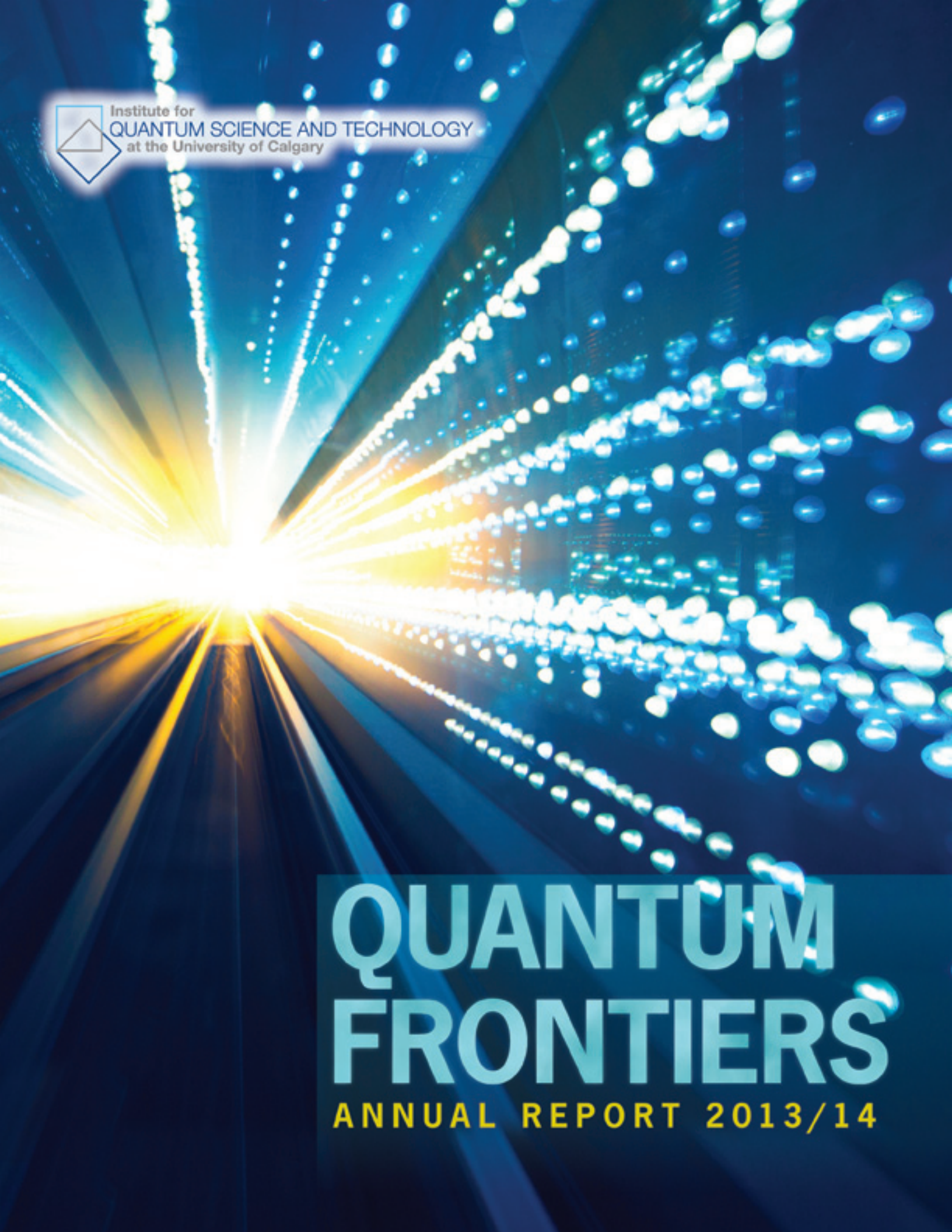

Institute for
QUANTUM SCIENCE AND TECHNOLOGY
at the University of Calgary
QUANTUM
FRONTIERS
ANNUAL REPORT 2013/14

VISION

To be a world leader in research and education in pure and applied quantum science and technology.

MISSION STATEMENT

To advance quantum science and technology through interdisciplinary research, teaching, and outreach.

KEY FACTS

[January 2013 - March 2014]

19 postdoctoral fellows

75 graduate students

27 undergraduate students

77 visiting researchers including 4 long-term visiting professors and 15 long-term visiting students

93 publications in refereed Journals and conference proceedings with 2 published in *Science*, 3 published in *Nature Physics*, 2 published in *Nature Communications*, 1 published in *Proceedings of the National Academy of Science of the United States of America*, 12 published in *Physical Review Letters*, and 3 published in *Journal of the American Chemical Society*

51 invited talks at national and international conferences/ workshops with 2 keynotes and 2 plenary talks

$3.05 million dollars income

Contents

Director's Report

Thanks to Alberta Innovates Technology Futures financial support for administration and for recruitment and colloquia activities, the Institute for Quantum Science and Technology has been established within the Faculty of Science at the University of Calgary. The newly formed Institute is an amalgamation of the former University of Calgary Institute for Quantum Information Science, which was a leading quantum information centre within Canada from 2005 to 2012, and several groups within the Departments of Chemistry and of Physics and Astronomy.

The research area of quantum science and technology aims to understand and harness the quantum properties of the physical world with a key objective being radical, transformative technological advances. Applications of quantum science and technology research include quantum computers for solving otherwise intractable problems, quantum cryptography for secure public-channel communication, informational memory, functional materials, renewable and clean energy solutions, and extreme sensor capabilities.

The Institute supports a community of quantum experts from the disciplines of chemistry, computing, mathematics, and physics, to expedite the cracking of hard problems that require a multi-disciplinary approach. The research groups combine state-of-the-art experimental capabilities with advanced theoretical insights and methods and are united within four interacting pillars of research: are molecular modeling, nanotechnology, quantum information, and quantum optics.

The Institute for Quantum Science and Technology was launched at special event at the University of Calgary on 20 September 2013. The speakers at the launch represented major stakeholders in the Institute. Linda Johnson, who is the Calgary-Glenmore Member of the Legislative Assembly, was the first speaker on behalf of the Government of Alberta. She was followed by Janaka Ruwanpura, who is the Vice-Provost (International), and was represented the leadership at the University of Calgary. On behalf Alberta Innovates Technology Future, iCORE General Manager gave the next speech, followed by National Institute for Nanotechnology Executive Director Marie D'Iorio. The closing speech was given by Chip Elliott, who is Chief Engineer of Raytheon BBN Technologies and Principal Investigator for Global Environment for Network Innovations (GENI).

In addition to these speakers, the Canadian Institute for Advanced Research was represented by Aimee Park (Senior Director, Research and Partnerships), Innovate Calgary with Robert Carruthers and Mark Williams in attendance, Annual Quantum Lecturer Paul Davies from Arizona State University, and the Dean of Science. The speakers and special guests were from industry, government and government laboratories, funding agencies, and academic organizations, thus representing a wide spectrum of the sectors where quantum science and technology is important. The daytime Institute Launch was followed by an evening Public Lecture by Professor Paul Davies of Arizona State University with an audience of over 750 participants.

The Institute is proud of its scientific achievements in its first year. These highlights are featured in their own section within this report. In addition to the highlights, the Annual Report provides detailed information about its contributions including visitors, colloquia, graduating students, and publications. These lists and tables demonstrate that the Institute is a prolific generation of new knowledge of the highest calibre.

In closing, the new Institute for Quantum Science and Technology is a crucible to elevate the University of Calgary's already formidable quantum science and technology activities to the highest standard by fostering collaboration within and beyond the Institute. In addition the Institute showcases the activities and accomplishments to the world, which enables building partnerships and recruiting the best talent.

Barry Sanders
Director, IQST

A Message From The Chair

I commend Barry Sanders and IQST's Administrator Nancy Jing Lu on producing an outstanding first report for the Institute. This Institute is formed under the aegis of the Faculty of Science. As Dean I have direct oversight over the Institute as Chair of the Advisory Board for the Institute and can confirm that the Institute is a model for others in the Faculty.

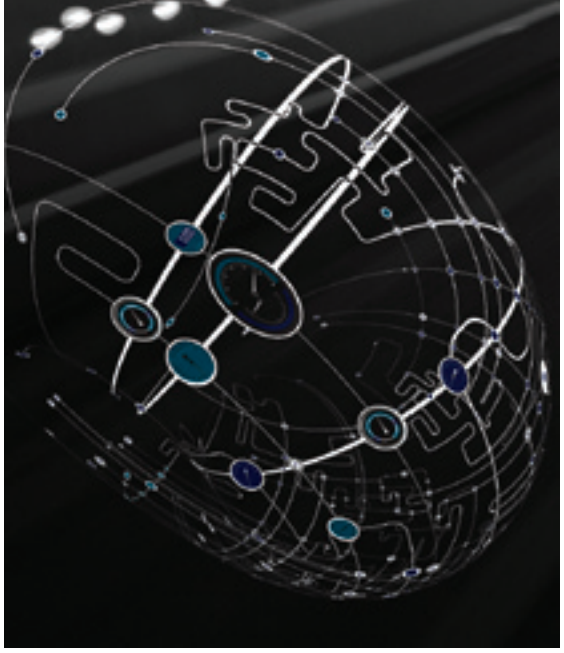
I am impressed by the quality and diversity of the research and training in the Institute as well as by the management of the Institute. The Institute comprises fifteen research groups across four departments in the Faculty of Science, which demonstrates the remarkable interdisciplinarity of quantum science and technology at the University of Calgary.

This Institute plays a crucial role in lifting quantum science and technology research within the Faculty of Science to a world-class standing. In fact the Institute is an exemplar within the Faculty of how to harness the strengths of disparate but potentially synergistic groups into a combined effort, making the whole much greater than the sum of the parts.

The Institute is guided in its activities by an Advisory Board comprising distinguished scientists, leaders and entrepreneurs. The Advisory Board met for the first time in 2013 on the same day as the auspicious Institute Launch and had the highest praise for the Institute. They also gave excellent guidance to the Director, and I am pleased to see earnest effort underway to meet the Board's high expectations.

The Institute is off to a great start and is well poised to deliver more outstanding outcomes in its second year.

Ken Barker
Chair of the Board of Directors, IQST



Highlights

Research Achievements

The Institute had an excellent first year of existence, as exemplified by the following highlights.

Robert I. Thompson is one of seven Canadian academic leaders of the Antihydrogen Laser Physics Apparatus (Alpha) project at the Conseil Européen pour la Recherche Nucléaire (CERN) in Geneva. A chief goal of the Alpha collaboration is to test fundamental symmetries of nature with trapped anti-matter. In 2013, the team of seven shared the Canadian Natural Sciences and Engineering Research Council (NSERC) Polanyi Prize.

The Polanyi prize is awarded annually to an individual or team whose research has led to a recent outstanding advance in the natural sciences or engineering, and the 2013 prize recognized the Canadian team's key role in demonstrating the possibility of capturing anti-hydrogen in a magnetic bottle then developing methods leading to the first measurement of the properties of atomic antimatter.

Paul Barclay and his group realized nanoscale cavity optomechanical systems in 2013, notably the observation of optomechanical back-action in gallium phosphide microdisks. This result, published in *Applied Physics Letters*, demonstrates silicon-based optomechanical torque sensors with record sensitivity.

Gilad Gour, collaborating with University of California at San Diego mathematician Nollan Wallach, solved a long-standing problem of systematically classifying all finite-dimensional multi-particle entanglement into equivalence classes based on stochastic local operations and classical communication between parties. The result appears in *Physical Review Letters*.

Two *Science* papers co-authored by Institute members appeared in 2013. One result, co-authored by chemist Simon Trudel, presents a breakthrough in amorphous thin-film electrocatalysis to mediate the water-splitting reaction with the aim of converting clean renewable energy to a chemical fuel for storage. The other *Science* result, co-authored by Barry Sanders, demonstrated at an ETH Zürich laboratory the phenomenon of photon-mediated interactions between distant artificial atoms in a superconducting circuit, thereby opening the door to controllable collective interactions between light and matter.

