen worked from 1985 to 1988 at the Privy Council Office, where he provided policy advice related to such developments as the Green Plan in 1990, the drafting of the Canadian Environmental Assessment Act and the Canadian Environmental Protection Act, and the creation of the Canadian Environmental Assessment Agency. He then became Director of Economic Framework Policies in the Strategic Policy Branch of Industry Canada. In 1999, David became the Director General of the Centre for Healthy Human Development at Health Canada. He became Assistant Deputy Minister of the Industry Sector in 2003, where he was primarily responsible for providing policy advice and delivering programs related to some of Canada's key economic sectors. He became executive director of the Institute for Quantum Computing in 2006. He is currently the Consul General, Canadian Consulate General in Los Angeles.

Peter Hackett

Dr. Peter Hackett has been President and CEO of Alberta Ingenuity since October 2004. He is the former Vice-President Research at the National Research Council of Canada where he led NRC corporate strategies emphasizing emerging technologies, entrepreneurship and technology clusters. He was the lead NRC executive behind the creation and design of the National Institute for Nanotechnology at the University of Alberta. He is a member of the Institute Advisory Board Institute of Genetics, the Canadian Institute of Health Research, a board member of Genome Alberta and a founding member of the Alberta Advisory Committee on the Bio-economy. He was honoured recently by a Specially Elected Fellow of the Royal Society of Canada (RSC).

Mike Lazaridis

Mike Lazaridis the founder of telecommunications company Research In Motion (maker of the BlackBerry). He currently serves as the Vice Chair of the company's Board, and Chair of the Board's new Innovation Committee. IQC was launched in 2002 thanks to the vision and incredible philanthropy of Lazaridis, who has given more than $105 million to the institute since inception. He is also the founder of Waterloo's Perimeter Institute for Theoretical Physics.

Peter Nicholson

Dr. Peter Nicholson is the inaugural President and Chief Executive Officer of the Council of Canadian Academies. He holds a BSc and MSc in Physics from Dalhousie University and a Ph.D. (Operations Research) from Stanford University, as well as honorary doctorates from Dalhousie University, Acadia University, and the Université du Québec (INRS). He joined the government of Canada in 1973, where he served in a senior policy advisory role in the Departments of Urban Affairs, Transport, and Regional Economic Expansion. In 1978 he was elected to the Legislature of the Province of Nova Scotia. He later served as Chief Strategy Officer of BCE Inc., Canada's largest telecommunications company. Between December 2003 and January 2006 he served in the Office of the Prime Minister of Canada as Deputy Chief of Staff for Policy. He ia member of the Order of Canada, awarded in recognition of his contribution to business through both the public and private sectors.

William R. Pulleyblank

William R. Pulleyblank is the IBM vice president responsible for the Center for Business Optimization. He was the director of exploratory server systems and director of the Deep Computing Institute. During this time, he was responsible for a number of IBM Research initiatives in ultra large-scale computing, including the creation of the Blue Gene/L supercomputer which, since November 2004, has been certified as the world's most powerful system. Dr. Pulleyblank has served on a range of boards and advisory panels, including the Advisory Committee of the Division of Mathematics & Physical Sciences of the National Science Foundation, the Board on Mathematical Sciences of the National Research Council, the iCORE Board of Directors, the Science Advisory Board of the National Institute of Aerospace, and the Scientific Advisory Panel of The Fields Institute for Research in Mathematical Sciences.

G. Scientific Advisory Committee Biographies

Harry Buhrman

Harry Buhrman is head of the research group 'Algorithms and Complexity' at the Centrum Wiskunde & Informatica, which he joined in 1994. Since 2000 he also has a joint appointment as full professor of computer science at the University of Amsterdam. Buhrman's research focuses on quantum computing, algorithms, complexity theory, and computational biology. One of the highlights in the work of Buhrman is the article co-authored with Richard Cleve (University of Waterloo, Canada) 'Quantum Entanglement and Communication Complexity'. They demonstrated that with quantum entanglement certain communication tasks can be solved more efficiently. He also co-developed a general method to

establish the limitations of quantum computers. He has written more than 100 scientific publications.

Anthony J. Leggett

Anthony J. Leggett, the John D. and Catherine T. MacArthur Professor and Center for Advanced Study Professor of Physics, has been a faculty member at Illinois since 1983. He was a co-winner of the 2003 Nobel Prize in Physics for pioneering work on superfluidity. He is a member of the National Academy of Sciences, the American Philosophical Society, the American Academy of Arts and Sciences, the Russian Academy of Sciences (foreign member), and is a Fellow of the Royal Society (U.K.), the American Physical Society, and the American Institute of Physics. He is an Honorary Fellow of the Institute of Physics (U.K.). He was knighted (KBE) by Queen Elizabeth II in 2004 "for services to physics." He is also a Mike and Ophelia Lazaridis Distinguished Research Chair.

Gerard Milburn

Gerard Milburn obtained a PhD in theoretical Physics from the University of Waikato in 1982 for work on squeezed states of light and quantum nondemolition measurements. He was appointed to a postdoctoral research assistantship in the Department of Mathematics, Imperial college London in 1983. In 1994 he was appointed as Professor of Physics and in 1996 became Head of Department of Physics at The University of Queensland. In 2000 he became Deputy Director of the Australian Research Council Center of Excellence for Quantum Computer Technology. He is currently an Australian Research Council Federation Fellow at the University of Queensland.

Chris Monroe

Christopher Monroe is an experimental atomic, molecular and optical physicist. Monroe obtained his PhD at the University of Colorado in 1992. From 1992-2000, Monroe was a postdoc and staff physicist in the Ion Storage Group of David Wineland at the National Institute of Standards and Technology in Boulder, CO. In 2000, Monroe moved to the University of Michigan, where he introduced the use of single photons to couple quantum information between atomic ions. In 2006, he became Director of the FOCUS Center at the University of Michigan. In 2007, Monroe became the Bice Sechi-Zorn Professor of Physics at the University of Maryland and a Fellow of the new Joint Quantum Institute between Maryland and NIST. In 2007-2008, Monroe's group succeeded in producing quantum entanglement between two widely separated atoms and teleported quantum information between atoms separated by a large distance.

Umesh Vazirani

Umesh Vazirani is a professor in the Computer Science Division of the Department of Electrical Engineering and Computer Sciences at the University of California, Berkeley. Professor Vazirani is a Director of the Berkeley Quantum Information and Computation Center (BQIC).
He received an NSF Presidential Young Investigator Award in 1987 and the Friedman Mathematics Prize in 1985. Professor Vazirani wrote the book, "An Introduction to Computational Learning Theory" with Michael Kearns and currently is at the forefront of research in the area of quantum computing.

Anton Zeilinger

Anton Zeilinger is a professor of physics at the University of Vienna (previously Innsbruck). Professor Zeilinger is known for multiple experiments in the realm of quantum interferometry and the demonstration of quantum teleportation. His work influenced the experimental progress in a new sub-field of physics, quantum information theory. He has contributed to theoretical physics and the foundations of quantum mechanics — he has showed an amplification of the Einstein-Podolsky-Rosen paradox, where one considers three, instead of just two, entangled particles.

Wojciech Hubert Zurek

Wojciech Hubert Zurek is a Laboratory Fellow at Los Alamos National Laboratory (LANL). He is a leading authority on a number of physics topics, including quantum theory, and particularly, decoherence. His work also has great potential benefit to the emerging field of quantum computing. He was educated in Krakow, Poland (M.Sc. 1974) and Austin, Texas (PhD 1979). He spent two years at Caltech as a Tolman Fellow, and began his appointment at LANL as a J. Oppenheimer Fellow. He was the leader of the Theoretical Astrophysics Group at LANL from 1991 until he was made a Laboratory Fellow in the Theory Division in 1996. Zurek is currently a foreign associate of the Cosmology Program of the Canadian Institute for Advanced Research.

H. Financial Supporters

IQC and its researchers are privileged recipients of donations, grants, gifts and awards. Over the next few pages you will find some highlights of these grants.

"We will also continue to support and encourage private sector research, development and commercialization of new products and innovations through our national science and technology strategy. For example, we will make further investments in Waterloo's Institute for Quantum Computing, an emerging world leader in the areas of computer, engineering, mathematical and physical sciences."

Stephen Harper, Prime Minister of Canada
in his response to the speech of the throne, 2009

Industry Canada
In 2009, the Government of Canada through Industry Canada granted $50 million to IQC to be allocated over a five-year period. $25 million to fund the IQC share of the Mike and Ophelia Lazaridis Quantum Nano Center and $25 million for operations. In the 2011/2012 year (2012 fiscal year), $5 million was awarded with the following allotment: $1.0 million for equipment purchasing, $1.6 million toward highly qualified personnel, $0.6 toward knowledge transfer and $1.8 million for operations.

Mike and Ophelia Lazaridis
Mike and Ophelia Lazaridis have donated a total of $105 million to IQC since inception.

The Government of Ontario
The Government of Ontario has granted $50 million to the University of Waterloo to help strengthen Ontario's leading-edge research capacity. The Ontario Ministry of Research and Innovation granted IQC more than $18 million. (Includes the Ontario Innovation Trust and the Ontario Research Development Challenge Fund.)

The University of Waterloo
The University of Waterloo has committed to supporting the salaries of 33 IQC faculty.

Canadian Foundation for Innovation
CFI has contributed more than $14 million to IQC since inception.

Natural Sciences and Engineering Research Council of Canada
NSERC has committed nearly $12 million to developing quantum information science and technology since the inception of IQC in 2002.

Canada Research Chairs
The Canada Research Chairs Secretariat Program supports IQC through faculty positions at the University of Waterloo that are jointly appointed by IQC and one of the departments in the Faculties of Science, Engineering or Mathematics. Current Research Chairs at IQC are: Raymond Laflamme, Michele Mosca and Debbie Leung.

Canada Excellence Research Chairs
The Canada Excellence Research Chairs program supports IQC with funding of $10 million over seven years to support faculty member David Cory.

Many other agencies provide grants to IQC and its researchers including IARPA, DARPA, CSEC, MITACS and more.

I. Summary of other Grants and Gifts

IQC and its researchers are privileged recipients of donations, grants, gifts and awards. Over the next few pages you will find some highlights of these grants from Fiscal Years 2010, 2011 and 2012.

Sponsor Type	Sponsor Name	Total Awarded
Canadian - Government and Public Sector - Federal - Network Centres of Excellence	CIPI - Canadian Institute for Photonic Innovations	45,000
	MITACS - NCE	244,641
	MITACS - non NCE	73,010
	Total	**362,651**
Canadian - Government and Public Sector - Federal - Other	Canadian Space Agency	250,000
	CERC (Canada Excellence Research Chairs)	930,302
	CFI - IOF (Infrastructure Operating Fund)	639,550
	CFI - LEF (Leading Edge Fund)	2,789,428
	CFI - LOF (Leaders Opportunity Fund)	289,000
	Communications Security Establishment Canada	69,670
	CRC - NSERC	5,693,252
	Human Resources Development Canada	194,364
	Total	**10,855,566**
Canadian - Government and Public Sector - Federal - Tri Agency	NSERC - Discovery Grants - Accelerator Supplement (RGPAS)	200,000
	NSERC - Discovery Grants - Individual (RGPIN)	1,670,674
	NSERC - Engage Grant	22,900

	NSERC - NRC (National Research Council) Research Partnership Program	76,000
	NSERC - Other	140,000
	NSERC - Research Tools and Instruments Grants (RTI) Category 1	379,698
	NSERC - SNG (Strategic Network Grants Program)	25,000
	NSERC - Strategic Project Grants Program (STP)	750,000
	NSERC Strategic (through McMaster)	120,000
	NSERC Strategic (through U of T)	18,000
	NSERC (C4 through McMaster)	25,000
	Total	**3,427,272**
Canadian - Government and Public Sector - Provincial - Ontario	MRI - ERA (Early Researcher Award)	361,123
	MRI - ORF-RE (Ontario Research Fund - Research Excellence)	99,195
	MRI - ORF-RI (Ontario Research Fund - Research Infrastructure)	4,777,924
	MRI - PDA (Premier's Discovery Award)	375,000
	MRI - PDF (Post Doctoral Fellowship)	50,000
	Total	**5,663,242**
Canadian - Government and Public Sector - Provincial - Ontario Centres of Excellence	OCE - CPRO	
	Total	**434,091**
Canadian - Non Profit - Foundations/Charities	Alfred P. Sloan Foundation	51,095
	Canadian Institute for Advanced Research	1,033,085
	Total	**1,084,180**
Foreign - Government and Public Sector - Other	Austrian Academy of Sciences	
	Total	16,969

US Government and Public Sector - Federal	IARPA	503,776
	DARPA	189,132
	US Army Research Office (includes one through MIT)	663,661
	Total	**1,356,569**

IQC also has several private and industry funding partners. In the past three years, gifts and grants from private and industry partners have totaled $992,920.

J. Publications

2011 Publications

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Yan, Z. Z., Akhlaghi, M. K., Orgiazzi, J. L., & Majedi, A. H. (2009). Optoelectronic characterization of a fiber-coupled NbN superconducting nanowire single photon detector. *JOURNAL OF MODERN OPTICS*, *56*(2-3), 380–384.

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Zhang, J. F., Cucchietti, F. M., Chandrashekar, C. M., Laforest, M., Ryan, C. A., Ditty, M., et al. (2009). Direct observation of quantum criticality in Ising spin chains. *PHYSICAL REVIEW A*, *79*(1).

Zhang, J. F., Ditty, M., Burgarth, D., Ryan, C. A., Chandrashekar, C. M., Laforest, M., et al. (2009). Quantum data bus in dipolar coupled nuclear spin qubits. *PHYSICAL REVIEW A*, *80*(1).

Zhao, Y. B., Heid, M., Rigas, J., & Lütkenhaus, N. (2009). Asymptotic security of binary modulated continuous-variable quantum key distribution under collective attacks. *PHYSICAL REVIEW A*, *79*(1).