Christoph Simon and Alex Lvovsky, with other collaborators, achieved optical micro-macro entanglement involving millions of photons, described in a *Nature Physics* article. They followed up with an elegant proposal to create and detect optomechanical micro-macro entanglement, which was published in *Physical Review Letters*. These results usher in tantalizing possibilities for testing quantum wave-function collapse theories.

In addition to the micro-macro entanglement achievement, Lvovsky's group implemented the first entanglement-distillation procedure for two-mode squeezed light. The *Physical Review Letters* article is especially notable in that this bipartite state of light serves as a crucial resource for continuous-variable quantum communication.

Wolfgang Tittel's group reports in their 2013 *Nature Communications* article the realization of two-photon interference for weak coherent laser pulses that are recalled from separate solid-state quantum memories. They demonstrate interference near the theoretical maximum, which shows that their system faithfully maps quantum information while preserving the entire photonic wave function as needed for quantum-information processing involving two-photon interference.

Awards

International Awards

HONORARY PROFESSOR, HENAN UNIVERSITY OF SCIENCE AND TECHNOLOGY OF CHINA (PEOPLE'S REPUBLIC OF CHINA)
Dennis Salahub

KING SAUD UNIVERSITY AWARD (SAUDI ARABIA)
Khulud Almutairi

PUBLIC AUTHORITY FOR APPLIED EDUCATION AND TRAINING AWARD (KUWAIT)
Hessa Alotaibi

"QIAN REN" CHAIR PROFESSOR, UNIVERSITY OF SCIENCE AND TECHNOLOGY OF CHINA (PEOPLE'S REPUBLIC OF CHINA)
Barry Sanders

National Awards

MITACS GLOBALINK
Priyank Shyam

Yilin Zhao

NINT NANO USRA
Fuluny Jang

NSERC ALEXANDER GRAHAM BELL CANADA GRADUATE SCHOLARSHIP – DOCTORAL
Neil Sinclair

Marcelo Wu

NSERC USRA PROGRAM
Adam Humeniuk

Stephen Wein

Jeremy Witmer

NSERC VANIER SCHOLARSHIP
Kyle Hall

NSERC JOHN C. POLANYI AWARD
Robert I. Thompson

PIMS POSTDOCTORAL FELLOWSHIP
Vlad Gheorghiu (ended July 2013)

Collin Trail (ended March 2013)

Provincial Awards

ALBERTA INNOVATES GRADUATE STUDENTS SCHOLARSHIP
John Travis Brannan

Chris Healey

Matthew Mitchell

Farokh Mivehvar

Neil Sinclair

Marcelo Wu

ALBERTA INNOVATES TECHNOLOGY FUTURES/ EYES HIGH POSTDOCTORAL FELLOWSHIP
Joydip Ghosh

University of Calgary Awards

EYES HIGH DOCTORAL SCHOLARSHIP
Ehsan Zahedinejad

GLOBAL OPEN DOCTORAL SCHOLARSHIP
Mojtaba Rezaei

PURE AWARD
Luis Welbanks

QUEEN ELIZABETH II GRADUATE SCHOLARSHIP
John Travis Brannan

Guosheng (Tom) Huo

Mohammad Khazali

David Lake

Farokh Mivehvar

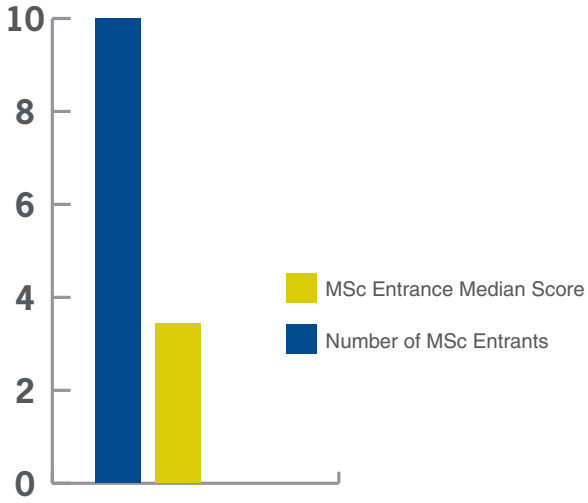
Mojtaba Rezaei

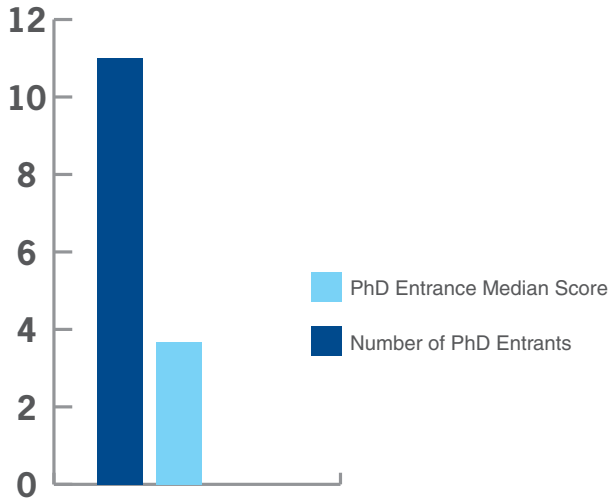
Sahar Sheybani-Deloui

Key Performance Indicators

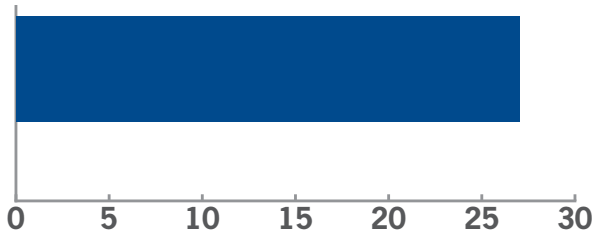
Information is for the fifteen-month period from January 2013 to March 2014.

GRADUATE STUDENTS ENROLMENT AND QUALITY OF ENTRANTS

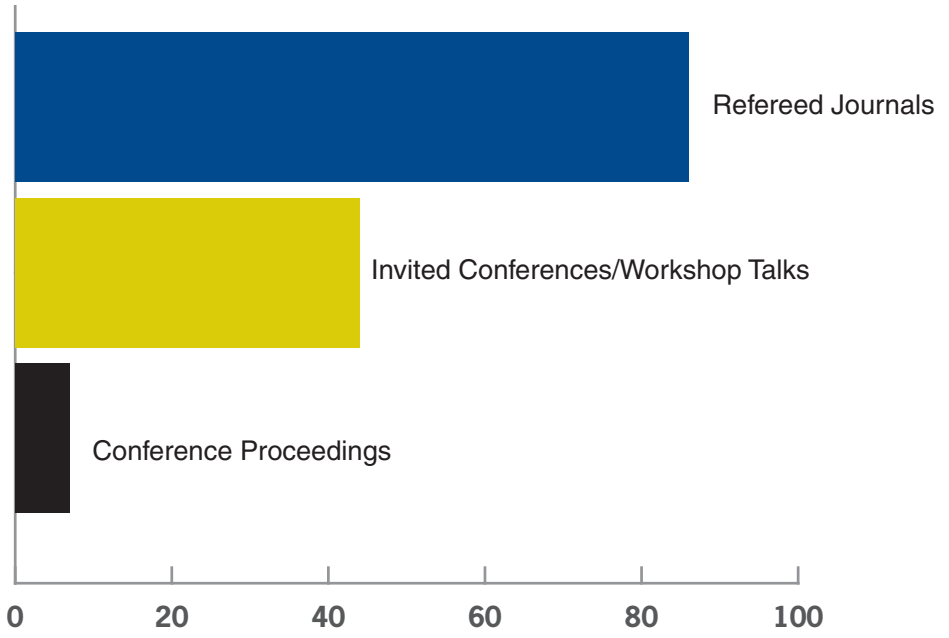




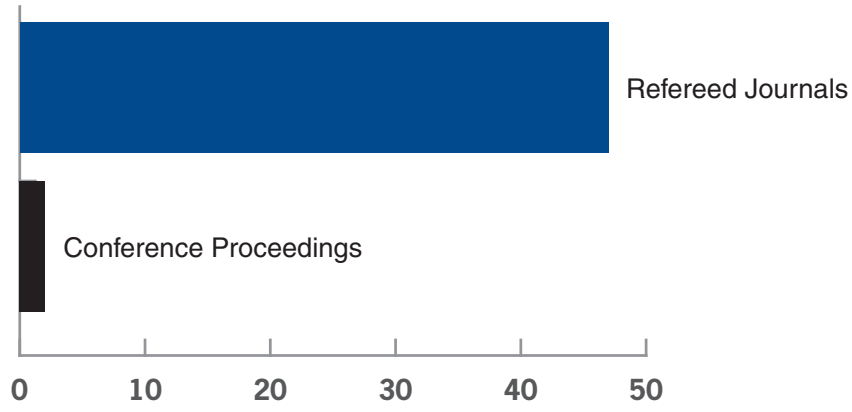
UNDERGRADUATE PROJECTS



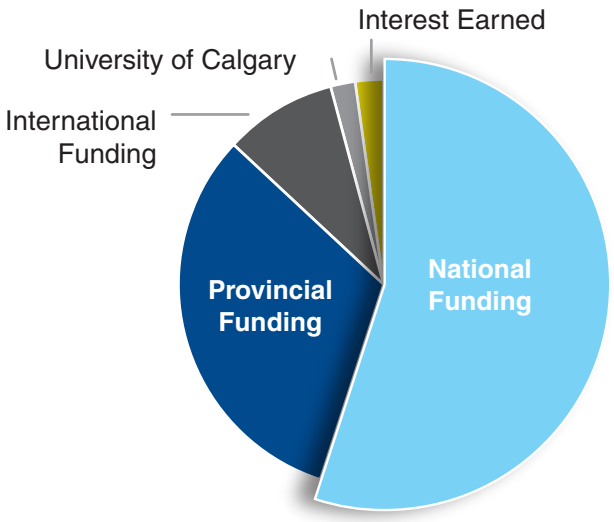
PUBLICATIONS AND PRESENTATIONS



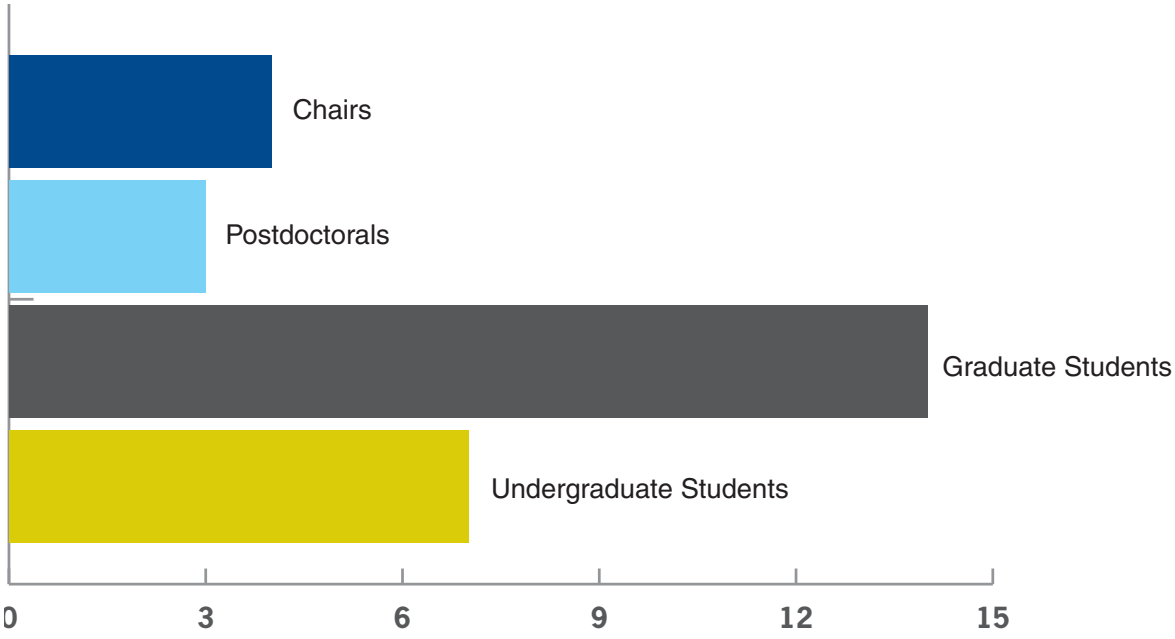
IQST STUDENT PUBLICATIONS



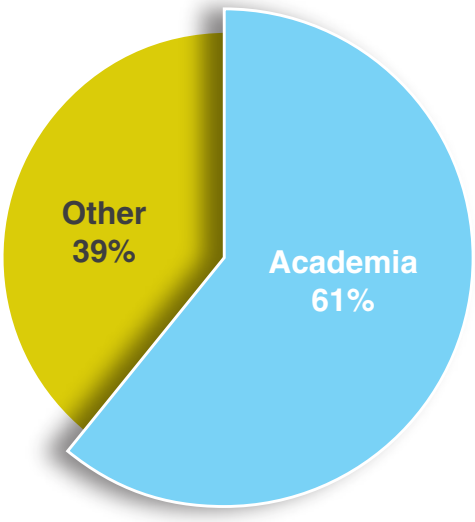
REVENUE (UNAUDITED)