K. Collaborations

2011 Collaborations

Publication Title	External Collaborators	Collaborating Organization	Location
Structural investigation of a new passivation method for InAs nanowires	C.M. Haapamaki	McMaster University	Hamilton, Ontario, Canada
	R.R. LaPierre	McMaster University	Hamilton, Ontario, Canada
Digital quantum simulation of the statistical mechanics of a frustrated magnet	Alan Aspuru-Guzik	Harvard University	Cambridge, Massachusetts, USA
The quantum query complexity of read-many formulas	Shelby Kimmel	Massachusetts Institute of Technology	Cambridge, Massachusetts, USA
Levinson's theorem for graphs, Journal of Mathematical Physics	DJ Strouse	University of Southern California	Los Angeles, California, USA
Quantum property testing for bounded-degree graphs, Proceedings of the 15th International Workshop on Randomization and Computation	Yi-Kai Liu	University of California, Berkeley	Berkeley, California, USA
Quantum entanglement and the communication complexity of the inner product function. To appear in Theoretical Computer Science	M. A. Nielsen	Los Alamos National Laboratory and University of New Mexico	New Mexico, USA
	A. Tapp	University of Montreal	Montreal, Quebec, CA
	W. van Dam	University of Oxford and CWI	Amsterdam
Noise Spectroscopy through Dynamical Decoupling with a Superconducting Flux Qubit	Simon Gustavsson	Massachusetts Institute of Technology	Cambridge, Massachusetts, USA
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Experimental Characterization Of Coherent Magnetization Transport In A One-Dimensional Spin System	Paola Cappellaro	Massachusetts Institute of Technology	Cambridge, Massachusetts, USA
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Experimental Realization of Decoherence-Free Subspace in Neutron Interferometry	M. Arif	National Institute of Standards and Technology	Gaithersburg, Maryland, USA
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Tensor networks and graphical calculus for the open quantum systems	Jacob D. Biamonte	Centre for Quantum Technologies (CQT), National University of Singapore	Singapore
Equivalent Hamiltonians for State to State Transfer in the Case of Partial Quantum Control	Chandrasekhar Ramanathan	Dartmouth College	Hanover, New Hampshire, USA
Driven dynamics and rotary echo of a qubit tunably coupled to a harmonic oscillator	V. Bolkhovsky	MIT Lincoln Laboratory	Lexington, Massachusetts, USA
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Noise Estimation via Randomization	Jay Gambetta	IBM T.J. Watson Research Center	Yorktown Heights, New York, USA
Gate Fidelity Fluctuations and Quantum Process Invariants	Robin Blume-Johout	Los Alamos National Laboratory	Los Alamos, New Mexico, USA
Encoding graphs into quantum states: an axiomatic approach	T.P. Spiller	Quantum Information Science, School of Physics and Astronomy, University of Leeds	Leeds LS2 9JT, United Kingdom
Proposal for a quantum delayed-choice experiment	D.R. Terno	Department of Physics & Astronomy, Macquarie University, Sydney	New South Wales 2109, Australia
Photon Triplets and Triple slit experiments, a new frontier in quantum optics	C. Couteau	Université de Technologie de Troyes	Rosières-prés-Troyes, France
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Single-photon device requirements for operating linear optics quantum computing outside the post-selection basis	Marco Barbieri	Department of Physics, and Centre for Quantum Computer Technology, University of Queensland	4027 St Lucia, QLD, Australia
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Fast optical source for quantum key distribution based on semiconductor optical amplifiers	W. Amaya	Institute of Telecommunications and Multimedia Applications (ITEAM)	Universidad Polit´ecnica de Valencia, Spain

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How to implement decoy-state quantum key distribution for a satellite uplink with 50-db channel loss	Allison MacDonald	Department of Physics and Astronomy, McMaster University	1280 Main Street W, Hamilton ON, Canada L8S 4M1.
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Digital quantum simulation of the statistical mechanics of a frustrated magnet	Alan Aspuri-Guzik	Department of Physics and Astronomy, University of Waterloo	Waterloo, ON, Canada
Experimental quantum simulation of entanglement in many-body systems	Tzu-Chiech Wei	Departement of Physics and Astronomy, University of British Columbia	Vancouver, British Columbia, Canada
Authentication of quantum messages @ The Application of Lasers for Sensing & Free Space Communication (LSC) topical meeting	P. Hayden	McGill University	Montreal, Quebec, Canada
	D. Mayers	Caltech	Pasadena, California, United States of America
Zero-error channel capacity and simulation assisted by non-local correlations	Toby S. Cubitt	Universidad Computense de Madrid	Madrid, Spain
	Andreas Winter	University of Bristol	Bristol, U.K
	Andreas Winter	National University of Singapore	Singapore
An exponential separation between entanglement & communication capacities of a bipartite unitary interaction	Aram. W. Harrow	Department of Mathematics, University of Bristol	Bristol, BS8 1TW, U.K.

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The locking-decoding frontier for generic dynamics	Frederic Dupuis	School of Computer Science - McGill University	Hamilton, Ontario, Canada
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Detection of Single Electrons or Photons using a Superconducting Nanowire	S.N. Dorenbos	Kavli Institute of Nanoscience, Delft University, The Neterlands	Postbus 5 2600 AA Delft The Netherlands
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	Gilles Nogues	Institut Neel	Institut Neel, 25 avenue des Martyrs, bâtiment T, BP 166, 38042 Grenoble cedex 9, France
Linear-optics realization of channels for single-photon multimode qudits	R. Kaltenbaek	Vienna Center for Quantum Science and Technology, Faculty of Physics, University of Vienna	Vienna, Austria
Efficient Heralding of Photonic Qubits with Applications to Device Independent Quantum Key Distribution	P.van Loock	Max Planck Institute for the Science of Light and University of Erlangen-Nürnberg	Erlangen, Germany
	R. Wickert	Max Planck Institute for the Science of Light and University of Erlangen-Nürnberg	Erlangen, Germany
Ultrafast Linear Kinetic Inductive Photoresponse of YBCO Meander-Line Structures by Photoimpedance Measurements	S.M. Anlage	Department of Physics, Center for Nanophysics and Advanced Materials, University of Maryland	College Park, Maryland, USA
	B.G. Ghamsari	Department of Physics, Center for Nanophysics and Advanced Materials, University of Maryland	College Park, Maryland, USA
Nonlinearity in Single Photon Detection: Modeling and Quantum Tomography	J. S. Lundeen	National Research Council - Institute for National Measurement Standards	Ottawa, Ontario, Canada
Surface Plasmon-Enhanced Coupling of Optical Guided-Waves to High-Temperature Superconducting Optoelectronic Structures	B.G. Ghamsari	Department of Physics, Center for Nanophysics and Advanced Materials, University of Maryland	College Park, Maryland, USA
Controlling Superconducting Nanowire Single-Photon Detector Using Tailored Bright Illumination	L. Lydersen	Department of Electronics and Telecommunications, Norwegian University of Science and Technology	Trondheim, Norway

Publication Title	External Collaborators	Collaborating Organization	Location
	V. Makarov	Department of Electronics and Telecommunications, Norwegian University of Science and Technology	Trondheim, Norway
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The Space Complexity of Recognizing Well-Parenthesized Expressions: the Index Function Revisited	Rahul Jain	Centre for Quantum Technologies and Department of Computer Science, National University of Singapore.	Singapore
Short Proofs of the Quantum Substate Theorem	Rahul Jain	Centre for Quantum Technologies and Department of Computer Science, National University of Singapore.	Singapore
On the Hitting Times of Quantum Versus Random Walks	Frédéric Magniez	LRI, Univ Paris-Sud, CNRS; F-91405 Orsay	France
	Peter C. Richter	LRI, Univ Paris-Sud, CNRS; F-91405 Orsay	France
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Search via Quantum Walk	Jérémie Roland	NEC Laboratories America; Princeton	NJ, USA
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Quantumness versus entanglement in quantum measurements	G. Adesso	School of Mathematical Sciences, University of Nottingham	University Park, Nottingham NG7 2RD, United Kingdom
Linear-optics realization of channels for singlephoton multimode qudits	R. Kaltenbaek	Univ Vienna, Fac Phys, Vienna Ctr Quantum Sci & Technol	A-1090 Vienna, Austria
Characterizing quantumness via entanglement creation	J. Calsamiglia	Física Teòrica: Informació i Fenòmens Quàntics, Universitat Autònoma de Barcelona	08193 Bellaterra, Spain
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All non-classical correlations can be activated into distillable entanglement	A. Winter	Department of Mathematics, University of Bristol	Bristol BS8 1TW, United Kingdom
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Operational interpretations of quantum discord	L. Aolita	ICFO Inst Ciencies Fotoniques, Castelldefels 08860	Barcelona, Spain
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Are general quantum correlations monogamous?	D. Bruss	Heinrich-Heine-University Düsseldorf	Düsseldorf, Germany
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Quantumness versus entanglement in quantum measurements	G. Adesso	School of Mathematical Sciences, University of Nottingham	University Park, Nottingham NG7 2RD, United Kingdom
Experimental Realization of Decoherence-Free Subspace in Neutron Interferometry	M. Arif	National Intitute of Standards and Technology	Gaithersburg, Maryland, USA
	M.G. Huber	National Intitute of Standards and Technology	Gaithersburg, Maryland, USA
Quantum query complexity of state conversion	T. Lee	Centre for Quantum Technologies	Singapore
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Entanglement-Enhanced Classical Communication over a Noisy Classical Channel	Roger Colbeck	Perimeter Institute for Theoretical Physics	Waterloo, Ontario, Canada
QIP = PSPACE	Rahul Jain	National University of Singapore	Singapore 119077
Microwave single photon counter based on Josephson Junctions	Y.-F. Chen	Department of Physics, University of Wisconsin	Madison, Wisconsin 53706, USA
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Tunable coupling between three qubits as a building block for a superconducting quantum computer	Austin G. Fowler	2Centre for Quantum Computation and Communication Technology, School of Physics, The University of Melbourne	Melbourne, Victoria 3010, Australia

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The University of Queensland, St Lucia, Australia
The University of Sydney, Sydney Australia
Universidad de Guanajuato, Guanajuato, Mexico
Universitat Autonoma de Barcelona, Cerdanyola del Vallès, Spain
Universitat des Saarlandes, Saarbrücken, Germany
Universität Stuttgart, Stuttgart, Germany
Université de Sherbrooke, Sherbrooke, Quebec, Canada
Université Joseph Fourier, Saint Martin d'Hères, France
Universite Paris Sud, Orsay, France
University of Bristol, Bristol, United Kingdom
University of British Columbia, Vancouver, British Columbia, Canada
University of California - Berkeley, Oakland, California, United States
University of California - Irvine, California, United States
University of California, Riverside, California, United States
University of California, Santa Barbara, California, United States
University of Cambridge, Cambridge, United Kingdom
University of Central Florida, Orlando, Florida, United States
University of Connecticut, Storrs, Connecticut, United States
University of Erlangen-Nuremberg, Erlangen, Germany
University of Gdańsk, Gdańsk, Poland
University of Georgia, Athens, Georgia, United States
University of Guelph, Guelph, Ontario, Canada
University of Innsbruck, Innrain, Austria
University of Latvia, Riga, Latvia

University of Leeds, Leeds, United Kingdom
University of Maryland, College Park, Maryland, United States
University of Michigan, Ann Arbor, Michigan, United States
University of Ottawa, Ottawa, Ontario, Canada
University of Toronto, Toronto, Ontario, Canada
University of Vienna, Wien, Vienna
University of Vigo, Spain
University of Wisconsin, Madison, Wisconsin, United States
University of Victoria, Victoria, British Columbia, Canada

2010 Collaborations

Collaborative Publication Title	Co-authors	# of external collaborators	Publication
Building a spin quantum bit register using semiconductor nanowires	J. Baugh, J. S. Fung, J. Mracek and R. R. Lapierre, Nanotechnology	2	Nanotechnology
The quantum query complexity of certification	A. Ambainis, A. M. Childs, F. Le Gall, and S. Tani	1	Quantum Information and Computation, arXiv:0903.1291.
Efficient discrete-time simulations of continuous-time quantum query algorithms	R. Cleve, D. Gottesman, M. Mosca, R. Somma, and D. Yonge-Mallo	2	*ACM Symp. on Theory of Computing (STOC 2009)*
Entanglement-resistant two-prover interactive proof systems and non-adaptive private information retrieval systems	R. Cleve, D. Gavinsky, and R. Jain	2	*Quantum Information and Computation*, 9: 648–656, 2009.
Exact and approximate unitary 2-designs and their application to fidelity estimation	C. Dankert, R. Cleve, J. Emerson, and E. Livine	2	*Physical Review A*, 80: 012304 (6 pages), 2009
Three Slit Experiments and the Structure of Quantum Theory	C. Ududec, H. Barnum, J. Emerson	1	submitted to Foundations of Physics (2009)
Anti-symmetrization reveals hidden entanglement	A. Fedrizzi, T. Herbst, M. Aspelmeyer, M. Barbieri, T. Jennewein and A. Zeilinger	5	Institute of Physics Select (2009)
The security of practical quantum key distribution	V. Scarani, H. Bechmann-Pasquinucci, N.J. Cerf, M. Dusek, N. Lütkenhaus, M. Peev	3	Rev. Mod. Phys. Vol 81, p. 1301 (2009)
nconditional security of the Bennett 1992 quantum key-distribution scheme with strong reference pulse,	K. Tamaki, N. Lütkenhaus, M. Koashi, J. Batuwantudawe	2	Phys. Rev. A Vol 80, 032302 (2009)
Efficient discretTopological optimization of quantum key distribution networks	R. Alleaume, F. Roueff, E. Diamanti, N. Lütkenhaus	3	Topological optimization of quantum key distribution networks

The SECOQC quantum key distribution network in Vienna	M. Peev, C. Pacher, R. Alléaume, C. Barreiro, J. Bouda, W. Boxleitner, T. Debuisschert, E. Diamanti, M. Dianati, J. F. Dynes, S. Fasel, S. Fossier, M. Fürst, J.-D. Gautier, O. Gay, N. Gisin, P. Grangier, A. Happe, Y. Hasani, M. Hentschel,_H. Hübel, G. Humer, T.Länger, M. Legré, R. Lieger, J. Lodewyck, T. Lorünser, N. Lütkenhaus, A. Marhold, T. Matyus, O. Maurhart, L. Monat, S. Nauerth, J.-B. Page, A. Poppe, E. Querasser, G. Ribordy, S. Robyr, L. Salvail, A. W. Sharpe, A. J. Shields, D. Stucki, M. Suda, C. Tamas, T. Themel, R. T. Thew, Y. Thoma, A. Treiber, P. Trinkler, R. Tualle-Brouri, F. Vannel, N. Walenta, H. Weier, H. Weinfurter, I. Wimberger, Z. L. Yuan, H. Zbinden and A. Zeilinger	54	New J. Phys, Vol 11 075001 (2009)
Symmetric extension in two-way quantum key distribution	G. O. Myhr, J. M. Renes, Andrew C. Doherty and N. Lütkenhaus	2	Phys. Rev. A 79, 042329 (2009)
Asymptotic security of binary modulated continuous-variable quantum key distribution under collective attack	Y.-B. Zhao, M. Heid, J. Rigas and N. Lütkenhaus	2	Phys. Rev. A 79, 012307 (2009)
Can Closed Timelike Curves or Nonlinear Quantum Mechanics Improve Quantum State Discrimination or Help Solve Hard Problems?	Charles H. Bennett, Debbie Leung, Graeme Smith, John A. Smolin	3	Phys. Rev. Lett. 103:170502, 2009
Improving zero-error classical communication with entanglement	Toby S. Cubitt, Debbie Leung, William Matthews, Andreas Winter	1	arXiv:0911.5300 new accepted for 2010 conf.
Adaptive versus non-adaptive strategies for quantum channel discrimination	Aram W. Harrow, Avinatan Hassidim, Debbie W. Leung, John Watrous	2	arXiv:0909.0256
Title: Microtraps for neutral atoms using superconducting structures in the critical state	A. Lupaşcu, A. Emmert , M. Brune , G. Nogues , M. Rosticher , F.-R. Ladan, J.-P. Maneval , and J.-C. Villégier	7	accepted for publication in the Proceedings of the IEEE Toronto International Conference - Science and Technology for Humanity (2009)
CHECK	M. Rosticher , F.-R. Ladan, J.-P. Maneval, T. Zijlstra, T. M. Klapwijk, S. N. Dorenbos, V. Zwiller, A. Lupaşcu, and G. Nogues	8	submitted (to ?)
Measurement of the trapping lifetime close to a cold metallic surface on a cryogenic atom-chip	A. Emmert, A. Lupaşcu, M. Brune , J.-M. Raimond, S. Haroche, and G. Nogues	5	*Physical Review A*, 80, 061604(R) (2009)