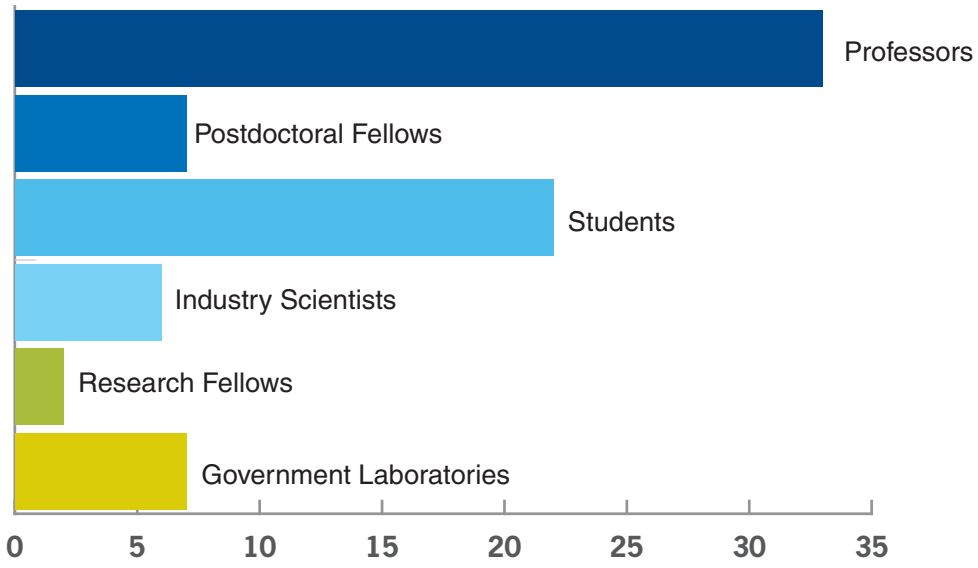
EXTERNAL AWARDS (CHAIRS, FELLOWSHIPS AND SCHOLARSHIPS)



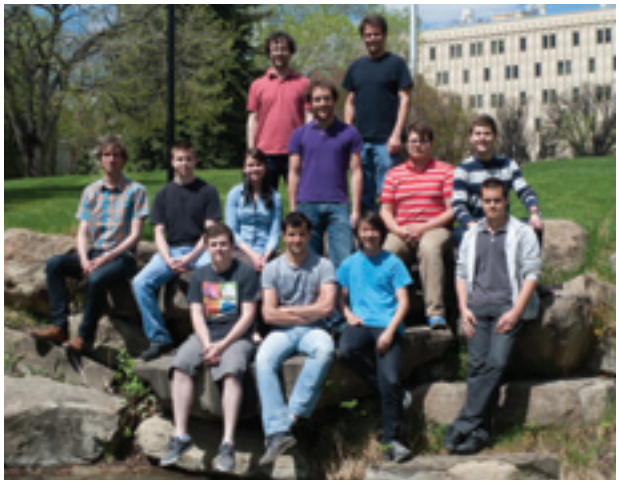
IN THE WORKFORCE AND ACADEMIA



VISITORS



Research Groups



Nanoscale Optics

DR. PAUL BARCLAY

Explores interactions between light and nanoscale systems such as single atoms, electron spins and nanomechanical structures. Employs nanofabrication methods to engineer optical properties of these systems in order to enhance light-matter coupling.

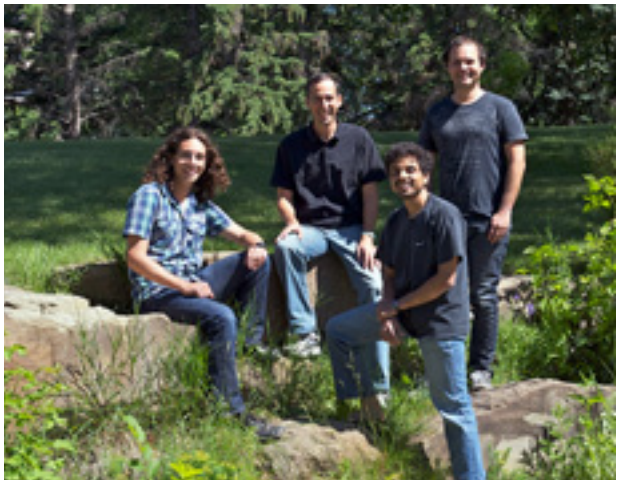
The current focus couples single quantum emitters, or “artificial atoms”, to optical nanocavities. These quantum emitters are impurities in materials such as diamond, whose quantum state is useful for storing information and sensitively probing magnetic fields. This research has applications in quantum information processing, developing low-power optical devices, and creating sensitive and compact environmental sensors.

The labs are at the University of Calgary and at the NRC National Institute for Nanotechnology, which has advanced nanofabrication tools plus leading quantum optics and nanotechnology researchers.

Practical Quantum Computation

DR. DAVID FEDER

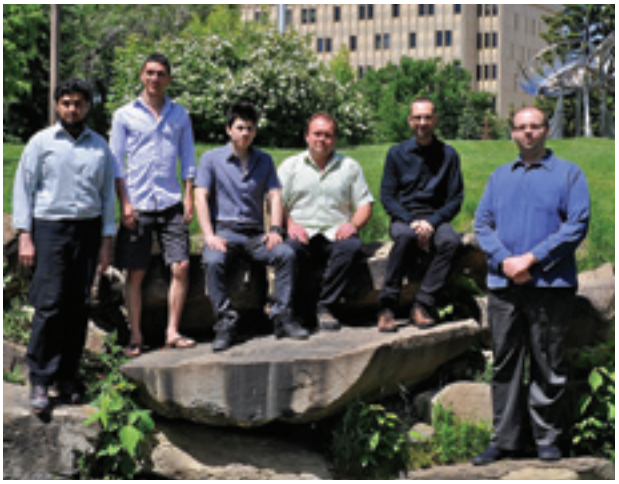
Focuses on understanding intrinsic properties of physical systems, such as ultracold atomic gases or spin lattices, can be employed to construct larger devices able to perform quantum computation. In addition, the group explores alternative models for the implementation of quantum logic, such as one-way quantum computation, quantum walks, and topological quantum computation.



Quantum Information Theory

DR. GILAD GOUR

Employs sophisticated mathematical methods, such as algebraic geometry, matrix analysis, group theory and C*-algebras, to solve core problems in quantum information science.



Quantum Computing

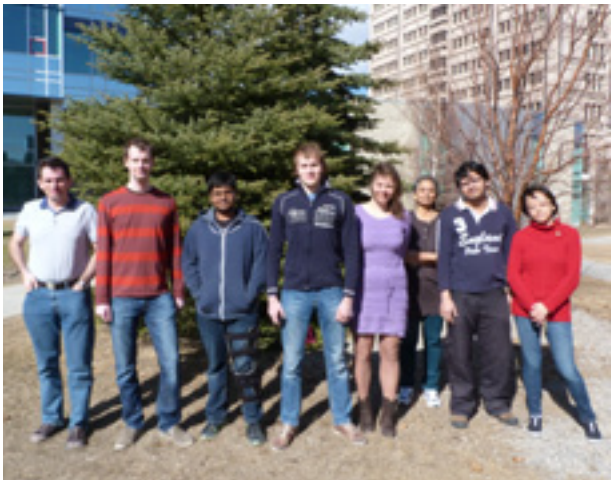
DR. PETER HØYER

Explores the potential powers of quantum systems to develop quantum algorithms, quantum communication protocols, quantum cryptographic protocols, and quantum computer simulations of quantum mechanical systems. Characterizes the powers and their limitations by studying quantum complexity theory, non-locality, entanglement, and quantum information theory.

Molecular Simulations of Liquids & Solutions, Interfaces and Crystallization

DR. PETER KUSALIK

Molecular simulations to examine collections of molecules representing solid or liquid systems. Probes the molecular behaviour to understand properties of liquids and solids and their transformations including nucleation and crystallization. Applications range from atmospheric and materials sciences to molecular biology and glaciation of a cloud. Explores behaviour of the hydroxyl radical in various aqueous environments.



Quantum Information Technology with Light and Experimental Quantum Optics

DR. ALEX LVOVSKY

Concentrates on implementing light for the purposes of quantum information technology – that is, learning to synthesize, control, characterize, and store arbitrary quantum states of the electromagnetic field, as well as causing photons to interact with each other.

Spectroscopy of Hydrocarbons and Molecular Clusters and Complexes

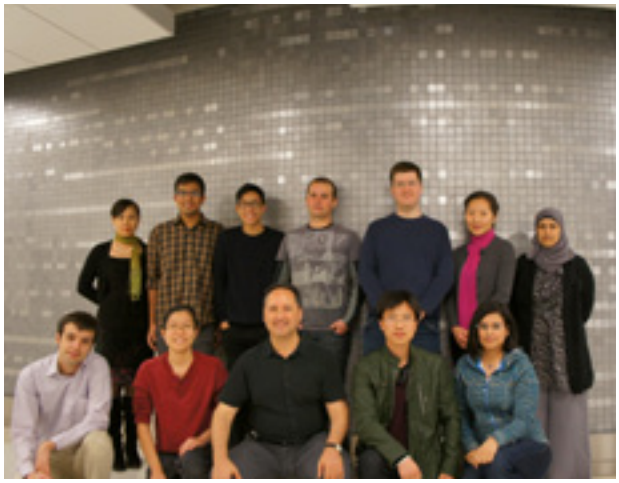
DR. NASSER MOAZZEN-AHMADI

Measures forces responsible for formation of atomic and molecular clusters. Investigates the intermolecular potential in the region of the potential minimum. Explores non-additive effects on the interaction energy and to determine possible condensation pathways. Relevant to a range of applications from atmospheric chemistry to molecular biology.

Multiscale Modeling of (Bio)chemical Reactions in Complex Environments

DR. DENNIS SALAHUB

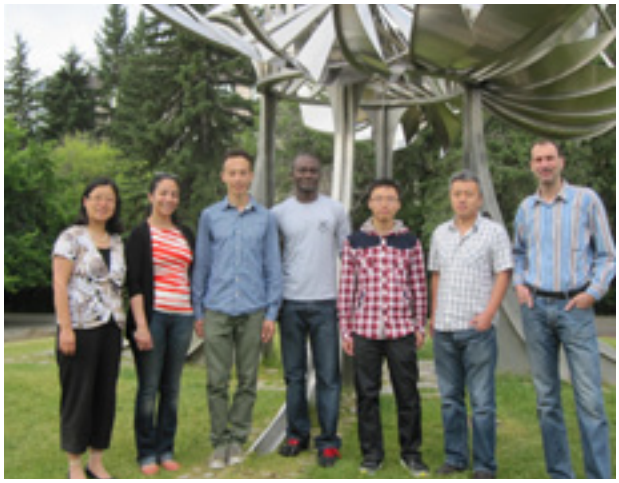
Investigates mechanisms and rates of chemical reactions occurring in complex environments. Models enzymatic catalysis, electron transfer between proteins and/or heavy oil upgrading. Employs multiple techniques, from quantum chemistry, to molecular dynamics, to stochastic network analysis, are brought to bear on the problem in a context of High Performance Computing.



Quantum Information Science

DR. BARRY SANDERS

Develops quantum information technologies that have transformative applications and will be feasible within a decade. The research program is divided into five strands: (i) long-distance secure communication, (ii) simulations of complex systems, (iii) implementations of quantum information tasks, (iv) empirical characterization of quantum states and processes, and (v) determining and quantifying all resources for quantum information processing.



Chemical Vapor Deposition Chemistry

DR. YUJUN SHI

Focuses on chemical and physical processes underpinning the formation of silicon-containing semiconductor thin film materials using hot-wire chemical vapour deposition. Applies technically demanding laser ionization mass spectrometric and laser spectroscopic techniques to investigate this process at the molecular level. Explores gas-phase reaction chemistry in the formation of silicon carbide and silicon nitride and laser spectroscopy of silicon carbide clusters generated using pulsed discharge and laser ablation methods. Applications include superior-quality films for industrial applications.

Theoretical Quantum Optics

DR. CHRISTOPH SIMON

Applies fundamentally quantum phenomena. One application is the quantum repeater, which will be essential for long-distance quantum communication, and motivates implementations of quantum memories and of quantum gates between individual photons in various systems. Explores the quantum-classical transition such as quantum amplification of photons to macroscopic levels and controlling quantum optomechanical systems.

Trapped Ion Physics with Atoms, Molecules, and Exotic Species

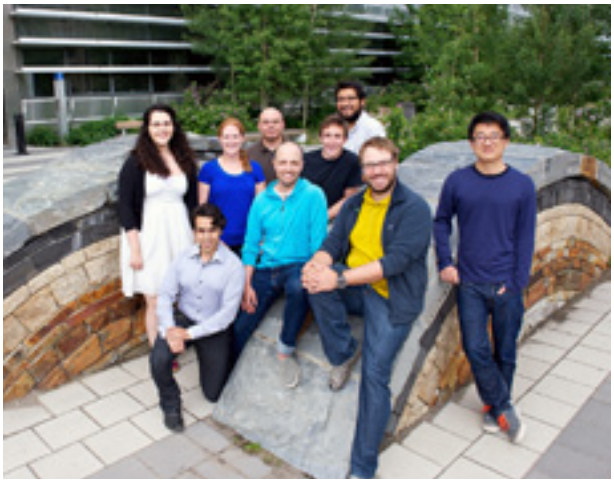
DR. ROBERT I. THOMPSON

Develops and measures low-density trapped atoms, molecules and exotic species, especially anti-matter Hydrogen. Collaboration with the Antihydrogen Laser Physics Apparatus (ALPHA) project at CERN involving 40 scientists across 16 institutions. Collaborates with TRIUMF's Ion Trap for Atomic and Nuclear (TITAN) Science, particularly on sympathetic and evaporative cooling.

Quantum Cryptography and Communication

DR. WOLFGANG TITTEL

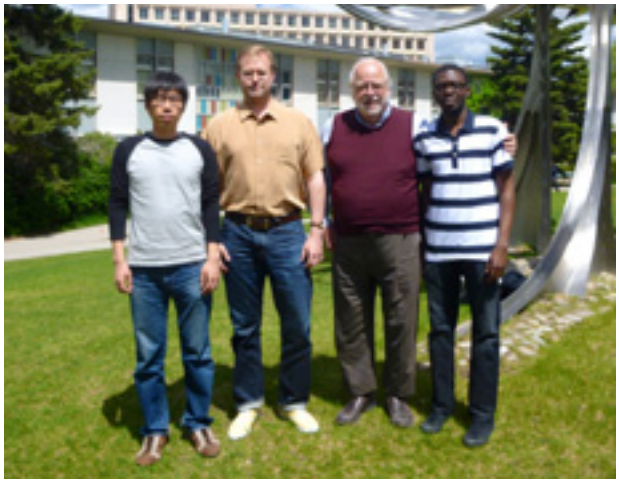
Builds photon-based quantum cryptography systems through optical fibres and targets the development of a quantum repeater to extend quantum cryptography past its current distance limit. Develops novel techniques for practical photonic quantum communication primitives such as quantum teleportation, plus hitherto unrealized means for efficient and reversible transfer of quantum information between photons and atoms for temporal storage.



Nanoscaled Material

DR. SIMON TRUDEL

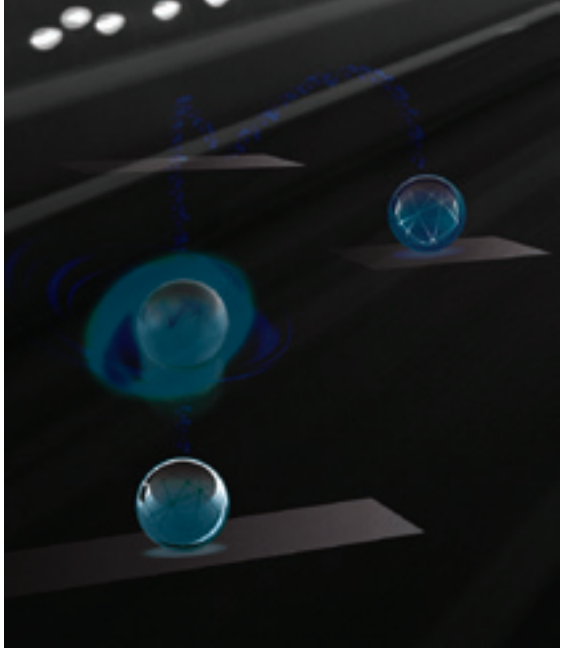
Investigates the synthesis, characterization, and structure-property relationships in inorganic solid-state nanomaterial, such as metal oxide thin films and multimetallic nanoparticles. Develops high-performance materials in technologically and commercially relevant focus areas such as clean-energy conversion and spin-based electronics. Characterizes materials using state-of-the-art methods, such as electrochemical testing, electron microscopy, x-ray diffraction, and magnetometry based on superconducting quantum interference devices. Properties are analyzed to provide feedback for synthetic approaches for improvement.



Probing Excited States from First Principles

DR. TOM ZIEGLER

Develops and applies new methods based on density functional theory describing structure and energetics of molecules in their excited state. Aims to describe photochemical processes and interpret experimental electronic spectra.



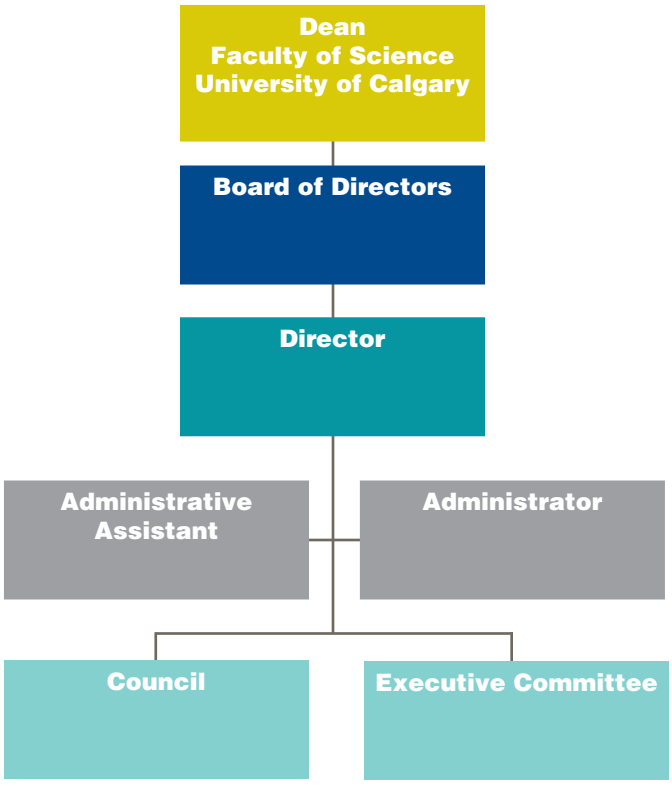
Management and Membership

Institute Structure

The Institute is managed on a day-to-day level by the Institute Director and the Institute Administrator. The Director and his research group are additionally supported by an administrative assistant. The Director reports to the Board of Directors and is ex officio a member of this Board. The Board reports to the Dean of Faculty of Science who chairs the Board.

The Director and the Administrator of the Institute work on day-to-day matters of the Institute. The Institute Executive comprises the Director, Administrator and five faculty members other than the Director. The Executive meets monthly to discuss and make decisions on executive matters. The Executive receives advice and guidance from the IQST Council, which comprises all full and affiliate faculty members of the Institute and meets three times annually.

All of the Institute's research, teaching, service and outreach activities are conducted by faculty members and their research groups.



Governance

Board of Directors

KEN BARKER,
Dean, Faculty of Science, University of Calgary

MARIE D'IORIO
Executive Director, National Institute for Nanotechnology (NINT)

CHIP ELLIOTT
Chief Engineer, Raytheon BBN Technologies

JOHN KENDALL
General Manager, Innovate Centres of Research Excellence (iCORE), Alberta Innovates Technology Futures (AITF)

SIR PETER KNIGHT
Principal, The Kavli Royal Society International Centre

SIR HAROLD W. KROTO
Francis Eppes Professor, Florida State University

BARRY SANDERS
Director, Institute for Quantum Science and Technology, University of Calgary

CARL WILLIAMS
Chief of the Quantum Measurement Division (QMD), Physical Measurement Laboratory, National Institute of Standards and Technology (NIST)

MARK WILLIAMS
Entrepreneur-in-Residence, Innovate Calgary

Executive Committee

DAVID FEDER
Associate Professor, Department of Physics and Astronomy, University of Calgary

GILAD GOUR
Associate Professor, Department of Mathematics and Statistics, University of Calgary

BARRY SANDERS
Director, Institute for Quantum Science and Technology, University of Calgary

YUJUN SHI
Associate Professor, Department of Chemistry, University of Calgary

WOLFGANG TITTEL
Professor, Department of Physics and Astronomy, University of Calgary

SIMON TRUDEL
Assistant Professor, Department of Chemistry, University of Calgary

Council

Faculty Members

PAUL BARCLAY
Assistant Professor, Department of Physics and Astronomy, University of Calgary

DAVID FEDER
Associate Professor, Department of Physics and Astronomy, University of Calgary

GILAD GOUR
Associate Professor, Department of Mathematics and Statistics, University of Calgary

PETER HØYER
Associate Professor, Department of Computer Science, University of Calgary

PETER KUSALIK
Professor, Department of Chemistry, University of Calgary

ALEX LVOVSKY
Professor, Department of Physics and Astronomy, University of Calgary

NASSER MOAZZEN-AHMADI
Professor, Department of Physics and Astronomy, University of Calgary

DENNIS SALAHUB
Professor, Department of Chemistry, University of Calgary

BARRY SANDERS
Director, Institute for Quantum Science and Technology, University of Calgary

YUJUN SHI
Associate Professor, Department of Chemistry, University of Calgary

CHRISTOPH SIMON
Associate Professor, Department of Physics and Astronomy, University of Calgary

ROBERT I. THOMPSON
Professor, Department of Physics and Astronomy, University of Calgary

WOLFGANG TITTEL
Professor, Department of Physics and Astronomy, University of Calgary

SIMON TRUDEL
Assistant Professor, Department of Chemistry, University of Calgary

TOM ZIEGLER
Professor, Department of Chemistry, University of Calgary

Affiliate Members

DAVID HOBILL
Associate Professor, Department of Physics and Astronomy, University of Calgary