One- and two-photon spectroscopy of a flux qubit coupled to a microscopic defect	A. Lupaşcu, P. Bertet, E.F.C. Driessen, C.J.P.M. Harmans, and J.E. Mooij	4	*Phys. Rev. B* 72, 172506 (2009).
Effect of vortices on the spin-flip lifetime of atoms in superconducting atom-chips	G. Nogues, C. Roux, T. Nirrengarten, A. Lupaşcu, A. Emmert, M. Brune , J.-M. Raimond, S. Haroche B. Plaçais, and J.-J. Greffet	9	*Europhysics Letters* 87, 13002 (2009).
Recognizing well-parenthesized expressions in the streaming model	Fr´ed´eric Magniez, Claire Mathieu, and Ashwin Nayak	2	." Submitted to the 42nd Annual ACM Symposium on Theory of Computing, 2009
On parallel composition of zero-knowledge proofs with black-box quantum simulators	R. Jain, A. Kolla, G. Midrijanis, B. Reichardt	3	Quantum Information and Computation, 9:513-532, 2009. (IF:3.379, 5IF:2.959)
Quantum trajectory equation for multiple qubits in circuit QED: Generating entanglement by measurement	Hutchison, Chantal L.; Gambetta, J. M.; Blais, Alexandre; Wilhelm, F. K.	1	CANADIAN JOURNAL OF PHYSICS
Two-message quantum interactive proofs are in PSPACE	R. Jain, S. Upadhyay, and J. Watrous.	1	*Proceedings of the 50th Annual IEEE Symposium on Foundations of Computer Science (FOCS)*, pages 534–543, 2009.
Symmetric extension in two-way quantum key distribution	Geir Ove Myhr1,2,*, Joseph M. Renes3, Andrew C. Doherty4, and Norbert Lütkenhaus1,2	1	*Phys. Rev. A 79, 042329 (2009) [10 pages]*
daptive versus non-adaptive strategies for quantum channel discrimination	Harrow, A. Hassidim, D. Leung, and J. Watrous	2	Submitted to *Physical Review A* in 2009. 11 pages.
Improving high-T_c dc-SQUID performance by junction asymmetry (2008)	*Urbasi Sinha, Aninda Sinha*, Frank K. Wilhelm	1	Supercond. Sci. Technol. 22 (2009) 055002
Current fluctuations in rough superconducting tunnel junctions	G. Heinrich and F.K. Wilhelm	1	Phys. Rev. B 80, 214536 (2009)
Microscopic model of critical current noise in Josephson-junction qubits: Subgap resonances and Andreev bound states	Rogerio de Sousa, K. Birgitta Whaley, *Theresa Hecht*, Jan von Delft, Frank K. Wilhelm	4	Phys. Rev. B 80, 094515 (2009).
The size of macroscopic superposition states in flux qubits	J. I. Korsbakken, F. K. Wilhelm, and K. B. Whaley	2	Phys. Scr. T 137, 014022 (2009).
Characterizing heralded single-photon sources with imperfect measurement devices	M. Razavi, I. Sollner, E. Bocquillon, C. Couteau, R. Laflamme, and G.Weihs	4	. Phys. B: At. Mol. Opt. Phys., 42:114013, 2009 and. Phys. B: At. Mol. Opt. Phys., 42:114013, 2009 and arXiv:0812.2445.
Testing born's rule in quantum mechanics with a triple slit experiment	U. Sinha, C. Couteau, Z. Medendorp, I. Sollner, R. Laflamme, R. Sorkin, and G Weih	4	Foundations of Probability and Physics

On the geometric interpretation of single qubit quantum operations on the bloch sphere	A Pasieka, D.W. Kribs, R. Laflamme, and R. Pereira	3	Applicandae Mathematicae, www.springerlink.com/content/1097u1t485053w54/, 2009.
Direct observation of quantum criticality in ising spin chains	J. Zhang, F.M. Cucchietti, C. Chandrashekar, M. Laforest, C.A. Ryan, M. Ditty, A. Hubbard, J.K. Gamble, and R. Laflamme.	2	Physical Review A, 79:012305, 2009 and arXiv:0808.1536.
Efficient Discrete-Time Simulations of Continuous-Time Quantum Query Algorithms	R. Cleve, D. Gottesman, M. Mosca, R. Somma, and D. Yonge-Mallo	2	Proceedings of 41st Annual ACM Symposium on Theory of Computing (STOC'09), Bethesda, USA, 2009.
Simulating Quantum Systems Using Real Hilbert Spaces	M. McKague, M. Mosca and N. Gisin	1	Physical Review Letters, 102 (2), 020505 (2009)
Capacity of Quantum Erasure Channel Assisted by Backwards Classical Communication	Leung, Debbie; Lim, Joungkeun; Shor, Peter	2	10.1103/PhysRevLett.103.240505 (2009)
Continuity of Quantum Channel Capacities	Leung, Debbie; Smith, Graeme	1	10.1007/s00220-009-0833-1
Simplifying quantum logic using higher-dimensional Hilbert spaces	Lanyon, Benjamin P.; Barbieri, Marco; Almeida, Marcelo P.; Jennewein, Thomas; Ralph, Timothy C.; Resch, Kevin J.; Pryde, Geoff J.; O'Brien, Jeremy L.; Gilchrist, Alexei; White, Andrew G.	8	Nature Physics 10.1038/NPHYS1150

L. Scientific Visitors

2011 - 2012 Visitors

- Mohamed Abutaleb, Massachusetts Institute of Technology
- Gerardo Adesso, The University of Nottingham
- Jason Alicea, University of California, Irvine
- Itai Arad, The Hebrew University of Jerusalem
- Michal Bajcsy, Stanford University
- Howard Barnum, Los Alamos National Laboratory
- Patrice Bertet, Commissariat à l'énergie atomique-Saclay
- Jacob Biamonte, University of Oxford
- Lev Bishop, University of Maryland
- Fernando Brandao, Imperial College London
- Daniel Braun, Université Paul Sabatier, Toulouse
- Misha Brodsky, AT&T
- Aaron Brodutch, Macquarie University
- Raffi Budakian, University of Illinois at Urbana-Champaign, Illinois
- Irfan Bulu, Harvard, Cambridge Massachusetts
- Jonas Bylander, Massachusetts Institute of Technology,
- John Calsamiglia, Universitat Autònoma de Barcelona
- Paola Cappellaro, Massachusetts Institute of Technology
- Carlton M. Caves, University of New Mexico
- Donny Cheung, Tornado Medical Systems
- Eric Chitambar , University of Toronto
- Matthias Christandl, Institute for Theoretical Physics Zurich
- Roger Colbeck, Perimeter Institute
- Jason Crann, Carleton University
- Toby Cubitt, Universidad Complutense de Madrid
- Hang Dinh, Indiana University South Bend
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- Steve Flammia, University of Washington
- Chi-Hang Fred Fung, The University of Hong Kong
- Joshua Geller, University of Rochester
- Alexey Gorshkov, Harvard
- David Gosset, Academia Sinica Europea
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- Simon Gröblacher, California Institute of Technology
- Jeongwan Haah, California Institute of Technology
- Alioscia Hamma, Perimeter Institute
- Lucien Hardy, Perimeter Institute
- Andrew Houck, Princeton University
- Hannes Hübel, Stockholm University
- Kazuo Iwama, Kyoto University
- Rahul Jain, Centre for Quantum Technologies
- Liang Jiang, Institute for Quantum Information (IQI)
- Stephen Jordan, National Institute of Standards and Technology
- María José, García Spanish National Research Council
- Dongpeng Kang, University of Toronto
- Marc Kaplan, Université de Montréal
- Gurneet Kaur, Massachusetts Institute of Technology
- Yoon-Ho Kim, Pohang University of Science & Technology
- Jens Koch, Northwestern University
- Vladimir Korepin, Stony Brook University
- Yuimaru Kubo, Commissariat à l'énergie atomique-Saclay
- Daniel Kumar, University of North Carolina at Chapel Hill
- Mitsuru Kusumoto, Kyoto University
- Paul G. Kwiat, University of Illinois at Urbana-Champaign
- Thomas Lauprêtre, Laboratoire Aimé Cotton
- Jonathan Leach, University of Ottawa
- Thomas Lehner, dotfast-consulting
- Marko Loncar, Harvard School of Engineering and Applied Sciences
- Dawei Lu, University of Science and Technology of China
- Shunlong Luo, Academy of Mathematics and Systems Science Chinese Academy of Sciences
- Thomas Lutz, Universität Ulm
- Vadim Lyubashevsky, École Normale Supérieure
- Steve MacLean, Canadian Space Agency
- Arka Majundar, Stanford University

- Matteo Mariantoni, University of California, Santa Barbara
- Eduardo Martin-Martinez, Instituto de Fisica Fundamental
- Ralph Merkle, Institute for Molecular Manufacturing and Singularity University
- Maiken Mikkelsen, University of California, Berkeley
- Nathaniel Nelson-Fitzpatrick, University of Alberta
- Leonardo Neves, University of Concepción - Center for Optics and Photonics
- Corey O'Meara, Technical University of Munich
- Steven Olmschenk, University of Maryland
- Gerardo Ortiz, Indiana University Bloomington
- Mauro Paternostro, Queen's University
- Jason Petta, Princeton University
- Daniel Posch, Office of Science and Technology
- Benedikt Pressl, Universität Innsbruck
- Robert Prevedel, Research Institute for Molecular Pathology
- Timothy Ralph, University of Queensland
- Chandrasekhar Ramanathan, Dartmouth College
- Christopher Raum, University of California, Irvine
- Grégoire Ribordy, id Quantique, Genève
- David Rideout, University of California, San Diego
- Arnau Riera, Potsdam University
- Alexander Rimberg, Dartmouth College
- Terence G. Rudolph, Imperial College London
- Mary Beth Ruskai, Tufts University
- Vincent Russo, Wayne State University
- Kei Sano, Kyoto University
- Dylan Saunders, Griffith University
- Carmelo Scarcella, Politecnico Di Milano
- Naresh Sharma, Tata Institute of Fundamental Research
- Fred Shultz, Wellesley College
- Irfan Siddiqi, University of California, Berkeley
- Ray Simmonds, National Institute of Standards and Technology
- Jonathan Simon, Harvard
- Sidharth Somanathan, Texas A&M
- Rolando Somma, Los Alamos National Laboratory
- William Stacey, University of Alberta
- David J. Starling, University of Rochester
- Douglas Stebila, Queensland University of Technology
- Gordon Stovel, Canadian Foundation for Innovation
- Dieter Suter, Universität Dortmund
- Mario Szegedy, Rutgers University
- Louis Taillefer, Université de Sherbrooke
- Yongchao Tang, Tsinghua University
- Seiichiro Tani, Nippon Telegraph and Telephone Communication Science Laboratories
- Daniel Terno, Macquarie University
- Junichi Teruyama, Kyoto University
- Oleg Tretiakov, Texas A&M (Agricultural and Mechanical) University
- Sarvagya Upadhyay, Centre for Quantum Technologiese
- Berkant Ustaoglu, Sabinci University
- Ramarathnam Venkatesan, Microsoft
- Rajamani Vijayaraghavan, University of California, Berkeley
- Paolo Villoresi, University of Padova
- Yun-jiang Wang, University of Calgary
- Amy Wang, Tsinghua University
- Tzu-Chieh Wei, University of British Columbia
- Gregor Weihs, University of Innsbruck
- Yaakov Weinstein, MITRE Corporation
- Birgitta Whaley, University of California, Berkeley
- Christopher Wilson, Chalmers University of Technology
- David Wineland, National Institute of Standards and Technology
- Jörg Wrachtrup, University of Stuttgart
- Xiaodi Wu, University of Michigan
- Lianao Wu, University of the Basque Country Universidad del País Vasco
- Amir Yacoby, Harvard
- Yutaro Yamaguchi, Kyoto University
- Jun Yong Khoo, University of Oxford
- Beni Yoshida, Massachusetts Institute of Technology
- Nengkun Yu, Tsinghua University and University of Technology
- Shengyu Zhang, The Chinese University of Hong Kong
- Shizhong Zhang, Ohio State University
- Hongchao Zhou, California Institute of Technology

2010-2011 Visitors

- 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 (KIAS)
- 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 in Garching, Germany
- Guido Burkard, University of Konstanz
- Jianming Cai, Institut für Theoretische Physik - Universität 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, Wilfred 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, Centre for Quantum Technologies & 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, QinetiQ Ventures
- Shunlong Luo, Chinese Academy of Sciences
- Alex Lvovsky, University of Calgary
- Lars Lydersen, Norwegian University of Science and Technology (NTNU)
- Xiongfeng Ma, No Affiliation
- Frederic Magniez, Laboratoire de Recherche en Informatique
- Vadim Makarov, Norwegian University of Science and Technology (NTNU)
- 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
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- 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, Universitè de Montrèal
- 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, Karlruche Institute
- Volkher Scholz, University Hannover
- Norbert Schuch, California Institute of Technology
- Pranab Sen, Tata Institute of Fundamental Research (TIFR)
- Zahra Shadman, Institue 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, IISc, Bangalore and President of the Indian Academy of Sciences
- Douglas Stebila, University of Queensland
- DJ Strouse, University of Southern California
- Martin Suchara, Princeton University
- G. Sundararajan, Director of 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, Milli Kelvin Technologiwa/ Leiden Cryogebics, The Netherlands
- 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
- Albion Yang, Simon Fraser University
- Man Hong Yung, Harvard University
- Wojciech Zurek, Los Alamos National Laboratory and Santa Fe Institute

2009-2010 Visitors

- Graeme Smith, IBM
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- Masato Koashi, Osaka University
- Eric Brown, McMaster
- Yun-Pil Shim, Institute for Microstructural Sciences
- Ian Town, University of Canterbury
- Miklos Santha, National University of Singapore
- John Preskill, Caltech University
- Stephanie Wehner, Caltech University
- Earl Campbell, University College London
- Abuzer Yakaryilmaz, Bogazici University
- Tony Leggett, University of Illinois

- Dervis Can Vural, University of Illinois
- Mao-Chuang Yeh, University of Illinois
- Jitong Yu, University of Illinois
- Alain Tapp, University of Montreal
- Jim Rabeau, Macquarie University
- Shengyu Zhang, The Chinese University of Hong Kong
- Harry Buhrman, University of Amsterdam
- Avinatan Hassidim, Hebrew University
- Jan Fischer, University of Basel
- Konrad Lehnert, JILA/NIST
- Fei Yan, MIT
- Atul Asthana, RIM
- Matthew Cheriyan, Industry Canada
- Richard Kolacz, COM DEV
- Ian D'Souza, COM DEV
- Pieter de Groot, Delft University
- Jun Yin, University of Oregon
- Jeff Lundeen, NRC
- Cheng Chin, University of Chicago
- Fernando Brandao, Imperial College
- Jason Soo Hoo, Siena College
- Steven Van Enk, University of Oregon
- Volkher Scholz, Leibniz Universitat Hannover
- Fernando Brandao, Imperial College
- Stuart Tessmer, Michigan State University
- Jonathan Friedman, Amherst
- Ben Lanyon, University of Queensland
- Toby Cubitt, University of Bristol
- Patrick Smutek Plassys
- Stephaine Simmons, St. John's College, Oxford
- John Morton, St. John's College, Oxford
- Chelsea Schmaltz, UW
- Martin Laforest, Delft University
- Yi-Kai Liu, Caltech University
- Daniel Burgarth, Imperial College
- Stephen Fenner, University of South Carolina
- Fei Yan, MIT
- Terry Rudolph, Imperial College
- Alessandro Cosentino, University Pisa
- Thomas Schulte-Herbruggen, Technical University Munich
- Louise Kauffman, University of Illinois
- Alexei Gilchrist, QISS
- Andrew White, University of Queensland
- Stephen Hughes, Queen's University
- Piotr Kolenderski, Nicolaus Copernicus University
- John Maritinis, University of California
- Miles Blenowe, Dartmouth College
- Mark Rudner, Harvard University
- Eric Lucero, University of California
- Christian Weedbrook, University of Queensland
- Hideo Hosono, UW, WIN
- Shiva Amiri, British Consulate
- Nicolas Menicucci, PI
- Greg Chaitin, IBM
- Don Aldrige, IBM
- Nancy Lu, University of Calgary
- Jerry Chow, Yale University
- Ting-An Wang, TECO Canada
- Howard Wiseman, Griffith University
- Anton Zeilinger, University of Vienna
- Peter Shor, MIT
- Dorit Aharonov, Hebrew University
- Andrew White, University of Queensland
- Gerard Milburn, University of Queensland
- Umesh Vazirani, University of California
- Barbara Terhal, IBM Watson Research Centre
- Stuart Wolf, University of Virginia
- Fei Yan, MIT
- Douglas Stebila, University of Queensland
- Brandon Armstrong, University of California
- Roman Barankov, Boston University
- Jonathan Hodges, MIT
- Dimitry Pushin, MIT
- Kevin Krsulich, MIT
- Sarah Sheldon, MIT
- Mohamed Abutaleb, MIT
- Daniel Kumar, MIT
- Myroslaw Tataryn, UW
- Olena Juzar
- Sergei Ailujko
- Adi Shamir, Weizmann Institute of Science
- Adan Cabello, Universidad de Sevilla
- Katja Nowack, Delft University
- Robin MacNab, Trade Commissioner, Ontario Region, Foreign Affairs and and International Trade
- Robert Ulmer, Counsellor (Commercial - Ontario) at Embassy of Canada in Japan
- Waichi Sekigucki, Nikkei Inc.