MICHAEL LAMOUREUX
Professor, Department of Mathematics and Statistics, University of Calgary

SERGEI NOSKOV
Associate Professor, Department of Biological Science, University of Calgary

REGINALD PAUL
Professor, Department of Chemistry, University of Calgary

RENATE SCHEIDLER
Professor, Department of Mathematics and Statistics & Department of Computer Science, University of Calgary

PETER TIELEMAN
Professor, Department of Biological Sciences, University of Calgary

RICHARD ZACH
Professor, Department of Philosophy, University of Calgary

Students

Graduate Students (PhD Program)

Hessa Alotaibi

Nathan Babcock

Ismail Badran

Philip Chan

Di Chang

Ish Dhand

Adam D'Souza (completed December 2013)

Catalin Dohotaru

Raphael Dong

Tim Friesen (completed January 2014 → Postdoc, Aarhus University)

Roohollah (Farid) Ghobadi (completed November 2013 → Postdoc, Vienna University of Technology)

Mark Girard

Kyle Hall

Chris Healey

Khabat Heshami (completed April 2013 → Postdoc, University of Calgary)

Jeongwan Jin

Hamidreza Kaviani

Behzad Khanaliloo

Mohammad Khazali

Connor Kupchak (completed May 2013 → Postdoc, Stony Brook University)

Hon-Wai Lau

Ben Lavoie (completed December 2013 → Postdoc, University of Calgary)

Xingchen Liu

Thomas Lutz

Armando Marenco

Itzel Lucio-Martinez

Adam Mayer

Farokh Mivehvar

Ali Mohandesi

Varun Narasimhachar

Jalal Norooz Oliaee (completed April 2013 → Postdoc, University of Calgary)

Ebenezer Owusu-Ansah

Pantita Palittapongarnpim

Marcel.li Grimau Puigibert

Mojtaba Rezaei

Erhan Saglamyurek (completed January 2013 → Postdoc, University of Calgary)

Issaka Seidu

Zahra Shaterzadeh-Yazdi

Neil Sinclair

Sahar Sheybani-Deloui

Joshua Slater (completed August 2013 → Postdoc, University of Calgary)

Arina Tashchilina

Rim Toukabri (completed August 2013 → Research Associate, University of Calgary)

Dongsheng Wang

Marcelo Wu

Ehsan Zahedinejad

Rui Zhang

Hristina Zhekova (completed November 2013)

Graduate Students (MSc Program)

Khulud Almutairi

Luvdeep Bandhari

John Travis Brannan

Aveek Chandra

Ish Dhand (transferred September 2013 → PhD, University of Calgary)

Jennifer Emara

Jobin George

Abhirup Goswami

Jonathan Johannes

Abdullah Khalid

Guosheng (Tom) Huo

David Lake

Hassan Mallahzadeh

Matthew Mitchell

Eugene Moiseev

Sylvester Ndambuki (completed February 2013)

Ebenezer Owusu-Ansah (transferred May 2013 → PhD, University of Calgary

Edouard Pelchat (completed August 2013 → Canadian Forces)

Adarsh Prasad

Lohrasp Seify

Sahar Sheybani-Deloui (completed December 2013 → PhD, University of Calgary)

Randy Squires

Terence Stuart (completed May 2013)

Venkata Ramana Raju Valivarthi

Tian Wang

Mahdi Yousefi Koopaee

Luke Zhang

Undergraduate Students

Aaron Barclay (PHYS 598)
Alejandra Bueno (CHEM 402)
Kristine Boone (PHYS 599)
Jeff Buhler (PHYS 599)
Alex Cameron (research assistant)
Deborah Chung (PHYS 598)
Leah Davies (PHYS 599)
Tobias Fischer (UNIV 402)
Zeus Forero (research assistant)
Breanne Hannaford (PHYS 598)
Jordan Herndier (PHYS 599)
Daniel Hogg (visiting student)
Adam Humeniuk (NSERC USRA & research assistant)
Lana Huynh (CHEM 502)
Fuluny Jang (research assistant)
Jeff Maki (PHYS 598)
David O'Connell (Trans-Atlantic Science Student Exchange Program)
Joseph Tega Oghoredafe (PHYS 599)
Arthur Pinon (UNIV 402)
Casey Platnich (CHEM 402)
Priyank Shyam (MITACS Globalink)
Alex Tennant (PHYS 598)
Alexander Tkalych (research assistant)
Stephen Wein (NSERC USRA, PURE & PHYS 598)
Luis Welbanks (PURE)
Jeremy Witmer (NSERC USRA)
Yilin Zhao (MITACS Globalink)

Postdoctoral Fellows

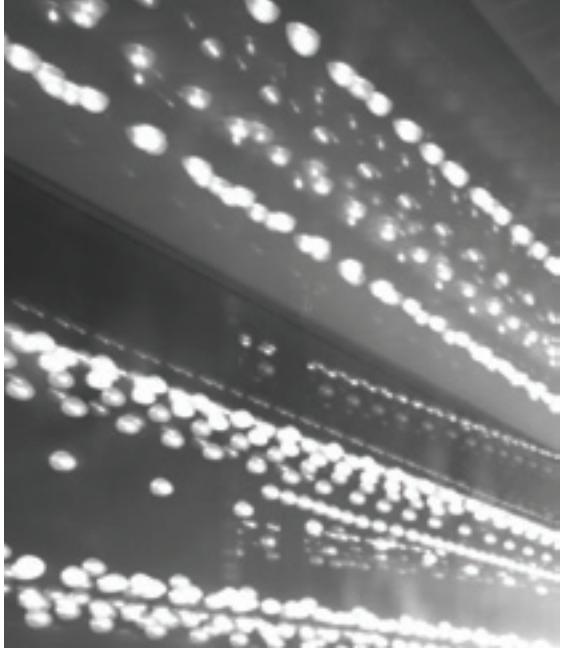
Farouq Ahmed (completed January 2014)
Anirban Bhattacharjee (completed November 2013)
Vlad Gheorghiu (completed July 2013 → Postdoc, University of Waterloo)
Joydip Ghosh
Lambert Giner
Bing He (completed July 2013 → Research Scientist, University of Arkansas)
Morgan Hedges (completed June 2013 → Postdoc, Princeton University)
Khabat Heshami
Harishankar Jayakumar
Neil Lovett (completed April 2013)
Stephanie Moore
Jalal Norooz Oliaee
Daniel Oblak
Erhan Saglamyurek
Maxim Shishkin (completed February 2014)
Joshua Slater
Collin Trail (completed March 2014)
Lucile Veissier
Yunjiang Wang (completed May 2013 → Associate Professor, Xidian University)

Research Associates

Edelsys Codorniu-Hernandez
Mykhaylo Krykunov
Rim Toukabri

Administration & Technical Support

Catherine Barrett
Arina Esmaeilpour (part-time)
Vladimir Kiselyov (part-time)
Nancy Jing Lu
Lucia Wang



Publications and Presentations

Refereed Journals

M. Adcock, P. Høyer and B. C. Sanders, "Gaussian quantum computation with oracle-decision problems", *Quantum Information Processing* **12**(4): 1759 – 1779, 1 April 2013.

F. Ahmed, R. Miura, N. Hatakeyama, H. Takaba, A. Miyamoto and D. R. Salahub, "Quantum chemical molecular dynamics study of the water-gas shift reaction on a Pd/MgO(100) catalyst surface", *Journal of Physical Chemistry C* **117**(10): 5051 – 5066, 18 February 2013.

H. M. Alotaibi and B. C. Sanders, "Double-double electromagnetically induced transparency with amplification", *Physical Review A* **89**(2): 021802 (R) (5 pp.), 27 February 2014.

C. Amole, M. D. Ashkezari, M. Baquero-Ruiz, W. Bertsche, E. Butler, A. Capra, C. L. Cesar, S. Chapman, M. Charlton, S. Eriksson, J. Fajans, T. Friesen, M. C. Fujiwara, D. R. Gill, A. Gutierrez, J. S. Hangst, W. N. Hardy M. E. Hayden, C. A. Isaac, S. Jonsell, L. Kurchaninov, A. Little, N. Madsen, J. T. K. McKenna, S. Menary, S. C. Napoli, P. Nolan, K. Olchanski, A. Olin, A. Povilus, P. Pusa, C. Ø. Rasmussen, F. Robicheaux, E. Sarid, D. M. Silveira, S. Stracka, C. So, R. I. Thompson, M. Turner, D. P. van der Werf, J. S. Wurtele, A. Zhmoginov, "Autoresonant-spectrometric determination of the residual gas composition in the ALPHA experiment apparatus", *Review of Scientific Instruments* **84**(6): 065110, 25 June 2013.

C. Amole, M. D. Ashkezari, M. Baquero-Ruiz, W. Bertsche, E. Butler, A. Capra, C. L. Cesar, M. Charlton, S. Eriksson, J. Fajans, T. Friesen, M. C. Fujiwara, D. R. Gill, A. Gutierrez, J. S. Hangst, W. N. Hardy, M. E. Hayden, C. A. Isaac, S. Jonsell, L. Kurchaninov, A. Little, N. Madsen, J. T. K. McKenna, S. Menary, S. C. Napoli, P. Nolan, A. Olin, P. Pusa, C. Ø. Rasmussen, F. Robicheaux, E. Sarid, D. M. Silveira, C. So, R. I. Thompson, D. P. van der Werf, J. S. Wurtele, A. I. Zhmoginov, A. E. Charman, "Description and first application of a new technique to measure the gravitational mass of antihydrogen", *Nature Communications* **4**: 1785 (9 pp.), 30 April 2013.

C. Amole, M. D. Ashkezari, M. Baquero-Ruiz, W. Bertsche, E. Butler, A. Capra, C. L. Cesar, M. Charlton, A. Deller, S. Eriksson, J. Fajans, T. Friesen, M. C. Fujiwara, D. R. Gill, A. Gutierrez, J. S. Hangst, W. N. Hardy, M. E. Hayden, C. A. Isaac, S. Jonsell, L. Kurchaninov, A. Little, N. Madsen, J. T. K. McKenna, S. Menary, S. C. Napoli, K. Olchanski, A. Olin, P. Pusa, C. Ø. Rasmussen, F. Robicheaux, E. Sarid, C. R. Shields, D. M. Silveira, C. So, S. Stracka, R. I. Thompson, D. P. van der Werf, J. S. Wurtele, A. Zhmoginov, L. Friedland, "Experimental and computational study of the injection of antiprotons into a positron plasma for antihydrogen production", *Physics of Plasmas* **20**(4): 043510, 10 April 2013.

C. Amole, M. D. Ashkezari, M. Baquero-Ruiz, W. Bertsche, E. Butler, A. Capra, C. L. Cesar, M. Charlton, A. Deller, N. Evetts, S. Eriksson, J. Fajans, T. Friesen, M. C. Fujiwara, D. R. Gill, A. Gutierrez, J.

S. Hangst, W. N. Hardy, M. E. Hayden, C. A. Isaac, S. Jonsell, L. Kurchaninov, A. Little, N. Madsen, J. T. K. McKenna, S. Menary, S. C. Napoli, K. Olchanski, A. Olin, P. Pusa, C. Ø. Rasmussen, F. Robicheaux, E. Sarid, D. M. Silveira, C. So, S. Stracka, T. Tharp, R. I. Thompson, D. P. van der Werf, J. S. Wurtele, "In situ electromagnetic field diagnostics with an electron plasma in a Penning–Malmberg trap", *New Journal of Physics* **16**(1): 013037 (18 pp.), 21 January 2014.