- Ramy Nassar, RIM
- Renjie, Butalid, TEDxWaterloo
- Giuseppe Prettico, ICFO/Varcelona
- Otfried Guhne, Institut für Quantenoptik und Quanteninformation
- Ray Filteau, Carnegie Mellon University
- Jessica Zhang, Carnegie Mellon University
- Dmitry Gavinsky, NEC Laboratories America
- Jerome Bourassa, Université de Sherbrooke
- Anya Tafliovich, University of Toronto
- Steve MacLean, President of the Canadian Space Agency
- Alex Russell, University of Connecticut
- Frederic Grosshans, Laboratoire d ePhotonique Quantiqueet Moléculaire, ENS de Cachan
- William Wooters, William College
- Chris Payette, McGill
- Paul Nation, Dartmouth College
- Chris Laumann, Prineton
- Anand Kumar, Rochester University
- Dmitry Pushin, MIT
- Oleg Gittsovich, University of Innsbruck
- Martin Laforest, Delft University
- William Slofstra, UC Berkeley
- Steven Bennett, McGill
- Krister Shalm, University of Toronto
- Emily Pritchett, University of Georgia
- Kent Fisher, University of Guelph
- Andris Ambainis, University Latvia
- Michel Pioro-Ladiere, Université de Sherbrooke
- Florian Ong, Universita de Sherbrooke
- Chandrasekhar Ramanathan, MIT
- Martin Roetteler, NEC Laboratories America
- Aram Harrow, University of Bristol
- Morgan Mitchell, The Institute of Photonic Sciences
- Patryk Gumann, Rutger University
- Robabeh Rahimi Darabad, Kinki University
- Hendrik Bluhm, Harvard University
- Howard Barnum, PI
- Alberto Marino, University of Rochester
- David Touchette, McGill
- Colm Ryan, MIT
- David Schuster, Yale University
- Dmitry Matsukevich, University of Maryland
- Roderich Tumlka, Rutger University
- Edward Farhi, MIT
- Jeff Lundeen, National Research Council Canada
- David Marcos, ICMM
- Catherine Holloway, Dallahouise
- Lai Choy Heng, CQT and NUS
- Kuldip Singh, CQT & NUS
- Tan Eng Chye, NUS
- Artur Ekert, CQT
- Roger Melko, UW
- Chris Fuchs, PI
- Peter Legg, University of Western Ontario
- Vincent Nesme, Institut für Theoretische Physik
- Lev Vaidman, Tel Aviv University
- Thomas Jochym-O'Connor, McGill
- Maarten van den Nest, Max Planck Institute of Quantum Optics in Garching
- Ion Nechita, University of Ottawa
- Ghadir Mohammadkani, Zanjan University
- Artem Kaznatcheev, McGill
- Stephen Turnbull, Carleton
- David Poulin, Université de Sherbrooke
- Pranab Sen, Tata Institute of Fundamental Research
- Rajat Mittal, Rutger University
- Vladimir Manucharyan, Yale University
- Scott Foubister, Thompson Rivers University
- Samuel Denny, Cambridge
- Michel Devoret, Yale University
- Spyridon Michalakis, Center for Nonlinear Studies
- David Frasen, Consul General of Canada
- Sasha (Alexander) Korotkov, University of California

M. Conferences

2012 (Upcoming)

1. Recent Progress in Quantum Algorithms
   April 11-13, 2012

2. Undergraduate School on Experimental Quantum Information Science
   May 28 - June 8, 2012

3. 12th Annual Canadian Summer School on Quantum Information
   June 11-16, 2012

4. The 9th Canadian Student Conference on Quantum Information, and the 2nd AQuA Student Congress on Quantum Information and Computation
   June 18-22, 2012

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

2011

1. Nano Structured & Entangled Photon Sources for Quantum Information Processing
   April 28 - 29, 2011
   25 participants

2. Women in Physics Canada
   July 19-21, 2011
   60 participants

3. Undergraduate School on Experimental Quantum Information Processing (USEQIP)
   May 30-June 10, 2011
   19 participants

4. Quantum Key Distribution Summer School
   July 25-29, 2011
   47 participants

5. Quantum Cryptography School for Young Students (QCSYS)
   August 8-12, 2011
   42 participants

2010

1. Cross-Border Workshop on Laser Science
   May 3 - May 5, 2010
   78 participants

2. Quantum Information Processing with Spin and Superconductors
   May 17 - May 19, 2010
   62 participants

3. Undergraduate School on Experimental Quantum Information Processing (USEQIP)
   May 24 - June 4, 2010
   13 participants

4. Theory and Realization of Practical Quantum Key Distribution
   June 14 - June 17, 2010
   69 participants

5. Quantum Cryptography School for Young Students (QCSYS)
   July 26 - July 30, 2010
   38 participants

2009

1. The Fourth Workshop on the Theory of Quantum Computation, Communication and Cryptography
   May 11 - 13, 2009
   100 participants

2. Undergraduate School on Experimental Quantum Information Processing (USEQIP)
   June 1 - 12, 2009
   11 participants

3. Quantum Cryptography School for Young Students (QCSYS)
   July 27 - July 31, 2009
   19 participants

4. Mathematics in Experimental Quantum Information Processing Workshop
   August 10-15, 2009
   30 participants

5. UW/MIT Spintronics Meeting
   September 19-22, 2009
   20 participants

N. Invited Talks

Jonathan D. Baugh	03-Jan-12	Digital Quantum Simulation of the Statistical Mechanics of a Frustrated Magnet	The 42nd Winter Colloquium on the Physics of Quantum Electronics
Jonathan D. Baugh	05-Oct-11	Coherent control of two nuclear spins using the anisotropic hyperfine interaction	Purdue University Physical Chemistry Seminar
Jonathan D. Baugh	18-Sep-11	Coherent control of two nuclear spins using the anisotropic hyperfine interaction	Buffalo Workshop on Quantum Computing
Andrew Childs	07-Oct-11	The quantum query complexity of read-many formulas	Workshop on Quantum Computer Science, Centre de Recherches Mathematiques
Andrew Childs	10-Dec-11	The quantum query complexity of read-many formulas	Canadian Mathematical Society
Andrew Childs	19-Jan-11	The quantum query complexity of read-many formulas	First NASA Quantum Future Technologies Conference
Andrew Childs	19-Sep-11	Constructing elliptic curve isogenies in quantum subexponential time	Dagstuhl Workshop on Quantum Cryptanalysis
Andrew Childs	09-Jun-11	Quantum algorithms: Unstructured search, quantum walk, and adversary lower bounds	Eleventh Canadian Summer School on Quantum Information
Richard Cleve	21-Jul-11	Nonlocality in an information processing context	Centrum Wiskunde & Informatica
Richard Cleve	5-Oct-11	Non-local games based on binary constraint systems	University of Montreal
David Cory	15-Nov-11	Electron spin actuator for nuclear spin control	University of Guelph
David Cory	05-Dec-11	Electron spin actuator for nuclear spin control	Quantum Error Correction 2011
David Cory	13-Oct-11	Quantum Devices	NSERC and Industry Canada Seminar
Joseph Emerson	28-Nov-11	Efficient and Robust Randomized benchmarking	Quantum Tomography Workshop
Thomas Jennewein	02-May-11	Triple Photons and Triple Slits – a New Frontier in Quantum Mechanics Tests	CLEO 2011 - Has Many Sponsers - not sure if one is primary

Thomas Jennewein	18-May-11	Satellite based Quantum Communications - Concepts and Requirements: Requirements for quantum communications with satellites, Invited Talk at the Information Photonics conference	ICO International - Information Photonics 2011
Thomas Jennewein	12-May-11	Satellite-Based QKD: Canadian Quantum Satellite Mission, an invited presentation at the QIP CIFAR program meeting	CIFAR
Thomas Jennewein	10-Jun-11	"High transmission-loss and classical-quantum multiplexing QKD enabled with short wavelength photons"	University of Toronto
Thomas Jennewein	20-Jun-11	High transmission-loss and classical-quantum multiplexing QKD enabled with short wavelength photons	University of Calgary
Thomas Jennewein	16-Mar-11	Final Review Meeting of the Feasibility Study	Canadian Space Agency
Thomas Jennewein	Jun-11	High transmission-loss and classical-quantum multiplexing QKD enabled with short wavelength photons: invited seminar at University of Toronto, Quantum Information Group, June 2011.	University of Toronto, Quantum Information Group
Thomas Jennewein	Jun-11	High transmission-loss and classical-quantum multiplexing QKD enabled with short wavelength photons: invited seminar at University of Calgary, June 2011.	University of Calgary
Thomas Jennewein	Oct-11	QEYSSAT – Quantum Science and Encryption Satellite, colloquium at Perimeter Institute, October 2011.	Perimeter Institute for Theoretical Physics
Thomas Jennewein	Nov-11	Qutrit experiments based on the 200 year old concepts of Young's interference, presentation at the CIFAR meeting, Calgary, Nov. 2011.	CIFAR
Raymond Laflamme	28-Jun-11	A peak into the quantum world: a place where there are no penalties for interference	World Conference of Science Journalists
Raymond Laflamme	10-May-11	Emerged/Emerging Disruptive Technologies	NATO: Research and Technology Agency
Raymond Laflamme	14-Oct-11	Experimental Quantum Error Correction	University of Ulm
Raymond Laflamme	05-Oct-11	Quantum Computing	RIM

Raymond Laflamme	10-Nov-11	Towards Experimental Quantum Error Correction	CIFAR
Raymond Laflamme	06-Dec-11	Experimental Quantum Error Correction	QEC
Debbie Leung	12-Jul-11	Authentication of quantum messages	The Optical Society of America, Imaging and Applied Optics: OSA Optics and Photonics Congress, LS&C Technical session on quantum information assurance.
Debbie Leung	21-Jul-11	Improving Zero-error Classical Communication with Entanglement	International Council for Industrial and Applied Mathematics (ICIAM) in Vancouver, Thematic Minisymposia: Current Interests in Mathematical Physics
Debbie Leung	12 - 16/Sep/ 2011	Composability of quantum message authentication and key recycling	QCRYPT 2011
Debbie Leung	04-Oct-11	"Non-maximally entangled state in quantum computation and communication complexity",	Centre de recherches mathematiques: Workshop on Quantum Computer Science, University of Montreal
Debbie Leung	10-Dec-11	"Finite amount of entanglement can be insufficient for a small size quantum game"	"Canadian Mathematical Society Winter Meeting, Quantum Information session"
Adrian Lupascu	25-May-11	Artificial atoms based on superconductors	Colloquium at Kavli Institute for Theoretical Physics China
Adrian Lupascu	27-May-11	Quantum gates for qubits with fixed coupling	Seminar in the dept. of Microelectronics at Tsinghua University
Adrian Lupascu	02-Jun-11	Quantum gates and quantum non-demolition photon detection in superconducting circuits	Talk at Kavli Institute for Theoretical Physics China, within the program “Atomic Physics with Superconducting Circuits”

Adrian Lupascu	25-Jul-11	Superconducting devices for quantum information processing	Seminar at University of Bucharest, National Institute of Material Science
Adrian Lupascu	06-Jan-11	Quantum computing and quantum optics with superconducting circuits	D-Wave Systems
Adrian Lupascu	07-Mar-11	Quantum Electrical Circuits (CAP Lecture Tour)	Carleton University
Adrian Lupascu	15-Mar-11	Quantum Electrical Circuits (CAP Lecture Tour)	Mount Alison University
Adrian Lupascu	16-Mar-11	Quantum Electrical Circuits (CAP Lecture Tour)	Université de Moncton
Adrian Lupascu	09-Mar-11	Quantum Electrical Circuits (CAP Lecture Tour)	Trent University
Adrian Lupascu	17-Mar-11	Quantum Electrical Circuits (CAP Lecture Tour)	University of New Brunswick at Fredericton
Adrian Lupascu	04-Mar-11	Quantum Electrical Circuits (CAP Lecture Tour)	University of Ottawa
Adrian Lupascu	14-Mar-11	Quantum Electrical Circuits (CAP Lecture Tour)	University of Prince Edward Island
Adrian Lupascu	31-Mar-11	Quantum Electrical Circuits (CAP Lecture Tour)	University of Western Ontario
Adrian Lupascu	07-Jun-11	Introduction to superconducting qubits and Selected topics in superconducting qubits	Institute for Quantum Computing - University of Waterloo
Adrian Lupascu	08-12-Aug-2011	Gates for superconducting qubits with fixed couplings	Conference on Quantum Information and Quantum Control - The Fields Institute for Research in Mathematical Sciences
Adrian Lupascu	17-18-Sep-2011	Quantum gates for qubits with fixed coupling	"US National Security Agency and Laboratory for Physical Sciences through the US Army Research Office, Department of Physics at the University at Buffalo, The State University of New York"
Adrian Lupascu	21-Oct-11	Superconducting quantum devices: generation of entangled states using one microwave driving line per qubit	Seminar at Northwestern University

Norbert Lütkenhaus	01-Mar-11	Quantum Optics & Quantum Information: A toolbox	Max Planck Institute (MPL) Winter Retreat
Norbert Lütkenhaus	06-Jun-11	Improved Heralding Devices and Applications to Device Independent QKD	International Conference on Quantum Information (ICQI)
Norbert Lütkenhaus	15-Jun-11	Linear-optics implementations of nondestructive single-photon measurements and arbitrary quantum channels	2011 DAMOP Annual Meeting
Norbert Lütkenhaus	19-Oct-11	Quantum Information Theory in Optics	Frontier in Optics (FiO) 2011 - APS/DLS Annual Meeting
Norbert Lütkenhaus	20-Mar-11	Directions in Optical Implementations of Quantum Key Distribution	Quantum Information and Measurement (QIM)
A. Hamed Majedi	19-Apr-11	Quantum Optoelectronics by NbN Superconducting Nanowire Single Photon Detectors	SPIE Optics +Optoelectronics 2011
Guo-Xing Miao	November-2011	Spin-polarized transport and magnetoresistance	Shandong University
Guo-Xing Miao	November-2011	Spin-polarized transport and magnetoresistance	Korea Institute of Science and Technology
Guo-Xing Miao	03-Oct-11	Spin-polarized transport and magnetoresistance	McMaster University
Guo-Xing Miao	September-2011	Spin-polarized transport and magnetoresistance	Texas State University
Michele Mosca	02-Dec-11	A new spin on Quantum Cryptography: Avoiding trapdoors and embracing public keys	University of Kyoto
Michele Mosca	30-Nov-11	A new spin on Quantum Cryptography: Avoiding trapdoors and embracing public keys	Contributed talk at Fourth International Conference on Post-Quantum Cryptography (PQCrypto 2011)
Michele Mosca	Oct-11	Unconditionally-secure and reusable public-key authentication	Workshop on Quantum Computer Science
Michele Mosca	Aug-11	Cryptography in a Quantum World	The Internet Task Force Meeting
Michele Mosca	Jun-11	Hot Topics in Crypto	The Certicom Research Elliptic Curve Cryptography (ECC) Conference

Michele Mosca	11-Jan-12	Quantum Cryptography	Computational Science and Applied & Statistical Modeling (CSASM), Wilfred Laurier University
Michele Mosca	01-Jul-11	Introduction to Quantum Information Processing	Women in Physics Conference
Michele Mosca	01-Jun-11	1 lecture on QKD at the QKD summer school	Institute for Quantum Computing
Ashwin Nayak	9-Jan-12	The Quantum Substate Theorem	Tata Institute for Fundamental Research
Ashwin Nayak	Oct 4-7, 2011	The Quantum Substate Theorem	Quantum Computer Science Workshop, CRM
Ashwin Nayak	28-Jun-11	The Quantum Substate Theorem	Institute for Quantum Information Seminar
Ashwin Nayak	6-Apr-11	Recognizing well-parenthesized expressions in the streaming model	DIMACS Theoretical Coimputer Science Seminar, Rutgers
Ashwin Nayak	04-Apr-11	Improved bounds for the randomized decision tree complexity of recursive majority	Computer Science and Discrete Mathematics seminar, IAS
Ashwin Nayak	28-Jan-11	The index function and the streaming complexity of Dyck languages	Centre for Quantum Techologies, National University of Singapore
Marco Piani	2-Jul-11	Signatures of Quantumness in Complex Systems	ESF-PESC Strategic Workshop
Marco Piani	10-Dec-11	Quantumness and entanglement in quantum measurements	Canadian Mathematical Society Winter Meeting
Marco Piani	2-Jul-11	Characterizing quantumness via entanglement creation	ESF-PESC Strategic Workshop on Signatures of Quantumness in Complex Systems,
Marco Piani	18-Nov-11	Quantumness versus entanglement in quantum measurements	LANL
Marco Piani	09-Nov-11	Quantumness of correlations in entanglement distribution and in quantum data hiding	University of New Mexico
Marco Piani	06-Jul-11	Characterizing quantumness via entanglement creation	Department of Physics

Marco Piani	28-Jun-11	Usefulness of entanglement in channel discrimination with and without restricted measurements	School of Mathematical Sciences, University of Nottingham
Marco Piani	31-Jan-11	Operational interpretations of quantum discord	Perimeter Institute Quantum Information group meeting, Perimeter Institute
Marco Piani	19-Jan-11	Activation of non-classical correlations: the entanglement potential of the relative entropy of quantumness	Center for Quantum Technologies, NUS,
Ben Reichardt	12-May-11	How to compose quantum algorithms	HRL Labs
Ben Reichardt	16-May-11	Optimal algorithms for quantum computers based on a norm	Sandia National Laboratories
Ben Reichardt	25-May-11	Span-program-based algorithm for evaluating unbalanced formulas	Conference on Theory of Quantum Computation, Communication and Cryptography (TQC 2011)
Ben Reichardt	23-Sep-11	Self-testing for sequential CHSH games	Dagstuhl seminar on Quantum Cryptanalysis
Ben Reichardt	7-Oct-11	Query complexity of converting states	Workshop on Quantum Computer Science
Ben Reichardt	7-Nov-11	Key distribution with minimal assumptions	Berkeley University of California
Ben Reichardt	15-Dec-11	Quantum query complexity for state conversion	Quantum Information Processing (QIP) 2012
Kevin Resch	19-May-11	Photon Triplets and Bound Entanglement	ICO International - Information Photonics 2011
Kevin Resch	30-Jun-11	Entangled photon sources and tests of quantum nonlocality	Extreme Photonics Summer school, University of Ottawa
Kevin Resch	2011	"From Quantum Physics to Bio-Medical Imaging, University of Vienna, Vienna, Austria (2011). Delivered by R. Prevedel"	University of Vienna
John Watrous	10-Dec-11	Hedging bets with correlated quantum strategies	Canadian Mathematical Society Winter Meeting
John Watrous	05-Oct-11	Parallel approximation of the completely bounded trace norm	Quantum Computer Science Workshop

John Watrous	18-May-11	Hedging bets with correlated quantum strategies	CIFAR
Frank Wilhelm-Mauch	06-Jan-11	Critical current noise in superconducing qubits	D-Wave Systesm
Frank Wilhelm-Mauch	07-Jan-11	Optimal control of imperfect qubits	University of Victoria
Frank Wilhelm-Mauch	12-Jan-11	NSERC Nano-qubits network	IMEC, National Research Council
Frank Wilhelm-Mauch	13-Jan-11	NSERC Nano-qubits network	IBM Bromont
Frank Wilhelm-Mauch	Jan-11	NSERC Nano-qubits network	Universite de Sherbrooke
Frank Wilhelm-Mauch	20-Jan-11	Theory of junction noise in superconducting qubits (at CSQ program review)	IARPA
Frank Wilhelm-Mauch	23-Mar-11	Multi-resonator circuit QED II: Generation and detection of NOON states (at APS March Meeting)	APS
Frank Wilhelm-Mauch	Mar-11	Verifying entanglement with near-quantum limited amplifiers: Theoretical aspects	"DARPA QuEST review meeting"
Frank Wilhelm-Mauch	June 6 - 8, 2011	Architecture for a superconducting quantum computer: Theoretical aspects	IARPA MQCO review
Frank Wilhelm-Mauch	Jun-11	Superconducting circuits: A quantum physics playground	University of Windsor
Frank Wilhelm-Mauch	Nov-11	Optimal control of imperfect qubits	University of the Basque country

O. Times Higher Education Rankings 2012

Harvard University
Massachusetts Institute of Technology
University of Cambridge
Stanford University
University of California Berkeley
University of Oxford
Princeton University
University of Tokyo
University of California Los Angeles
Yale University
California Institute of Technology
University of Michigan
Imperial College London
University of Chicago
Columbia University
Cornell University
University of Toronto
Johns Hopkins University
University of Pennsylvania
Kyoto University
University College London
ETH Zürich - Swiss Federal Institute of Technology Zürich
University of Illinois at Urbana Champaign
National University of Singapore
University of British Columbia
McGill University
University of Wisconsin-Madison
University of Washington
London School of Economics and Political Science
Tsinghua University
University of California San Francisco
University of Texas at Austin
Duke University
New York University
Northwestern University
University of California San Diego
Carnegie Mellon University
Peking University
University of Hong Kong
University of Massachusetts
Georgia Institute of Technology
Ludwig-Maximilians-Universität München
University of Melbourne
Australian National University
University of California Davis
University of North Carolina at Chapel Hill
University of Minnesota
Purdue University
University of Edinburgh
University of Sydney
Delft University of Technology
Karolinska Institute
University of Manchester
Ohio State University
Osaka University
Pennsylvania State University
University of California Santa Barbara
Seoul National University
Tohoku University
Tokyo Institute of Technology
École Polytechnique Fédérale de Lausanne
Hebrew University of Jerusalem
Hong Kong University of Science and Technology
Humboldt-Universität zu Berlin
King's College London
Technische Universität München
University of Pittsburgh
University of São Paulo
University of Southern California
National Taiwan University
University of Amsterdam
Universität Heidelberg
Michigan State University
Université Paris-Sorbonne
University of Queensland Australia
Texas A&M University
Uppsala University
Utrecht University
Washington University in St Louis
University of Zürich
Brown University
Chinese University of Hong Kong
University of Florida
Katholieke Universiteit Leuven
Korea Advanced Institute of Science and Technology
University of Leeds
Leiden University
Lund University
Nanyang Technological University
Tel Aviv University

University of Arizona
Boston University
University of Bristol
École Polytechnique
Indiana University
Middle East Technical University
Université Paris-Sud
Université Pierre et Marie Curie
Rutgers, The State University of New Jersey
Wageningen University and Research Center

P. Commentary & Analysis

Below is a list of papers, presentations and videos that give an overview or provide comments about advances and challenges in quantum information research.

General Scientific Commentary

Articles

1. A Survey of Quantum Information Processing Funding in Canada, 2001 - 2010
   - Raymond Laflamme and Sean Collins, QuantumWorks, IQC, uWaterloo
   - Summer 2011
2. Harnessing the Quantum World: 2008 CAP Congress Herzberg Lecture
   - Raymond Laflamme and Jeremy Chamilliard
   - La Physique au Canada, Vol. 65, No. 1 (2009)

Videos

1. Ten Quantum Years
   - Raymond Laflamme and Michele Mosca
   - February 2012
2. The Quantum Mechanics of Time Travel
   - Seth Lloyd
   - November 2010
3. Quantum Computing Breakthrough: QIP=PSPACE
   - John Watrous
   - March 2011
4. Quantum Tamers: Revealing Our Weird & Wired Future
   - Raymond Laflamme, Joseph Emerson, David Cory
   - October 2009
5. Born to Rule: Dr. Urbasi Sinha explains the triple-slit experiment
   - August 2010
6. Quantum Computing Breakthrough: QIP=PSPACE
   - John Watrous
   - March 2011
7. TEDxWaterloo “Sparked by Curiosity” Public Lecture
   - Raymond Laflamme
   - February 2010
8. Harnessing the Quantum World: Perimeter Institute Public Lecture
   - Raymond Laflamme
   - June 2008
9. From Weird to Wired: Perimeter Institute Public Lecture
   - Joseph Emerson
   - March 2010

10. USEQIP 2011 Playlist
    - 13 videos
    - Summer 2011
11. QCSYS 2011 Playlist
    - 16 videos
    - Summer 2011
12. What Great Philanthropy Can Do: Interview
    - Interview with Raymond Laflamme and former University of Waterloo president, David Johnston

Quantum Information and Communication

Articles

1. Introduction to Quantum Information Processing R. Laflamme and collaborators
2. Introduction to Quantum Complexity Theory, by R. Cleve
3. Non-locality and Communication Complexity, by R. Cleve and collaborators

Lectures

1. USEQIP 2010: Introduction to Quantum Information Processing, by M. Mosca

Quantum Algorithms and Complexity

Articles

1. Quantum Algorithms, by J. Smith and M. Mosca
2. Quantum Algorithms for Algebraic Problems, by A. M. Childs and W. van Dam
3. Quantum Computational Complexity, by J. Watrous,

Lectures

1. IOI 2010: Algorithms for Quantum Computers, by A. Childs
2. USEQIP 2010: Quantum Algorithms, by M. Laforest and M. Mosca

Quantum Cryptography

Articles

1. The case for quantum key distribution, by D. Stebila, M. Mosca and N. Lütkenhaus
2. Quantum cryptography, by N. Lütkenhaus and collaborators

Lectures

1. USEQIP 2010: Quantum key distribution: Linking theory and experiment, by N. Lütkenhaus)
2. USEQIP 2010: Quantum communication with polarized entangled photons, by T. Jennewein

Videos

1. Quantum Key Distribution Animation
2. Quantum Key Distribution, Chris Erven

Quantum Error Correction and Fault-Tolerance

Articles

1. Introduction to Quantum Error Correction, by R. Laflamme and collaborators

Lectures

1. USEQIP 2010: Quantum Error Correction, by R. Laflamme

Videos

1. Experimental Quantum Error Correction, by R. Laflamme

Spin-based Quantum Information Processing

Articles

1. How to built a better iPod: Spintronics hold the key, by W. A. Coish
2. Quantum physics and voltmeters, by F. K. Wilhelm
3. 2-Qubit Quantum Information Processing by Zeeman-Perturbed Nuclear Quadrupole Resonance, by P. Xian and T. Borneman
4. Introduction to NMR quantum information processing, by R. Laflamme, D. G. Cory, C. Negrevergne and collaborators
5. Quantum information processing using nuclear and electron magnetic resonance: review and prospects, by J. Baugh, J. Chamilliard, C. M. Chandrashekar, D. G. Cory, M. Ditty, A. Hubbard, R. Laflamme*, M. Laforest, D. Maslov, O. Moussa, C. Negrevergne, M. Silva, S. Simmons, and C. A. Ryan and collaborators
6. Nuclear spin in nanostructures, by W. A. Coish and J. Baugh
7. Quantum computing with spins in solid, by W. A. Coish and D. Loss
8. Spins interactions, relaxation and decoherence in quantum dots, W. A. Coish and collaborators

Lectures

1. Introduction to NMR and NMR QIP, by J. Baugh

Nanoelectronics-based Quantum Information Processing

Articles

1. Quantum computing with superconductors I: Architectures, by F. K. Wilhelm and collaborators
2. Superconducting qubits II: Decoherence, by F. K. Wilhelm and collaborators

Lectures

1. USEQIP 2010: Introduction to superconducting qubit, by A. Lupascu
2. USEQIP 2010: Infra red single photon detectors, by H. Majedi

Videos

1. Nuclear Magnetic Resonance at IQC

Optical Quantum Information Processing

Articles

1. Linear optics quantum computation: an overview, by C. R. Myers and R. Laflamme

Lectures

1. USEQIP 2010: Bell's inequalities and quantum optics, by K. Resch
2. USEQIP 2010: Mach-Zehnder interferometer, by K. Resch
3. USEQIP2010: State tomography of one and two-qubit systems, by K. Resch
4. USEQIP 2010: Optical implementations of quantum information, by K. Resch

Videos

1. What is Entanglement, by Krister Shalm

Q. Outreach Activities

Fiscal 2012 Events

AAAS
- Annual Meeting of the American Association for the Advancement of Science
- IQC Executive Director Raymond Laflamme and Prof. Thomas Jennewein were among the IQC researchers who spoke in symposia about quantum information research and global quantum communication in 2012
- February 16 to 20, 2012
- February 17 - 21, 2011

Quantum: Music at the Frontier of Science
- A collaboration with the Kitchener-Waterloo Symphony
- An innovative mash-up of art and science that was meant to entertain, educate and enthrall. An exploration of how music — and everything — works at nature's most fundamental level
- February 23 to 24, 2012

Quantum Physics of Harry Potter
- Postdoctoral fellow Krister Shalm explains the quantum physics behind the movie Harry Potter with the help of a magician
- IQC's demo booth was also at the event
- July 14 - 15, 2011

Cirque de la Science
- More than 250 young students from grades 4 to 8 at St. Matthew Elementary School tinkered with levitating trains, electromagnets and other interactive demonstrations of quantum physics
- June 8, 2011

TEDxWaterloo
- Postdoctoral fellow, Krister Shalm presented a talk using swing dance, poetry and magic to explain quantum mechanics
- IQC was a co-sponsor for the "Continuum of Success," an interactive exhibition describing the process of innovation, from fundamental research, to commercialization process, to commercial success
- Also provided scientific demonstrations at a nearby screening for young students
- March 21, 2012
- 1500 participants

TEDxUW
- Postdoctoral fellow, Krister Shalm presented a talk using poetry to explain quantum mechanics
- Booth with quantum demonstrations
- November 12, 2011
- 200 participants

Quantum Frontiers Distinguished Lecture Series
- Don Eigler, IBM's Almaden Research Centre in California
    - Classical Computation in Quantum Spin Structures