C. Amole, G. B. Andresen, M. D. Ashkezari, M. Baquero-Ruiz, W. Bertsche, P. D. Bowe, E. Butler, A. Capra, P. T. Carpenter, C. L. Cesar, S. Chapman, M. Charlton, A. Deller, S. Eriksson, J. Escallier, J. Fajans, T. Friesen, M. C. Fujiwara, D. R. Gill, A. Gutierrez, J. S. Hangst, W. N. Hardy, R. S. Hayano, M. E. Hayden, A. J. Humphries, J. L. Hurt, R. Hydomako, C. A. Isaac, M. J. Jenkins, S. Jonsell, L. V. Jørgensen, S. J. Kerrigan, L. Kurchaninov, N. Madsen, A. Marone, J. T. K. McKenna, S. Menary, P. Nolan, K. Olchanski, A. Olin, B. Parker, A. Povilus, P. Pusa, F. Robicheaux, E. Sarid, D. Seddon, S. Seif El Nasr, D. M. Silveira, C. So, J. W. Storey, R. I. Thompson, J. Thornhill, D. Wells, D. P. van der Werf, J. S. Wurtele, Y. Yamazaki, "The ALPHA antihydrogen trapping apparatus", *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* **735**: 319 – 340, 21 January 2014.

R. Blatt, G. J. Milburn and A. I. Lvovsky, "The 20th anniversary of quantum state engineering", *Journal of Physics B: Atomic, Molecular and Optical Physics* **46**(10): 100201 (2 pp.), 9 May 2013.

B. Braverman and C. Simon, "Proposal to observe the nonlocality of bohmian trajectories with entangled photons", *Physical Review Letters* **110**(6): 060406 (5 pp.), 7 February 2013.

M. Brela, A. Michalak, P. P. Power and T. Ziegler, "Analysis of the bonding between two M(μ-Nar#) monomers in the dimeric metal(II) imido complexes $\{M(\mu\text{-Nar}^{\#})\}_2$ [M = Si, Ge, Sn, Pb; $Ar^{\#} = C_6H_3$-2,6-$(C_6H_2$-2,4,6-$R_3)_2$]. The stabilizing role played by R = Me and iPr",*Inorganic Chemistry* **53**(4): 2325 – 2332, 6 February 2014.

F. Bussières, N. Sangouard, M. Afzelius, H. de Riedmatten, C. Simon and W. Tittel, "Prospective applications of optical quantum memories", *Journal of Modern Optics* **60**(18): 1519 – 1537, 19 November 2013.

R. H. Choi, B. Fortescue, G. Gour and B. C. Sanders, "Entanglement sharing protocol via quantum error correcting codes", *Physical Review A* **87**(3): 032319 (7 pp.), 15 March 2013.

E. Codorniu-Hernández, A. D. Boese and P. G. Kusalik, "The hemibond as an alternative condensed phase structure for the hydroxyl radical", *Canadian Journal of Chemistry* **91**(1-8): 544 – 551, 24 January 2013.

A. G. D'Souza, B. C. Sanders and D. L. Feder, "Fermionized photons in the ground state of one-dimensional coupled cavities", *Physical Review A* **88**(6): 063801 (15 pp.), 2 December 2013.

M. E. Kahou and D. L. Feder, "Quantum search with interacting Bose-Einstein condensates", *Physical Review A* **88**(3): 032310 (11 pp.), 11 September 2013.

N. J. English, P. G. Kusalik and J. S. Tse, "Density equalisation in supercooled high- and low density water mixtures", *Journal of Chemical Physics* **139**(8): 084508 (9 pp.), 28 August 2013.

S. Friedland, V. Gheorghiu and G. Gour, "Universal uncertainty relations", *Physical Review Letters* **111**(23): 230401 (5 pp.), 3 December 2013.

V. Gheorghiu and B. C. Sanders, "Accessing quantum secrets via local operations and classical communication", *Physical Review A* **88**(2): 022340 (5 pp.), 30 August 2013.

R. Ghobadi, A. I. Lvovsky and C. Simon, "Creating and detecting micro-macro photon-number entanglement by amplifying and deamplifying a single-photon entangled state", *Physical Review Letters* **110**(17): 170406 (5 pp.), 25 April 2013.

R. Ghobadi, S. Kumar, B. Pepper, D. Bouwmeester, A. I. Lvovsky and C. Simon, "Optomechanical micro-macro entanglement", *Physical Review Letters* **112**(8): 080503 (5 pp.), 27 February 2014.

J. Ghosh, "Simulating Anderson localization via a quantum walk on a one-dimensional lattice of superconducting qubits", *Physical Review A* **89**(2): 022309 (12 pp.), 10 February 2014.

G. Gour and N. R. Wallach, "Classification of multipartite entanglement of all finite dimensionality", *Physical Review Letters* **111**(6): 060502 (5 pp.), 8 August 2013.

A. Ü. C. Hardal, P. Xue, Y. Shikano, Ö. E. Müstecaplıoğlu and B. C. Sanders, "Discrete time quantum walk with nitrogen-vacancy centers in diamond coupled to a superconducting flux qubit", *Physical Review A* **88**(2): 022303 (11 pp.), 1 August 2013.

X. He, J. Borau-Garcia, A. Y. Y. Woo, S. Trudel and T. Baumgartner, "Dithieno[3,2-*c*:2',3'-*e*]-2, 7-diketophosphepin: A unique building block for multifunctional π-conjugated materials", *Journal of*

the American Chemical Society **135**(3): 1137 – 1147, 11 January 2013.

X. He, J.-B. Lin, W. H. Kan, P. C. Dong, S. Trudel and T. Baumgartner, "Molecular engineering of 'click'-phospholes towards self-assembled luminescent soft materials", *Advanced Functional Materials* **24**(7): 897 – 906, 8 August 2013.

X. He, J.-B. Lin, W. H. Kan, S. Trudel and T. Baumgartner, "Synthesis and properties of cholesteric click-phospholes", *Organic Letters* **16**(5): 1366 – 1369, 14 February 2014.

P. Høyer and J. Rashid, "Quantum nonlocal boxes exhibit stronger distillability", *Modern Physics Letters A* **28**(17): 1330012 (29 pp.), 29 May 2013.

A. C. Hryciw and P. E. Barclay, "Optical design of split-beam photonic crystal nanocavities", *Optics Letters* **38**(10): 1612 – 1614, 6 May 2013.

J. Jin, J. A. Slater, E. Saglamyurek, N. Sinclair, M. George, R. Ricken, D. Oblak, W. Sohler and W. Tittel, "Two-photon interference of weak coherent laser pulses recalled from separate solid-state quantum memories", *Nature Communications* **4**: 2386 (7 pp.), 29 August 2013.

H. Kaviani, M. Khazali, R. Ghobadi, E. Zahedinejad, K. Heshami and C. Simon, "Quantum storage and retrieval of light by sweeping the atomic frequency", *New Journal of Physics* **15**(8): 085029 (9 pp.), 28 August 2013.

A. Khalique, W. Tittel and B. C. Sanders, "Practical long-distance quantum communication using concatenated entanglement swapping", *Physical Review A* **88**(2): 022336 (8 pp.), 28 August 2013.

P. H. Kim, C. Doolin, B. D. Hauer, A. J. R. MacDonald, M. R. Freeman, P. E. Barclay and J. P. Davis, "Nanoscale torsional optomechanics", *Applied Physics Letters* **102**(5): 053102 (5 pp.), 4 February 2013.

M. Krykunov, M. Seth and T. Ziegler, "Introducing constricted variational density functional theory in its relaxed self-consistent formulation (RSCF-CV-DFT) as an alternative to adiabatic time dependent density functional theory for studies of charge transfer transitions", *Journal of Chemical Physics* **140**: 18A502 (12 pp.), 2 January 2014.

M. Krykunov and T. Ziegler, "Self-consistent formulation of constricted variational density functional theory with orbital relaxation, implementation, and applications", *Journal of Chemical Theory and Computation* **9**(6): 2761 – 2773, 16 May 2013.

R. Kumar, E. Barrios, C. Kupchak and A. I. Lvovsky, "Experimental characterization of bosonic creation and annihilation operators", *Physical Review Letters* **110**(13): 130403 (5 pp.), 25 March 2013.

Y. Kurochkin, A. S. Prasad and A. I. Lvovsky, "Distillation of the two-mode squeezed state", *Physical Review Letters* **112**(7): 070402 (5 pp.), 20 February 2014.

P. G. Kusalik and E. Codorniu-Hernández, "Probing the mechanisms of proton transfer in liquid water", *Proceedings of the National Academy of Sciences of the United States of America* **110**(34): 13697 – 13698, 20 August 2013.

A. de la Lande, N. S. Babcock, J. Řezáč, B. C. Sanders and D. R. Salahub, "Correction: Surface residues dynamically organize water bridges to enhance electron transfer between proteins (PNAS, vol 107, pp. 11799, 2010)", *Proceedings of the National Academy of Sciences of the United States of America* **110**(3): 1136 –1137, 15 January 2013.

K. Lalumière, B. C. Sanders, A. F. van Loo, A. Fedorov, A. Wallraff and A. Blais, "Input-output theory for waveguide QED with an ensemble of inhomogeneous atoms", *Physical Review A* **88**(4): 043806 (15 pp.), 16 September 2013.

B. Lavoie, P. M. Leung and B. C. Sanders, "Slow light with three-level atoms in metamaterial waveguides", *Physical Review A* **88**(2): 023860 (6 pp.), 30 August 2013.

S. Liang and P. G. Kusalik, "Nucleation of gas hydrates within constant energy systems", *Journal of Physical Chemistry B* **117**(5): 1403 – 1410, 18 January 2013.

X. Liu, A. Tkalych, B. Zhou and D. R. Salahub, "Adsorption of hexacyclic C_6H_6, C_6H_8, C_6H_{10} and C_6H_{12} on a Mo-terminated α-Mo_2C (0001) surface", *Journal of Physical Chemistry C* **117**(14): 7069 – 7080, 19 March 2013.

J. M. H. Lo, Z. A. Premji, T. Ziegler and P. D. Clark, "First-principles investigation of selective oxidation of propane on clean and sulfided V_2O_5 (010) surfaces", *Journal of Physical Chemistry C* **117**(21): 11258 – 11274, 23 April 2013.

A. F. van Loo, A. Fedorov, K. Lalumière, B. C. Sanders, A. Blais and A. Wallraff, "Photon-mediated interactions between distant artificial atoms", *Science* **342**(6165): 1494 – 1496, 20 December 2013.

N. B. Lovett, C. Crosnier, M. Perarnau-Llobet and B. C. Sanders, "Differential evolution for many-particle adaptive quantum metrology", *Physical Review Letters* **110**(22): 220501 (4 pp.), 28 May 2013.

A. I. Lvovsky, R. Ghobadi, A. Chandra, A. S. Prasad and C. Simon, "Observation of micro-macro entanglement of light", *Nature Physics* **9**: 541 – 544, 25 July 2013.

A. I. Lvovsky, "Photonic qubits: A quantum delivery note", *Nature Physics* **9**(1): 5 – 6, 1 January 2013.

F. Mivehvar and D. L. Feder, "Synthetic spin-orbit interactions and magnetic fields in ring-cavity QED", *Physical Review A* **89**(1): 013803 (12 pp.), 6 January 2014.

N. Moazzen-Ahmadi and A. R. W. McKellar, "Spectroscopy of dimers, emonrs, and larger clusters of linear molecules", *International Reviews in Physical Chemistry* **32**(4): 611 – 650, 16 July 2013.

N. Moazzen-Ahmadi, J. Norooz Oliaee and V.-M. Horneman, "The $\nu_{12}+\nu_6-\nu_6$ and $\nu_{11}-\nu_{12}$ bands of $^{12}CH_3{}^{13}CH_3$: A frequency analysis including data from the four lowest vibrational states", *Journal of Quantitative Spectroscopy and Radiative Transfer* **129**: 316 – 323, 1 November 2013.

S. Ndambuki and T. Ziegler, "An analysis of unsupported triple and quadruple metal-metal bonds between two homonuclear group 6 transition elements based on the combined natural orbitals for chemical valence and extended transition state method", *International Journal of Quantum Chemistry* **113**(6): 753 – 761, 15 March 2013.