    - 200 participants
    - April 1, 2011
  - Ralph Merkle, Singularity University
    - Molecular nanotechnology and molecular computing
    - 150 participants
    - June 24, 2011
- David Wineland, NIST
    - Lecture on atomic clocks
    - January 19, 2012
- Louis Taillefert, Sherbrooke University
    - Lecture on the puzzles of superconductivity
    - February 7, 2012
    - 150 participants

WIN Special Seminar Series
- Marko Loncar, December 2, 2011
- Amir Yacoby, November 2, 2011

Royal Canadian Institute Public Lecture
- Faculty member Joseph Emerson
- Public lecture titled "The Quantum World: Weird to Wired"
- Royal Canadian Institute, approximately 200 participants
- February 6, 2011

Steel Rails
- Participated in a partnership with MakeBright to create a human sized version of the double-slit experiment, displayed on a moving train between Waterloo and St. Jacob's
- June 24, 2011

Zoom Career Days/Canada 3.0
- Martin Laforest and Marco Piani presented to a group of young students considering careers in Science, Engineering, Technology, Mathematics, etc.
- May 24, 2012
- 100 participants

Tech Leadership Conference
- Sponsored this conference organized by Communitech, present at the University of Waterloo's booth
- May 10, 2012
- 500 participants

Shad Valley — National Engineering Month
- Presentation for middle school students about quantum technology, lasers and the transistor
- March 26, 2012
- 300 participants

Ontario Centre of Excellence Discovery 2011
- IQC exhibit
- May 18, 2011

- 2,600 participants

Additional Lectures
- Engineering Science Quest, Marco Piani on July 25, 2011
- International Summer School for Young Physicists, Martin Laforest on July 27, 2011
- Research in Motion Advanced Technology Department, Raymond Laflamme on October 4, 2011
- Everything Has Rhythm: The Physics of Light, Krister Shalm on February 23, 2012
- The Ancient Art of Keeping a Secret: A Quantum Twist of Cryptography, Krister Shalm February 24, 2012
- Explaining the Quantum World, Krister Shalm on March 9, 2012
- Waterloo Unlimited: Quantum Key Distribution, Evan Meyer-Scott on May 15, 2012

Fiscal 2011 Events

Innovation Insights
- Executive Director Raymond Laflamme
- Presentation about IQC and quantum information for a business-technology audience
- Accelerator Centre, Waterloo, 150 participants
- June 3, 2010

Canadian Undergraduate Mathematics Conference
- Deputy Directory Michele Mosca
- Keynote speaker for undergraduate students
- University of Waterloo, 245 participants
- July 8, 2010

International Olympics of Informatics
- Faculty member Andrew Childs
- Presenter about quantum algorithms
- University of Waterloo, approximately 250 participants
- August 15, 2010

IQC Open House/Doors Open Waterloo
- Tours of IQC's labs and theory rooms, a hands-on Discovery Zone for children, public lecture by Prof. David Cory, a science show for kids, animation and video displays, a screening of the *Quantum Tamers* and more
- RAC I & II, 800+ participants
- September 18, 2010

Ladies Night Out
- Postdoctoral fellow Anne Broadbent
- Public talk for the Federated Women's Institutes of Ontario
- Listowell, Ontario, approximately 120 participants

Royal Canadian Institute Public Lecture
- Faculty member Joseph Emerson

- Public lecture titled “The Quantum World: Weird to Wired”
- Royal Canadian Institute, approximately 200 participants
- February 6, 2011

TEDxWaterloo
- IQC sponsored the 2011 TEDxWaterloo event, also staging a quantum exhibit that demonstrated some quantum experiments to hundreds of attendees
- March 3, 2011, approximately 1,000 participants

Quantum Frontiers Distinguished Lecture Series
- The inaugural lecture was presented by Dr. Don Eigler, an eminent physicist at IBM’s Almaden Research Centre in California
- Approximately 200 people attended
- April 1, 2011

Graduate Fairs
- University of Waterloo Graduate Fair
  - September 21, 2010
- University of British Columbia Graduate Fair
  - September 29, 2010
- University of Alberta Graduate Fair
  - October 20, 2010
- Canadian Undergraduate Physics Conference Graduate Fair
  - October 25, 2010, Dalhousie University
- University of Western Ontario Graduate Fair
  - October 28, 2010

China Recruitment Trip
- Gave a seminars about the University of Waterloo and IQC at Beijing Normal University, Tsinghua University and Peking University
- Attended a graduate fair in Beijing

Fiscal 2010 Events

Tony Leggett Lecture Series
- June 4 - July 2, 2009
- 40 participants per talk

Gregory Chaitin Lecture
- September 23, 2009
- 60 participants per talk

University of Waterloo Science Open House Day
- September 24, 2009

Quantum to Cosmos
- October 15 - 25, 2009

- Participation by Raymond Laflamme, Michele Mosca, Anne Broadbent

IQC Open House and Public Lecture
- October 17, 2009
- 125 participants

Quantum Dance
- October 27, 2009
- 75 participants

TEDxWaterloo
- February 24, 2010
- Raymond Laflamme, speaker

Perimeter Institute Public Lecture
- March 3, 2010
- Joseph Emerson, speaker

Graduate Fairs
- University of Waterloo Graduate Fair
  - September 29, 2009
- Canadian Undergraduate Physics Conference Graduate Fair
  - September 4, 2009
- McGill Graduate and Professional Schools Fair
  - November 4, 2009
- Atlantic University Physics and Astronomy Conference Graduate Fair
  - February 5 - 7, 2010

R. News Releases and Web Updates

2012 News Releases and Web Updates

2-May-11	Watch IQC's Quantum Frontiers lecture online
31-May-11	International young scholars begin quantum summer school
2-Jun-11	IQC scholar earns university's Dean of Science Award
2-Jun-11	Observing the Unobservable: IQC researcher and colleagues achieve a physics first
6-Jun-11	Reporter earns science journalism award for IQC profile
22-Jun-11	Distinguished Lecture series continues with nanotech expert
28-Jun-11	International journalists in Qatar get a quantum "peek"
7-Jul-11	Young students join the quantum "cirque"
19-Jul-11	IQC congratulates student scholarship winners
24-Jul-11	IQC optics team tests new uncertainty principle
3-Aug-11	IQC faculty members earn provincial research awards
4-Aug-11	IQC outreach manager co-authors Science paper
4-Aug-11	IQC student earns national fellowship
17-Oct-11	Researchers achieve "simple yet elegant" result with quantum dots
20-Oct-11	IQC's experimental "tango" draws attention
25-Oct-11	Building for the Future: the Quantum-Nano Centre
15-Nov-11	IQC congratulates student scholarship recipients
17-Nov-11	Recent IQC research showcased on PhysOrg
21-Nov-11	IQC Executive Director named APS Fellow
28-Nov-11	IQC hosts major science funding announcement
2-Dec-11	Quantum behaviour "in the eye of the beholder"
12-Dec-11	Walrus article examines Quantum Valley
14-Dec-11	Online quantum community in the works
16-Dec-11	IQC postdoc part of Breakthrough of the Year
22-Dec-11	IQC and NIST collaboration yields advance in sensors
17-Jan-12	Wineland to deliver Quantum Frontiers lecture Thursday
19-Jan-12	International team achieves breakthrough in secure quantum computing

2-Feb-12	IQC congratulates student scholarship recipients
12-Feb-12	IQC part of world's largest science conference this week
15-Feb-12	IQC prof explores quantum devices at Vancouver science summit
16-Feb-12	Laflamme explores quantum revolution in public lecture
17-Feb-12	Lazaridis speaks on the power of ideas
18-Feb-12	IQC executive director named AAAS Fellow
19-Feb-12	international panel explores quantum communications
24-Feb-12	Entanglement takes off
27-Feb-12	Summer school applications open
14-Mar-12	IQC to bring quantum world to TEDxWaterloo
15-Mar-12	Quantum Hacker joins IQC as research assistant professor
13-Apr-12	New chip advances quantum optics research
11-Apr-12	IQC to host aspiring young female scientists

2011 News Releases and Web Updates

05/02/10	Still time to sign up for QCSYS 2010
05/06/10	IQC postdoc and international collaborators probe quantum correlations
05/11/10	Can quantum mechanics get you out of a speeding ticket
05/12/10	QISS workshop kicks off next week
05/14/10	IQC student wins prestigious national scholarship
05/17/10	David Cory joins IQC as Canada Excellence Research Chair
05/31/10	Undergrad quantum workshop underway at IQC
05/31/10	Researcher gets major grant to pursue multi-qubit systems
07/15/10	IQC director to discuss mentor Stephen Hawking on TVO
06/21/10	Watch Hawking's Universe online
06/22/10	The boomerang of life reunites Hawking and Laflamme
07/05/10	Explore the quantum revolution during IQC's open house
07/27/10	Research team tests fundamental rule in Science paper
07/29/10	IQC-led research team achieves quantum optics breakthrough

08/06/10	Canadian government unveils prestigious postdoctoral fellowships
08/17/10	Research team achieves milestone in superconducting qubits
08/19/10	Watch Born to Rule - A fundamental experiment explained
09/10/11	Finance Minister Flaherty visits IQC
09/14/11	IQC faculty member named Royal Society Fellow
09/17/11	IQC Welcomes new research assistant professors
09/20/11	Big crowds explore quantum science at IQC Open House
09/22/11	IQC bids good luck to Governor General-designate
09/30/11	Postdoctoral positions available at IQC
10/01/11	Physics alumni explore quantum future
10/08/11	New IQC research assistant professor co-authors key papers
10/20/11	IQC optics team advances measurement-based quantum computing
11/24/11	IQC accepting faculty applications
11/29/11	IQC postdoc earns prestigious Polanyi Prize
12/15/11	Seth Lloyd, quantum mechanic, talks shop at IQC
01/28/11	Broadbent to speak at "Ladies Night Out"
01/28/11	Faculty recognized with Outstanding Performance Award
01/28/11	IQC postdoc brings quantum computing to Ladies' Night Out
02/01/11	Hamed Majedi receives Distinguished Performance Award
03/10/11	Researchers achieve "important building block" in quantum error correction
12/23/11	The amazing possibilities of quantum devices
02/15/11	IQC researcher "spins" a good yarn
03/15/11	Graduate Program in Quantum Information
02/16/11	Leading physicist joins IQC Scientific Advisory Board
02/24/11	Researcher earns prestigious Sloan Fellowship
02/24/11	Joseph Emerson named among 40 Under 40
03/15/11	Quantum entanglement as a game-changer
04/06/11	Nanotech pioneer kicks off IQC's Distinguished Lecture Series

04/28/11	IQC deputy director wins national award

2010 News Releases and Web Updates

01-May-09	Prestigious award goes to PhD student
04-May-09	Taking a spin around the block
13-May	TCQ 2009 Underway
03-Jun-09	Sir Anthony Leggett Lecture Series
08-Jun-09	Canada Excellence Research Chair
17-Jun-09	Spotlight on quantum cryptography
19-Jun-09	New CIFAR Inductee
17-Jul-09	What great philanthropy can do
07-Aug-09	Fields Institute workshop begins next week
19-Aug-09	QIP = PSPACE
24-Aug-09	IQC faculty member wins Early Researcher Award
15-Sep-09	IQC welcomes new minds for fall term
16-Sep-09	Dr. Gregory Chaitin at IQC
23-Sep-09	IQC faculty member shares in US government grant
03-Oct-09	Public event: open house and panel discussion
21-Oct-09	Quantum Tamers captures prize in Paris
25-Nov-09	IQC featured in Nature
07-Jan-10	Quantum Grad program set for fall 2010
08-Jan-10	IQC researchers solve difficult classical problem with one quantum bit
27-Jan-10	Quantum grad program set for fall 2010
09-Feb-10	IQC faculty receive grant for collaborative research
11-Feb-10	The Quantum Tamers returns to TV
12-Feb-10	Researchers probe tim travel as computing tool
24-Feb-10	Michele Mosca named among 40 Under 40
26-Feb-10	IQC director wows crowd at TEDxWaterloo
22-Feb-10	Joseph Emerson public lecture
04-Mar-10	IQC researchers investigate boson problems
09-Mar-10	International deal signed for quantum collaboration
15-Mar-10	IQC director featured in Motivated Magazine
22-Mar-10	Nature article examines quantum computing possibilities
24-Mar-10	Raymond Laflamme's TEDxWaterloo talk online

S. Media Coverage

2012 Media Coverage

External Media Coverage:

9-May-11	Windsor Star	Windsor Native Math Whiz Among Top 40 Under 40

19-May-11	Waterloo Chronicle	Brain Gain: University of Waterloo scores a coup by attracting MIT quantum pioneer
1-Jun-11	XL	Canada's Top 40 Under 40
2-Jun-11	ScienceNOW	Quantum Mechanics Get Weirdly Less Weird
2-Jun-11	Nature News	A Quantum Take on Certainty
2-Jun-11	Technology and Science	Impossible Physics Feat Traces Path of Light
2-Jun-11	Nature News	The Power of Discord
2-Jun-11	EurekAlert	U of T scientist leads international team in quantum physics first
2-Jun-11	Science Daily	Quantum Physics First: Physicists Measure Without Distorting
3-Jun-11	The Record	Scientist "Shaking the Box"
4-Jun-11	OptoIQ	Team applies weak measurement principles to two slit interferometer experiment
22-Jun-11	Forbes	Blackberry Co-Chiefs No Longer Billionaires
23-Jun-11	Financial Post	RIM Bosses Lose Billionaire Status
24-Jun-11	The Record	Is There Trouble in RIM Country?
24-Jun-11	RQ Magazine	Steel Rail Sessions
26-Jun-11	The Record	A Ride on the Steel Rails will Leave You Smiling
4-Jul-11	Canada NOW	The Quantum News
4-Jul-11	The Record	My Former Employer is an Important Part of Community
6-Jul-11	The Record	The Quantum Physics of Harry Potter
11-Jul-11	Waterloo Chronicle	It's All About Harry and Quantum Mechanics
15-Jul-11	The Record	Conference Hopes to Boost Women's Role in Physics
4-Aug-11	The Record	UW Students among winners of prestigious scholarships
4-Aug-11	Exchange Magazine	Five University of Waterloo Grad Students Win Coveted Vanier Canada Awards
7-Aug-11	Waterloo Region Record	The Power of Two
9-Aug-11	Wall Street Journal	An Apple Store Comes to RIM's Hometown
13-Aug-11	The Record	Quantum Cryptography School Takes High School Students to Cutting Edge of Science
20-Aug-11	osa-opn.org	Triple-Slit Experiment has quantum Implications