S. Ndambuki and T. Ziegler, "A theoretical analysis of supported quintuple and quadruple chromium-chromium bonds", *Inorganic Chemistry* **52**(7): 3860 – 3869, 1 April 2013.

J. Norooz Oliaee, M. Dehghany, N. Moazzen-Ahmadi and A. R. W. McKellar, "Fundamental and torsional combination bands of two isomers of OCS-CO_2 complex in the CO_2 ν_3 region", *Journal of Physical Chemistry A* **117**(39): 9605 – 9611, 16 January 2013.

P. Pirzadeh and P. G. Kusalik, "Molecular insights into clathrate hydrate nucleation at an ice-solution interface", *Journal of the American Chemical Society* **135**(19): 7278 – 7287, 22 April 2013.

M. Rezaei, K. H. Michaelian, N. Moazzen-Ahmadi and A. R. W. McKellar, "A new look at the infrared spectrum of the weakly bound CO-N_2 complex", *Journal of Physical Chemistry A* **117**(50): 13752 – 13758, 17 September 2013.

M. Rezaei, S. Sheybani-Deloui, N. Moazzen-Ahmadi, K. H. Michaelian and A. R. W. McKellar, "CO dimer: the infrared spectrum revisited", *Journal of Physical Chemistry A* **17**(39): 9612 – 9620, 15 February 2013.

M. Rezaei, S. Sheybani-Deloui, N. Moazzen-Ahmadi, K. H. Michaelian and A. R. W. McKellar, "Communication: Spectroscopic evidence for a planar cyclic CO trimer", *Journal of Chemical Physics* **138**(7): 071102 (3 pp.), 15 February 2013.

M. Rezaei, J. Norooz Oliaee, N. Moazzen-Ahmadi and A. R. W. McKellar, "Infrared spectrum of the CS_2 tetramer: Observation of a structure with D_{2d} symmetry", *Chemical Physics Letters* 570: 12 – 15, 21 January 2013.

M. Rezaei, K. H. Michaelian, A. R. W. McKellar and N. Moazzen-Ahmadi, "Infrared spectra of the Ne–C_2D_4 and Ar–C_2D_4 complexes", *Journal of Molecular Spectroscopy* **289**: 21 – 25, 7 June 2013.

M. Rezaei, K. H. Michaelian and N. Moazzen-Ahmadi, "New combination bands of N_2O-CO_2, N_2O-OCS, and N_2O-N_2 complexes in the N_2O ν_1 region", *Journal of Chemical Physics* **140**(4): 044332, 31 January 2014.

M. Rezaei, A. R. W. McKellar and N. Moazzen-Ahmadi, "On the ν_{12} band of C_6D_6 at 2289 cm^{-1}", *Journal of Molecular Spectroscopy* **296**: 14 – 16, 1 February 2014.

A. Rubenok, J. A. Slater, P. Chan, I. Lucio-Martinez and W. Tittel, "Real-world two-photon interference and proof-of-principle quantum key distribution immune to detector attacks", *Physical Review Letters* **111**(13): 130501 (5 pp.), 23 September 2013.

I. Seidu, M. Seth and T. Ziegler, "Role played by isopropyl substituents in stabilizing the putative triple bond in Ar'EEAr' [E = Si, Ge, Sn; Ar' = C_6H_3-2,6-(C_6H_3-2,6-Pr^i_2)$_2$] and Ar*PbPbAr* [Ar* = C_6H_3-2,6-(C_6H_2-2,4,6-Pr^i_3)$_2$]",*Inorganic Chemistry* **52**(15): 8378 – 8388, 16 July 2013.

I. Seidu, M. Krykunov and T. Ziegler, "The formulation of a constricted variational density functional theory for double excitations", *Molecular Physics* **112**(5-6): 661 – 668, 28 October 2013.

M. Seth, T. Ziegler, M. Steinmetz. And S. Grimme, "Modeling transition metal reactions with range-separated functionals", *Journal of Chemical Theory and Computation* **9**(5): 2286 – 2299, 19 March 2013.

L. K. Shalm, D. R. Hamel, Z. Yan, C. Simon, K. J. Resch and T. Jennewein, "Three-photon energy–time entanglement", *Nature Physics* **9**(1): 19 – 22, 1 January 2013.

Z. Shaterzadeh-Yazdi, L. Livadaru, M. Taucer, J. Mutus, J. L. Pitters, R. A. Wolkow and B. C. Sanders, "Characterizing the rate and coherence of single-electron tunneling between two dangling bonds on the surface of silicon", *Physical Review B* **89**(3): 035315 (12 pp.), 28 January 2014.

Y. J. Shi, I. Badran, A. Tkalych, W. H. Kan and V. Thangadurai, "Growth of crystalline tungsten carbides using 1,1,3,3-tetramethyl-1, 3-disilacyclobutane on a heated tungsten filament",

Journal of Physical Chemistry C **117**(7): 3389 – 3395, 29 January 2013.

M. Shishkin and T. Ziegler, "Coke-tolerant Ni/$BaCe_{1-x}Y_xO_{3-\delta}$ anodes for solid oxide fuel cells: DFT+U study", *Journal of Physical Chemistry C* **117**(14): 7086 – 7096, 11 April 2013.

M. Shishkin and T. Ziegler, "Direct modeling of the electrochemistry in the three-phase boundary of solid oxide fuel cell anodes by density functional theory: A critical overview", *Physical Chemistry Chemical Physics* **16**: 1798 – 1808, 14 November 2013.

M. Skotiniotis, B. Toloui, I. T. Durham and B. C. Sanders, "Quantum frameness for *CPT* inversion symmetry", *Physical Review Letters* **111**(2): 020504 (5 pp.), 11 July 2013.

R. D. L. Smith, M. S. Prevot, R. D. Fagan, Z. Zhang, P. A. Sedach, M. K. J. Siu, S. Trudel and C. P. Berlinguette, "Photochemical route for accessing amorphous metal-oxide materials for heterogeneous water oxidation catalysis", *Science* **340**(6128): 60 – 63, 5 April 2013.

R. D. L. Smith, B. Sporinova, R. D. Fagan, S. Trudel and C. P. Berlinguette, "Facile photochemical preparation of amorphous iridium oxide films for water oxidation catalysis", *Chemistry of Materials* **26**(4): 1654 – 1659, 11 February 2014.

R. D. L. Smith, M. S. Prevot, R. D. Fagan, S. Trudel, C. P. Berlinguette and V. Dana, "Water oxidation catalysis: electrocatalytic response to metal stoichiometry in amorphous metal oxide films containing iron, cobalt, and nickel", *Journal of the American Chemical Society* **135**(31): 11580 – 11586, 24 July 2013.

T. Stuart, J. A. Slater, F. Bussières and W. Tittel, "Flexible source of nondegenerate entangled photons based on a two-crystal Sagnac interferometer", *Physical Review A* **88**(1): 012301 (6 pp.), 8 July 2013.

S.-H. Tan, Y. Y. Gao, H. de Guise and B. C. Sanders, "SU(3) quantum interferometry with single-photon input pulses", *Physical Review Letters* **110**(11): 113603 (5 pp.), 12 March 2013.

R. Thomas, C. Kupchak, G. S. Agarwal and A. I. Lvovsky, "Observation of electromagnetically induced transparency in evanescent fields", *Optics Express* **21**(6): 6880 – 6888, 25 March 2013.

R. Toukabri and Y. J. Shi, "Decomposition and gas-phase chemistry of dimethylsilane in a hot-wire chemical emon deposition process", *Physical Chemistry Chemical Physics* **16**: 7896 – 7906, 4 March 2014.

R. Toukabri and Y. J. Shi, "Effect of trimethylsilane pressure on gas-phase reaction chemistry in the hot-wire chemical vapour deposition process", *Journal of Vacuum Science and Technology A* **31**(6): 061606, 11 October 2013.

R. Toukabri, N. Al-Kadhi and Y. J. Shi, "Formation of methyl radicals from decomposition of methyl-substituted silanes over tungsten and tantalum filament surfaces", *Journal of Physical Chemistry A* **117**(33): 7697 – 7704, 22 July 2013.

D.-S. Wang, M. C. de Oliveira, D. W. Berry and B. C. Sanders, "A Solovay-Kitaev decomposition strategy for single-qubit channels", *Physical Review Letters* **111**(13): 130504 (5 pp.), 25 September 2013.

T. Wang, R. Ghobadi, S. Raeisi and C. Simon, "Precision requirements for observing macroscopic quantum effects", *Physical Review A* **88**(6): 062114 (5 pp.), 27 December 2013.

P. Xue and B. C. Sanders, "Controlling and reversing the transition from classical diffusive to quantum ballistic transport in a quantum walk by driving the coin", *Physical Review A* **87**(2): 022334 (7 pp.), 22 February 2013.

C. J. Zhang, S. Trudel and C. P. Berlinguette, "Water oxidation catalysis: Survey of amorphous binary metal oxide films containing lanthanum and late 3d transition metals", *European Journal of Inorganic Chemistry* **2014**(4): 660 – 664, 1 February 2014.

H. R. Zhekova, M. Seth and T. Ziegler, "Density functional theory studies on the structure and electron distribution in the peroxide intermediate of the catalytic cycle of the multicopper oxidases", *Canadian Journal of Chemistry* **91**(9): 847 – 858, 11 April 2013.

Conference Proceedings

C. Amole, G. B. Andresen, M. D. Ashkezari, M. Baquero-Ruiz, C. Burrows, W. Bertsche, E. Butler, A. Capra, C. L. Cesar, S. Chapman, M. Charlton, A. Deller, S. Eriksson, J. Fajans, T. Friesen, M. C. Fujiwara, D. R. Gill, A. Gutierrez, J. S. Hangst, W. N. Hardy, M. E. Hayden, A. J. Humphries, A. Isaac, S. Jonsell, L. Kurchaninov, A. Little, N. Madsen , J. T. K. McKenna , S. Menary, S. C. Napoli, P. Nolan, K. Olchanski, A. Olin, A. Povilus, P. Pusa, C. Ø. Ramussen , F. Robicheaux, R. L. Sacramento, S. Stracka, J. Sampson , E. Sarid, D. Seddon, D. M. Silveira, C. So, R. I. Thompson, T. Tharp, J. Thornhill, P. Tooley, D. P. van der Werf, D. Wells, J. S. Wurtele, "Silicon vertex detector upgrade in the ALPHA experiment", *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*

732, Proceedings of Vienna Conference on Instrumentation 2013, Vienna, Austria, 11 Feb – 15 Feb 2013, published by Elsevier: 134 – 136.

T. Friesen, C. Amole, M. D. Ashkezari, M. Baquero-Ruiz, W. Bertsche, P. D. Bowe, E. Butler, A. Capra, C. L. Cesar, M. Charlton, A. Deller, N. Evetts, S. Eriksson, J. Fajans, M. C. Fujiwara, D. R. Gill, A. Gutierrez, J. S. Hangst, W. N. Hardy, M. E. Hayden, C. A. Isaac, S. Jonsell, L. Kurchaninov, A. Little, N. Madsen, J. T. K. McKenna, S. Menary, S. C. Napoli, K. Olchanski, A. Olin, P. Pusa, C. Ø. Rasmussen, F. Robicheaux, E. Sarid, D. M. Silveira, C. So, S. Stracka, R. I. Thompson, D. P. van der Werf, J. S. Wurtele, "Electron plasmas as a diagnostic tool for hyperfine spectroscopy of antihydrogen" *AIP Conference Proceedings* **1521**, Proceedings of Non-Neutral Plasma Physics VIII: 10th International Workshop on Non-Neutral Plasmas, Greifswald, Germany, 27 Aug – 30 Aug 2013, published by AIP Publishing: 123 – 133.

B. C. Sanders, "Efficient algorithms for universal quantum simulation" (invited), *Lecture Notes in Computer Science* **7948**, Proceedings of 5th International Conference on Reversible Computation (RC 2013), Victoria, Canada, 4 Jul 2013 – 5 Jul 2013, published by Springer: 1 – 10.