24-Aug-11	The Reporter (McGill)	Quantum movements for objects, giant leaps for research
25-Aug-11	kijk.nl	Filmpje: onderzoeker legt drie-spleten-experiment
1-Sep-11	Canada NOW	The Quantum News
17-Sep-11	The Record	Perimeter Institute set to revolutionize the 21st century
18-Sep-11	IEEE Spectrum	Practically quantum computers creep closer to reality
25-Sep-11	The Record	Physicists cautious about reports of faster-than-light neutrinos
2-Oct-11	Globe and Mail	Scientific encounters light up Governor General's B.C. visit
15-Oct-11	New Scientist	Life on research's cutting edge
17-Oct-11	APS Physics	Viewpoint: nuclear spins tango to the tune of electron
25-Oct-11	Macleans.ca	Music: Edwin Outwater's research in (rhythm and) motion
31-Oct-11	The Record	Technology Spotlight (ad)
31-Oct-11	Ostina.org	Entangled: Introducing quantum physicists Thomas Jennewein and Robert Prevedel
2-Nov-11	www.ic.gc.ca	The Canada 2020 Innovation Summit (press release)
11-Nov-11	communitech.ca	It's no joke -- Waterloo Regions sets up expansive connections
28-Nov-11	cerc.gc.ca	Government of Canada launches new competition for 10 Canada Excellence Research Chairs
28-Nov-11	CTV.ca	CERC announcement segment
29-Nov-11	The Record	More federal funding to recruit top scientists
29-Nov-11	The Record	Federal grants funding "next industrial revolution"
30-Nov-11	Waterloo Chronicle	$53.5 million for new program
2-Dec-11	APS Physics	Focus: another step back for wave-particle duality
5-Dec-11	The Walrus	The Invention of Waterloo
5-Dec-11	The Record	Computing New Ideas
13-Dec-11	The Record	The invention of Waterloo no accident, writer says
14-Dec-11	Physics in Canada	Women in Physics Conference
14-Dec-11	Macquarie University news	A new lens for looking at quantum behaviour
16-Dec-11	Physics World	Physics World reveals its top 10 breakthroughs for 2011
20-Dec-11	Ottawa Citizen	Canada becomes a quantum science hotspot

20-Dec-11	www.nist.gov	NIST sensor improvement brings analysis method into mainstream
23-Dec-11	overclockersclub.com	Advancing an analysis method out of a concrete bunker
29-Dec-11	Test And Measurement	NIST sensor improvement brings analysis method into mainstream
30-Dec-11	The Record	New Year provides bridges to the future
30-Dec-11	ThomasNet News	NIST sensor innovation may aid material analysis
1-Jan-12	The Guardian UK	Stephen Hawking at 70: still the brightest star in the scientific universe
4-Jan-12	The Record	Going for a quantum leap
5-Jan-12	www.cerc.gc.ca	At the cusp of a new Industrial Revolution
7-Jan-12	PhilSTAR.com	Stephen Hawking at 70
7-Jan-12	The Record	Ontario Liberals kill $42 million in university research grants
8-Jan-12	Globe and Mail	My Time with Stephen Hawking
14-Jan-12	The Record	TEDxWaterloo ad
19-Jan-12	BBC News	Quantum Computing could head to the cloud
19-Jan-12	www.popsci.com	Could-based quantum computing will allow secure calculation on encrypted bits
20-Jan-12	The Record	New encryption will bring security to cloud computing
20-Jan-12	Science	Moving beyond trust in quantum computing
20-Jan-12	Kitchener Post	Orchestral Manoeuvres
23-Jan-12	The Record	A pair of giants at RIM pass the torch
23-Jan-12	The Record	Community confident RIM founders will continue charitable work
24-Jan-12	The Record	RIM shakeup creates tech buzz
24-Jan-12	Council of Ontario Universities	University of Waterloo researcher leads quantum security innovation
25-Jan-12	The Record	Raising the bar and expectations
26-Jan-12	National Post	Don't scapegoat corporate Canada
26-Jan-12	itbusiness.ca	Waterloo still a tech hub despite RIM's slide
28-Jan-12	New Scientist	Computer is blind to its own actions
29-Jan-12	CTV.ca	Edwin Outwater on The Beat

30-Jan-12	Le Droit	Anne Broadbent, scientifique superstar
30-Jan-12	CTV.ca	Krister Shalm, Sun Spot Science, "National Affairs"
30-Jan-12	The Hamilton Spectator	Stepping down was a hard decision, but right one
30-Jan-12	Fars News Agency	Quantum Physics enables perfectly secure cloud computing
14-Feb-12	aaas.com	Raymond Laflamme and the potential of quantum computers
21-Feb-12	ABC Australia	Quantum security looks beyond the skies
22-Feb-12	Orchestras Canada	Speaking of Science
23-Feb-12	Al Jazeera	The best information is quantum information
23-Feb-12	The Record	Symphony concert delves into world of quantum music
25-Feb-12	The Economist	An Uncertain Future
26-Feb-12	The Guardian UK	Krister Shalm: the lindy hop can explain quantum mechanics
29-Feb-12	Space.com	Secret codes ready to take quantum leap into space
4-Mar-12	Cultureguru blog	Music as weirdly beautiful as the universe itself
5-Mar-12	PhysicsWorld	Topological quantum computing moves closer
5-Mar-12	Perimeter Institute	Associate faculty member Raymond Laflamme named AAAS Fellow
12-Mar-12	The Record	We in Waterloo Region show our appreciation for RIM
12-Mar-12	CTV.ca	Krister Shalm, The Dark Heart of Dark Matter, "National Affairs"
22-Mar-12	The Record	TEDxWaterloo connects with crowd of 1,500
30-Mar-12	Macleans.ca	Quantum Fiddling
1-Apr-12	Watch Magazine	Mike & Ophelia Lazaridis Quantum-Nano Centre Opening - Advertisement
12-Apr-12	IEEE Spectrum	Path clears toward a quantum internet

Internal UW Media Coverage:

11-May-11	UW Daily Bulletin	Campus hosts summer programs for kids
3-Jun-11	UW Daily Bulletin	New look at the double-slit experiment
15-Jun-11	Imprint	UW Student Explores the Science Behind Harry Potter's Universe
3-Aug-11	UW Daily Bulletin	$12 from Ontario Research Fund

21-Sep-11	The Cord	Science in the Club
28-Sep-11	UW Daily Bulletin	TEDxUwaterloo
29-Nov-11	UW Daily Bulletin	Government of Canada's Announcement
6-Dec-11	UW Daily Bulletin	IQC Director named APS Fellow
21-Dec-11	UW Daily Bulletin	Postdoc part of breakthrough of the year
8-Feb-12	UW Daily Bulletin	A $21M gift from Mike & Ophelia Lazaridis
21-Feb-12	UW Daily Bulletin	A blueprint for sustainable energy
11-Mar-12	Imprint	Waterloo professors spread their knowledge at international conference
21-Mar-12	UW Daily Bulletin	IQC postdoc dances around quantum issues

2011 Media Coverage

External Media Coverage:

Date	Title	Publication
05/13/10	Vanier Scholarships, Rewarding Excellence, fostering innovation, Strengthening Canada	Association of Universities and Colleges of Canada
05/17/10	UW lands two key research posts	Waterloo Region Record
05/17/10	New UW research chairs	570 News
05/17/10	Water, quantum computing get big research boost at UW	Waterloo Region Record
05/18/10	Waterloo earns two of 19 newly created Canada Excellence Research Chairs	Exchange Magazine
05/18/10	Canada Excellence Research Chairs	Government of Canada
05/18/10	Canada's brain gain - advertisement	The Globe and Mail
05/18/10	UW receives research boost	The Waterloo Region Record
05/18/10	Brain Gain: Federal investments in research attracts leading global researchers to Canada	The Globe and Mail
05/18/10	Canada's hub for research excellence	Globe and Mail
05/18/10	David Cory: Canada Excellence Research Chair in Quantum Information	CERC website
05/19/10	Fed grant big dollars to all-male research group	Toronto Star

05/19/10	Brain Gain: University of Waterloo scores a coup by attracting MIT quantum pioneer	Waterloo Chronicle
05/20/10	Waterloo students win prestigious Vanier Canada Graduate scholarships	Exchange Magazine
05/27/10	Incompetence as an impediment to commercialization	Communitechblog.ca
06/18/10	The man who proved Hawking wrong	Waterloo Region Record
06/01/10	UW earns Canada Excellence Research Chairs	SNAP KW
06/24/10	Giving Back to former mentor	Waterloo Region Record
06/27/10	Superstars could reverse innovation brain drain	CTV News
06/20/10	The boomerang of life reunites Hawking and Laflamme at IQC	Waterloo Chronicle
07/08/10	Johnston's career rooted in the law and academia	Waterloo Region Record
07/22/10	Photonics professor works on quantum computing	azonano.com
07/22/10	Quantum theory survives its latest ordeal	physicsworld.com
07/22/10	Quantum mechanics not in jeopardy	physorg.com
07/23/10	To be precise, from JU to physics feat	The Telegraph (India)
07/23/10	Quantum mechanics survives triple-slit test	arstechnica.com
07/23/10	Quantum mechanics not in jeopardy	Science Daily
07/22/10	Physicists confirm Born's Rule	photonics.com
07/22/10	Quantum mechanics is square	scienceblogs.com
07/27/10	Two is the magic number	sciencenews.org
07/27/10	Two is the magic number	Wired.com
07/28/10	IQC-led research team tests fundamental rule in Science paper	Exchange Magazine
07/29/10	Waterloo team gives birth to photon triplets	Waterloo Region Record
07/31/10	Quantum school helps the scientists of tomorrow	Waterloo Region Record
08/07/11	The Power of Two	Waterloo Region Record

08/13/10	The Indian-origin scientist who is shaking up the world of physics	India Abroad
08/20/11	Triple-Slit Experiment has quantum Implications	osa-opn.org
08/09/10	Untitled	anandabazar.com
08/24/11	Quantum movements for objects, giant leaps for research	The Reporter (McGill)
08/25/11	Filmpje: onderzoeker legt drie-spleten-experiment	kijk.nl
09/07/11	Open the Doors of History	London Free Press
09/07/11	Doors Open Waterloo Region -- Made in Waterloo Region	Waterloo Region Record
09/07/11	Doors Open Waterloo Region	heritageresources.blogspot.com
09/14/11	Open House at the Institute for Quantum Computing	Snapkw.com
09/16/11	Doors open into world of quantum computing	Waterloo Region Record
09/08/11	Exploring our past through doors open	Waterloo Region Record
09/10/11	A bit Cold: Physicists Devise a quantum particle refrigerator	Scientific American
09/15/11	Come on in: Doors Open invites public for behind the scenes look	Waterloo Chronicle
09/18/11	Area institutes throw open doors to public	www.therecord.com
09/20/11	World's tiniest fridge could chill quantum computers	Dailyindia.com
10/28/11	Campaign Waterloo makes 613.2 million impact on Canada	nanotech-now.com
09/26/11	Ideas Having Sex	yourlearningcurve.com
11/03/11	IQC optics team at Waterloo advances measurement-based quantum computing	
11/01/11	Campaign Waterloo makes 613.2 million impact on Canada	Exchange Magazine
11/04/11	IQC optics team at Waterloo advances measurement-based quantum computing	Waterlootechnews.com
11/04/11	IQC optics team at Waterloo advances measurement-based quantum computing	Exchange Magazine

11/09/11	High profile visit sparks war of words	570 News
11/02/11	Jim Balsillie and Mike Lazaridis set standards in smart-phone market	Globe and Mail
11/22/11	Minister Clement Updates Canadians on Canada's Digital Economy Strategy	sys-con.com
12/04/11	Freewheeling in the snow	Waterloo Region Record
12/15/11	Mike Lazaridis profile	greekgateway.com
12/17/11	quantum unicorns	portabledigitalvideorecorder.com
12/17/11	The Clock is Ticking on Encryption	Computerworld
12/24/11	Classical computing can match quantum computing speed	topnews.us
12/02/10	Researcher wins innovation prize	Waterloo Region Record
12/06/10	Rankings and Reputation of Waterloo University	AAA Study Abroad
12/23/10	Software Said to Match Quantum Computing Speed	Itworld
12/17/10	Bound Entanglement Mysterious Invention of Nature	europhysicsnews
02/07/11	New in Canada's Economic Plan	Action Plan
01/08/11	Best Brains' Quantum of Solace Physics Meet on Philosophy of the Universe	The Telegraph (India)
01/19/11	Silicon Quantum Computer a Possibility	Nature News
01/20/11	First USC Student to Receive Churchill Scholarship	USC News
01/20/11	Billions of Entangled Particles Advance Quantum Computing	The New York Times
01/25/11	Experimental Magic State Distillation for Fault-Tolerant Quantum Computing	Nature News
02/24/11	The Kitchener-Waterloo Symphony	Exchange Magazine
02/25/11	Minister Clement Issues Statement on Digital Economy Round Table in Waterloo	marketwire.com/Industry Canada
02/25/11	Local Tech Leaders Meet with Industry Minister	570 News
03/08/11	A Crown of Quantum Entanglements	IEEE Spectrum

01/28/11	Second TEDxWaterloo Looks to the Future	The Record
01/22/11	A Quantum Spin on Life	The Record
02/17/11	Czech Ambassador Visits Region Promoting Partnerships	The Record
02/23/11	Outwater to Bring Fresh Sounds to Symphony's New Season	The Record
02/24/11	Joseph Emerson - 40 Under 40	The Record
02/25/11	Clement Leaves Door Open While Slamming Internet Usage Based Billing	The Record
03/24/11	Kids' Summer Programs - QCSYS	The Record
03/35/11	Russians visit city for ideas	The Record
04/15/11	RIM makes a play for its future	Globe and Mail
04/20/11	RIM's hope, the region's future	The Record
04/28/11	The Impact Players -- Top 40 Under 40	Globe and Mail
04/28/11	Kitchener-Waterloo Debate	570 News

Internal UW Media Coverage:

05/01/10	People and Places : Quantum Computing	Watch magazine
05/17/10	Waterloo Earns two of 19 newly created CERC chairs	UW news release
05/17/10	Waterloo earns two new research chairs	UW news release
05/18/10	Two multi-million-dollar federal chairs	UW Daily Bulletin
06/02/10	Thirteen exceptional undergraduates	UW Daily Bulletin
06/04/10	UW wins a $10 million federal lottery	Imprint
06/25/10	Astronomer Hawking pays a visit to IQC	UW Daily Bulletin
07/23/10	IQC-led research team tests fundamental rule in Science paper	UW news release
07/26/10	Quantum researchers test Born's rule	UW Daily Bulletin
07/28/10	Waterloo-led team achieves breakthrough in quantum optics	UW news release
08/23/11	Born to Rule video	UW Daily Bulletin
09/13/11	Finance Minister Flaherty visits IQC	UW Daily Bulletin

09/24/11	Fun with Science	Imprint
09/30/11	Johnston leaves today -- his name remains	UW Daily Bulletin
11/03/11	IQC optics team advances measurement-based quantum computing	UW news release
11/30/11	Polanyi prize for postdoc physicist	UW Daily Bulletin
03/01/11	Quantum Computing and Physics	UW Daily Bulletin
04/01/11	Quantum Frontiers Distinguished Lecture	UW Daily Bulletin
04/15/11	A Magnet for Talent: UW Science Annual Report	Science Annual Report
04/21/11	Pushing Science Forward: Martin Laforest	Watch magazine
04/21/11	Pushing Science Forward: David Cory	Watch magazine
04/21/11	For the Love of Math: Anne Broadbent	Watch magazine
04/29/11	Top 40 honor for quantum physics prof	UW Daily Bulletin
04/29/11	IQC deputy director wins national award	Waterloo Science website

2010 Media Coverage

External Media Coverage:

Date	Title	Publication
05-Jun-09	Lazaridis quantum gift tops $101M	Waterloo Region Record
05-Jun-09	RIM co-CEO, wife, donate $25 million to quantum research centre	Canadian Press
05-Jun-09	Another donation from Mike Lazaridis	570 News
05-Jun-09	Mike and Ophelia Lazaridis donations top $101M	Exchange Magazine
17-Jul-09	Waterloo research park growing	Waterloo Region Record
25-Aug-09	High-tech center excites McGuinty	Waterloo Region Record
23-Sep-09	Quantum device group sharing in multi-institutional grant	azonano.com
28-Sep-09	Math guru sees miracle in Waterloo's intellectual culture	Waterloo Region Record
10-Oct-09	Harper government marks major investments in leading-edge research infrastructure	Marketwire
19-Oct-09	A quantum leap in film	Waterloo Region Record
Fall 2009	Are we the next big nano-hub	Tech Next

25-Nov-09	Quantum Potential	Nature
26-Nov-09	Bad news for time travelers	Nature Physics
09-Dec-09	Canada Revolutionizing ICT	Nikkei Business Daily
15-Dec-09	Group provides support for spouses of PhD students	Waterloo Region Record
08-Jan-10	Physicists solve difficult classical problem with one quantum bit	Nature Physics
26-Jan-10	Quantum computing	The Manitoban
29-Jan-10	The Next Frontier: Quantum Computing	The Globe and mail
26-Feb-10	Michele Mosca: 40 Under 40	Waterloo Region Record
26-Feb-10	Curiosity sparks quantum discoveries	Waterloo Region Record
06-Mar-10	TED goes independent in Waterloo	Imprint
Spring 2010	Driven by Curiosity: Raymond Laflamme	Motivated Magazine
09-Mar-10	Deal boosts quantum race	Waterloo Region Record
09-Mar-10	Race on to build quantum computer	570 News
10-Mar-10	Quantum tech partnership signed between UW and Singapore	Waterloo Chronicle
12-Mar-10	Artificial atoms from superconducting circuits	Imprint
18-Mar-10	Tales from the Quantum Frontier	MSNBC Science
1-Apr-10	UW signs exciting agreement!	SNAP Kitchener-Waterloo
Apr – 10	Institute for Quantum Computing: People and Place	Watch Magazine

Internal UW Media Coverage:

07-May-10	Physics department builds cosmology group	UW Daily Bulletin
19-May-10	TQC 2009 underway at IQC	wrtpark.uwaterloo.com
29-May-09	Lectures in Quantum Information	UW Daily Bulletin
08-Jun-09	Lazaridis gifts to UW reach $101M	UW Daily Bulletin
17-Jun-09	Spotlight on quantum cryptography	nanowerk.com
18-Jun-09	Spotlight on quantum cryptography	wrtpark.uwaterloo.com
18-Jun-09	New role for Lazaridis at convocation	UW Daily Bulletin
22-Jun-09	Tangled up in photons	Engineering.uwaterloo.ca
22-Jul-09	Laflamme talks on research and giving	UW Daily Bulletin
13-Aug-09	Two week course in quantum information processing	science.uwaterloo.ca
26-Aug-09	Premiere visits UW: now that's networking	UW Daily Bulletin
23-Oct-09	Gold medals at tomorrow's convocation	UW Daily Bulletin
06-Nov-10	The next big (very small) thing	UW Daily Bulletin
07-Jan-10	Quantum Grad Programs start this fall	UW Daily Bulletin

04-Feb-10	Dr. Wilhelm and the quantum device theory group	Iron Warrior
10-Mar-10	Quantum link with Sinagpore institute	UW Daily Bulletin

T. YouTube Video Library

1. Quantum: Music at the Frontier of Science
2. The Making of the Quantum Symphony
3. QCSYS One-Minute Promo
4. Atomic Clocks: Precision and Accuracy — David Wineland
5. Hybrid Ion Traps: David Wineland
6. Ion Trapping for Quantum Computation — David Wineland
7. Ion Trapping Schemes — Dr. David Wineland
8. Ion Trapping — Dr. David Wineland
9. Atomic Clocks & Quantum Computation — David Wineland
10. Chip-Scale Atomic Clocks — Dr. David Wineland
11. How Atomic Clocks Work — Dr. David Wineland
12. Atomic Clock Applications — Dr. David Wineland
13. Quantum Frontiers Lecture: Louis Taillefer — The Puzzles of Superconductivity
14. Developing Diamond Nanostructures — Jorg Wrachtrup
15. Neural Communication — Jorg Wrachtrup
16. Developing a Quantum Processor — Jorg Wrachtrup
17. Quantum Medical Research — Jorg Wrachtrup
18. Quantum Error Correction — Jorg Wrachtrup
19. Quantum technologies for oil and water exploration — Jorg Wrachtrup
20. Quantum Computing with Magnetic Spins — Jorg Wrachtrup
21. Ten Quantum Years: The Institute for Quantum Computing
22. Quantum Frontiers Lecture: Dr. David Wineland on Atomic Clocks and Ion Trapping Quantum Computing
23. Quantum Concert: IQC and the KW Symphony
24. Krister Shalm at TEDx: Poetry, Physics & Dance
25. Quantum Information Technologies: A New Era for Global Communication
26. Beni Yoshida, MIT - Studying Many-Body Physics Through Coding Theory
27. IQC Food Drive (In Fast Forward)
28. Canada's Science Investment: CERC Launch at IQC
29. Marko Loncar — Diamond nanophotonics and quantum optics
30. QKD - BB84 Protool - Sarah Croke - QCSYS 2011
31. QKD - Extraction of a Secure Key - Sarah Croke - QCSYS 2011
32. Entanglement-Based Protocols - Sarah Croke - QCSYS 2011
33. Quantum Optics - Krister Shalm - QCSYS 2011
34. QKD in Space - Evan Meyer-Scott - QCSYS 2011
35. Quantum Hacking - Evan Meyer-Scott - QCSYS 2011
36. Introduction to QKD (Experiment) - Evan Meyer-Scott - QCSYS 2011
37. Dr. Amir Yacoby: Quantum Information and Metrology Using Few Electron Spins
38. The Photoelectric Effect - Andrew Childs - QCSYS 2011
39. No cloning theorem - Andrew Childs - QCSYS 2011
40. Double-slit experiment - Andrew Childs - QCSYS 2011
41. Intro to Quantum Mechanics - Andrew Childs - QCSYS 2011

42. Quantum Bomb Detector - Catherine Holloway - QCSYS 2011
43. Authentication - Stacey Jeffery - QCSYS 2011
44. Public Key Schemes - Stacey Jeffery - QCSYS 2011
45. Classical Cryptography - Stacey Jeffery - QCSYS 2011
46. Building for the Future: The Quantum-Nano Centre
47. The QCSYS Experience: Quantum Cryptography Summer School at IQC
48. Jacob Biamonte on Tensor Network States --- Interview and Series Trailer
49. The Many Worlds Theory - Sir Anthony Leggett
50. Quantum Mechanics vs. Macrorealism - Sir Anthony Leggett
51. Validity Tests of Quantum Mechanics Part 2 - Sir Anthony Leggett
52. Validity Tests of Quantum Mechanics Part 1 - Sir Anthony Leggett
53. Implications of the Bell-EPR Experiment - Anthony Leggett
54. Bell-EPR Experiments Lecture 2 - Anthony Leggett
55. Jacob Biamonte on Tensor Network States --- Lecture 4
56. Bell-EPR Experiments Lecture 1 - Anthony Leggett
57. Jacob Biamonte on Tensor Network States --- Lecture 3
58. Weak Measurements in Quantum Mechanics (General Idea) - Anthony Leggett
59. Weak Measurements of Quantum Mechanics (Application) - Anthony Leggett
60. Jacob Biamonte on Tensor Network States --- Lecture 1
61. Time Symmetry of Quantum Mechanics - Anthony Leggett
62. Women in Physics Conference
63. Jacob Biamonte on Tensor Network States --- Lecture 2 - Quantum Legos
64. The Human Double-Slit Experiment: Steel Rail Sessions 2011
65. Quantum Physics & Harry Potter
66. Bringing Quantum Technology to the Marketplace - Grégoire Ribordy
67. Quantum Entanglement for Communication -- Gregoire Ribordy
68. Quantum Key Distribution - Norbert Lütkenhaus - USEQIP 2011
69. Single Quantum Dots - Martin Laforest - USEQIP 2011
70. Intro to Quantum Computing - Michele Mosca - USEQIP 2011
71. Foundations of Quantum Mechanics - Joseph Emerson - USEQIP 2011
72. Quantum Error Correction - Raymond Laflamme - USEQIP 2011
73. Double Quantum Dots - Martin Laforest - USEQIP 2011
74. Spin Polarized Transport - Guo Xing Miao - USEQIP 2011
75. Practical Decoherence Modeling - Frank Wilhelm-Mauch - USEQIP 2011
76. Quantum Algorithms - Andrew Childs - USEQIP 2011
77. MATLAB - Chris Ferrie - USEQIP 2011
78. The USEQIP Experience - USEQIP 2011
79. Linear Algebra Lecture #2 - Chris Ferrie - USEQIP 2011
80. Linear Algebra Lecture #1 - Chris Ferrie - USEQIP 2011
81. Superconducting Qubits - Adrian Lupascu - USEQIP 2011
82. Quantum Mechanics: Two Rules and No Math
83. The Music of Quantum Science - Tommaso Calarco
84. Quantum Frontiers Lecture: Don Eigler of IBM
85. The Benefits of Quantum Research - Tommaso Calarco
86. Understanding Quantum Computing: Tommaso Calarco
87. Quantum: Harnessing the Fundamental Forces of Nature
88. Quantum Gets Big: Andrew Cleland on the Breakthrough of the Year
89. Quantum Computing 101
90. Teleportation: Fact vs. Fiction

91. Quantum Cryptography: The Future of Information Security
92. Quantum Cryptography Pioneer: Gilles Brassard
93. Quantum Computing Breakthrough: QIP=PSPACE
94. Casimir Effects: Peter Milonni's lecture at the Institute for Quantum Computing
95. Stephen Hawking at the Institute for Quantum Computing: The Boomerang of Time
96. The USEQIP Experience
97. Harnessing Quantum Mechanics: David Cory
98. Speaking the Language of Quantum Mechanics: David Cory
99. Seth Lloyd on Canada's Quantum Leadership
100. The Quantum Mechanics of Time Travel
101. Seth Lloyd on the Universe as a Quantum Computer
102. Seth Lloyd on the Simple Beauty of Quantum Mechanics
103. Seth Lloyd on the Importance of Quantum Research
104. Seth Lloyd on Quantum Weirdness
105. Nuclear Magnetic Resonance @ IQC
106. Mike & Ophelia Lazaridis Quantum-Nano Centre - Virtual tour
107. Introduction to the Institute for Quantum Computing
108. Born to Rule - Dr. Urbasi Sinha Explains the Triple-Slit Experiment
109. Quantum Key Distribution Animation
110. Quantum Key Distribution

U. Tour Groups

2012

Academic Tour Groups

Scarlett Heights	Dec 15 2011	30
McMaster Physics student from Quantum computing class given by Matheus Grasselli	Dec 5 2011	15
Laurentian University/Science North	Feb 1 2012	15
Dr. Sukekatsu Ushioda, President of the National Institute for Materials Science, Japan	July 11 2011	2
Einstein Plus Teachers (PI Program)	July 14 2011	45
Women in Physics Conference	July 20 2011	65
Yun-Jiang Wang, Xidian University	July 21 2011	1
Soochow University Delegation	July 26 2011	6
ISSYP Students (PI Program)	July 27 2011	40
University of Waterloo Laurel Society Donors	July 7 2011	20
Barbara Whitment, Senior Manager Stakeholder Development for the Toronto Region Research Alliance	June 1 2011	1
University of Wollongong	June 16 2011	2
Freeman Dyson, Institute for Advanced Study	June 2 2011	1
Serguei Beloussov and Vadim Moroz, Q-Wave Capital	March 14 2012	2
Students of Introducton to Quantum Information Processing (CO481/ CS467/PHYS467)	March 23 2012	60
King Faud University of Petroleum and Minerals, Saudi Arabia, delegation	March 28 2012	20
Georges Hadziioannou, University Bordeaux 1	March 5 2012	1
CBET Students	May 31 2011	20
RIM Advanced Technology division	Nov 22 2011	15
National Institute of Material Science	Nov 22 2011	8
Uxbridge Secondary School	Nov 23 2011	34
Centre Wellington District High School	Nov 30 2011	32
Perimeter Scholars International Students	Oct 19 2011	40

Woodlands Public School	Oct 26 2011	28
Czech Embassy Delegation	Sept 22 2011	15
Glenn Cartwright, Principal and Vice Chancellor of Renison University College	Sept 28 2011	1

Government Tour Groups

Yaprak Baltacioglu Deputy Minister, Transport Canada	Dec 9 2011	2
Sir Peter Gluckman, Science Advisor to the Prime Minister of New Zealand	Feb 22 2012	1
Communication Security Establishment Canada	Jan 26 2012	3
Brazilian Delegation	June 14 2011	16

Business/Industry Tour Groups

Michael Kearney, IBM	Aug 3 2011	1
iCanada Delegation	Jan 26 2012	8
Kevin Michaluk Crackberry.com	July 12 2011	3
Deloitte auditor	March 15 2012	4
Perimeter Institute, Educational Outreach	Nov 8 2011	2
Gordon Stovel, Board Member of CFI	Jan 19 2012	1
RIM, Analyst Relation and Market Intelligence Department	Jan 25 2012	8
Canada Foundation of Innovation	Oct 19 2011	2

2011

Academic Tour Groups

Group	Date	Participants
Gerald Sussman UW CS Club Tour Group	5/14/10	5
Centre Wellington District High School Tour Group	5/27/10	40
Stephen Hawking	6/23/11	1
ISSYP Students	7/14/10	40
Leo Kadanoff, James Franck Institute in Chicago	7/19/10	2
EinsteinPlus Teachers	7/29/10	40
UW Physics Alumni Tour	9/25/10	75
Senior Science Students at Uxbridge Secondary School	10/14/10	20

Group	Date	Participants
Raytheon BBN Technologies Group	10/25/10	4
Massey Fellow Journalists	11/3/10	10
The Woodlands Public School	11/17/10	28
The Woodlands Public School	11/19/10	29
Perimeter Scholars International	11/26/10	34
Wilfrid Laurier Students	12/3/10	12
Sherbrooke University, Quebec Delegation	2/18/11	4
University of Toronto	2/23/11	3
Laurentian University/Science North graduate program in science communication	3/2/11	16
The Waterloo Space Society	3/10/11	10
Wilfrid Laurier Students	3/11/11	20
University of Waterloo, 1st year Physics Students	3/22/11	20
University of Waterloo	3/23/11	20
University of Guelph	3/25/11	23
The Woodlands Public School	3/25/11	27
Introduction to Quantum Information Processing Class	3/29/11	20
University of Waterloo, General Physics & Computer Science Students	4/6/11	15
Taiwan Delegation	4/14/11	12
Georgian Bay Secondary School	4/15/11	50

Government Tour Groups

Group	Date	Participants
Jim Flaherty, Peter Braid, Stephen Woodworth and Kenneth Tam	9/9/10	4
Advanced Leadership Tour Deputy Minister's Office	9/30/10	9
The Government of Ontario: The Honourable Glen Murray, Tom Allison, and Mark Hazelden	10/7/11	3

Group	Date	Participants
Government of Japan: Dr. Masuo Aizawa and Mr. Shiro Numajiri	11/19/11	2
Ambassador of Czech Republic	2/16/11	4
Dr. Gustav Kalbe, European Commission	3/25/11	3
Russian Delegation	3/30/11	5
Ontario Lieutenant Governor, the Honourable David C. Onley	4/11/11	3

Business/Industry Tour Groups

Group	Date	Participants
Michael Goodkin	7/19/10	2
RIM Tour Group	8/6/10	10
RIM Tour Group	9/3/10	6
Lockheed Martin: Ned Allen, Dr. Edward Allen and Mark Elliot	11/11/11	3
Moloney Electric Inc: John Cheng, Nilesh Sarode, Venkat Yechuri and Alife Rivera	11/19/11	4
Jason Sanabia	1/1/11	1
Waterloo Chapter of the Canadian Forum of the International Womens Forum	1/13/11	12
Royal Bank of Canada	2/10/11	4
Mario Tokoro, President and CEO of Sony Computer Science Laboratories	2/24/11	1