B. C. Sanders, "Forty-five years of entangled coherent states" (invited), Proceedings of 1st International Workshop on Entangled Coherent States and Its Application to Quantum Information Science, Machida, Japan, 26 Nov 2012 – 28 Nov 2012, published by Quantum ICT Research Institute: 111 – 113.

D. M. Silveira, G. B. Andresen, M. D. Ashkezari, M. Baquero-Ruiz, W. Bertsche, P. D. Bowe, E. Butler, C. L. Cesar, S. Chapman, M. Charlton, J. Fajans, T. Friesen, M. C. Fujiwara, D. R. Gill, J. S. Hangst, W. N. Hardy, M. E. Hayden, R. Hydomako, S. Jonsell, L. Kurchaninov, N. Madsen, S. Menary, P. Nolan, K. Olchanski, A. Olin, A. Povilus, P. Pusa, F. Robicheaux, E. Sarid, C. So, J. W. Storey, R. I. Thompson, D. P. van der Werf, J. S. Wurtele, "Evaporative cooling of antiprotons for the production of trappable antihydrogen", *AIP Conference Proceedings* **1521**, Proceedings of Non-Neutral Plasma Physics VIII: 10th International Workshop on Non-Neutral Plasmas, Greifswald, Germany, 27 Aug – 30 Aug 2013, published by AIP Publishing: 165 – 174.

C. Trail and B. C. Sanders, "Coupling of quantum fluctuations in a two-component condensate" (invited), *Proceedings of SPIE* **8635**: 863517 (7 pp.), Proceedings of SPIE: Advances in Photonics of Quantum Computing, Memory, and Communication VI, San Francisco, United States of America, 2 Feb 2013 – 7 Mar 2013, published by SPIE Publications.

Y. J. Wang, B. Zeng, M. Grassl and B. C. Sanders, "Stabilizer formalism for generalized concatenated quantum codes", Proceedings of IEEE International Symposium on Information Theory (ISIT 2013), Istanbul, Turkey, 7 Jul 2013 – 12 Jul 2013, published by IEEE: 529 – 533.

Book Chapters

A. I. Lvovsky, "Fresnel equations", in: *Encyclopedia of Optical Engineering*, published by Taylor & Francis, Oxford, 2013.

D. R. Salahub, A. de la Lande, A. Goursot, R. Zhang and Y. Zhang, "Recent progress in density functional methodology for biomolecular modeling", in: *Applications of Density Functional Theory to Biological and Bioinorganic Chemistry*, 1 – 46, Mihai V. Putz, D. Michael P. Mingos, eds. Published by Springer, Berlin, 2013 (Book Series: Structure and Bonding).

Invited Conference/Workshop Presentations

(presenter is underlined)

4 Jan 2013, B. C. Sanders, "Universal quantum simulation for fun & profit", 100th Indian Science Congress, Kolkata, India, 3 Jan 2013 – 7 Jan 2013.

7 Jan 2013, B. C. Sanders, "Computing immanants from photon coincidences", International Conference on Quantum Information and Quantum Computing (ICQICQ), Bangalore, India, 6 Jan 2013 – 11 Jan 2013.

25 Jan 2013, E. Codorniu-Hernández and P. G. Kusalik, "The hemibond as an alternative structure of the hydroxyl radical in condensed phase", 4th Annual Kananaskis Symposium of Theoretical Models in Chemistry and Biology, Banff, Canada, 25 Jan 2013.

25 Jan 2013, K. Hall, S. Carpendale and P. G. Kusalik, "Focusing viewer attention in 3-D animation: applying information visualization to molecular simulations", 4th Annual Kananaskis Symposium of Theoretical Models in Chemistry and Biology, Banff, Alberta, 25 Jun 2013.

6 Feb 2013, E. Saglamyurek, N. Sinclair, J. Jin, J. A. Slater, D. Oblak, F. Bussières, M. George, R. Ricken, W. Sohler and W. Tittel, "Solid-state photon-echo quantum memory for quantum repeaters", SPIE

Photonics West 2013, San Francisco, United States of America, 2 Feb 2013 – 7 Feb 2013.

7 Feb 2013, C. Trail and B. C. Sanders, "Coupling of quantum fluctuations in a two-component condensate", SPIE Photonics West 2013, San Francisco, United States of America, 2 Feb 2013 – 7 Feb 2013.

21 Feb 2013, B. C. Sanders, "Artificial-intelligence reinforcement learning for quantum metrology with adaptive measurements", Workshop on Mathematical Methods of Quantum Tomography, Toronto, Canada, 19 Feb 2013 – 22 Feb 2013.

25 Feb 2013, B. C. Sanders, "Efficient algorithm for designing universal quantum circuits to simulate efficiently open-system quantum dynamics", New Directions in the Quantum Control Landscape, Santa Barbara, United States of America, 25 Feb 2013 – 1 Mar 2013.

21 Mar 2013, B. C. Sanders, "Quantum frameness for charge-parity-time inversion symmetry", APS March Meeting, Baltimore, United States of America, 18 Mar 2013 – 22 Mar 2013.

26 May 2013, Y. J. Shi, "Hot-wire chemical emon deposition using organosilicon precursors", The 96th Canadian Chemistry Conference and Exhibitions, Québec, Canada, 26 May 2013 – 30 May 2013.

26 May 2013, M. Shishkin and T. Ziegler, "Coke-tolerant Ni/$BaCeO_3$ anodes", The 96th Canadian Chemistry Conference and Exhibitions, Québec, Canada, 26 May 2013 – 30 May 2013.

27 May 2013, B. C. Sanders, "Collective atomic effects in waveguide quantum electrodynamics", Quantum Optics and New Materials (V) (QONM-V), Beijing, People's Republic of China, 26 May 2013 – 29 May 2013.

2 Jun 2013, P. E. Barclay, "Nanoscale silicon optomechanics", Si-EPIC Program Passive Photonics Workshop 2013, Ottawa, Canada, 27 May 2013 – 2 Jun 2013.

5 Jun 2013, P. E. Barclay, "Optomechanical nanocavities for sensing and quantum optics", Photonics North 2013, Ottawa, Canada, 3 Jun 2013 – 5 Jun 2013.

13 Jun 2013, K. Hall, P. G. Kusalik and S. Carpendale, "Chemical reaction: electronic and atomic visualization", SurfNet Summer 2013 Workshop, Calgary, Canada, 13 Jun 2013.

17 Jun 2013, M. Rezaei, N. Moazzen-Ahmadi, A. R. W. McKellar and K. H. Michaelian, "Infrared spectra of the Ne_2-N_2O, Ar_2-N_2O trimers", 68th International Symposium on Molecular Spectroscopy, Columbus, United States of America, 17 Jun 2013 – 21 Jun 2013.

19 Jun 2013, A. Rubenok, J. A. Slater, P. Chan, I. Lucio-Martinez and W. Tittel, "Real-world Bell-state measurement & proof-of-principle demonstration of QKD immune to detector attacks", The Conference on Coherence and Quantum Optics X (CQO X) and Quantum Information and Measurement 2 (QIM 2), Rochester, United States of America, 17 Jun 2013 – 25 Jun 2013.

20 Jun 2013, C. Simon, "Micro-macro entanglement", The Conference on Coherence and Quantum Optics X (CQO X) and Quantum Information and Measurement 2 (QIM 2), Rochester, United States of America, 17 Jun 2013 – 25 Jun 2013.

21 Jun 2013, A. I. Lvovsky, A. S. Prasad, R. Ghobadi, A. Chandra, C. Simon and Y. Kurochkin, "Making a large entangled state from a small one", International Conference on Coherent and Nonlinear Optics (ICONO/LAT 2013), Moscow, Russia, 18 Jun 2013 – 22 Jun 2013.

25 Jun 2013, D. R. Salahub, "deMon quo vadis?", deMon Developer Workshop 2013, Toulouse, France, 24 Jun 2013 – 26 Jun 2013.

26 Jun 2013, B. C. Sanders, " Universal quantum simulation for fun & profit", The 10th Annual Canadian Quantum Information Students' Conference, Calgary, Canada, 24 Jun 2013 – 28 Jun 2013.

7 Jul 2013, E. Codorniu-Hernández, "Introduction to Car-Parrinello molecular dynamics simulations", 9th Seminar of Advanced Studies on Molecular Design and Bioinformatics: Energy, Varadero, Cuba, 7 Jul 2013 – 12 Jul 2013.

8 Jul 2013, D. R. Salahub, "Towards the multiscale modeling of chemical reactions in complex environments", 9th Seminar of Advanced Studies on Molecular Design and Bioinformatics: Energy, Varadero, Cuba, 7 Jul 2013 – 12 Jul 2013.

8 Jul 2013, W. Tittel, "Measurement-device-independent QKD across the Calgary network: enhanced security and a step towards the quantum repeater" (keynote), Summer Topicals 2013, Waikoloa, United States of America, 8 Jul 2013 – 10 Jul 2013.

15 Jul 2013, N. Sinclair, E. Saglamyurek, H. Mallahzadeh, J. A. Slater, M. Hedges, M. George, R. Ricken, D. Oblak, W. Sohler and W. Tittel, "Frequency-multiplexed quantum memories with read-out on demand for quantum repeaters", International Laser Physics Workshop (LPHYS 2013), Prague, Czech Republic, 15 Jul 2013 – 19 Jul 2013.

18 Jul 2013, T. Brannan, Z. Qin, A. MacRae, A. Lezama and A. I. Lvovsky, "Measuring the temporal wavefunction of a photon", International Laser

Physics Workshop (LPHYS 2013), Prague, Czech Republic, 15 Jul 2013 – 19 Jul 2013.

18 Jul 2013, A. Rubenok, J. A. Slater, P. Chan, I. Lucio-Martinez and W. Tittel, "Real-world Bell-state measurement and proof-of-principle demonstration of quantum key distribution immune to detector attacks over deployed optical fiber", International Laser Physics Workshop (LPHYS 2013), Prague, Czech Republic, 15 Jul 2013 – 19 Jul 2013.

24 Jul 2013, A. I. Lvovsky, R. Ghobadi, Y. Kurochkin and C. Simon, "Micro-macro entanglement in optics", 2nd International Conference on Quantum Technologies, Moscow, Russia, 20 Jul 2013 – 24 Jul 2013.

29 Jul 2013, A. I. Lvovsky, "Technology of light as a harmonic oscillator", 5th International Conference Frontiers of Nonlinear Physics (FNP 2013), Nizhny Novgorod, Russia, 28 Jul 2013 – 2 Aug 2013.

29 Jul 2013, B. C. Sanders, "Quantum interferometry for computation: estimating immanants from photon coincidences" (plenary), 5th International Conference Frontiers of Nonlinear Physics (FNP 2013), Nizhny Novgorod, Russia, 28 Jul 2013 – 2 Aug 2013.

1 Aug 2013, T. Stuart, J. A. Slater, R. Colbeck, R. Renner and W. Tittel, "An experimental bound on the maximum predictive power of physical theories", Frontiers in Quantum and Mesoscopic Thermodynamics (FQMT13), Prague, Czech Republic, 29 Jul 2013 – 3 Aug 2013.

16 Aug 2013, P. E. Barclay, "Nanoscale optomechanics for sensing and hybrid quantum systems", The 16th Canadian Semiconductor Science and Technology Conference (CSSTC 2013), Thunder Bay, Canada, 13 Aug 2013 – 16 Aug 2013.

19 Aug 2013, P. E. Barclay, "Nanoscale optomechanical sensors: split-beam nanocavities", 13th International Conference on Numerical Simulation of Optoelectronic Devices, Vancouver, Canada, 19 Aug 2013 – 22 Aug 2013.

26 Aug 2013, D. R. Salahub, "Towards the multiscale modeling of catalysis", ISTCP-VIII International Symposium on Theoretical Chemical Physics, Budapest, Hungary, 25 Aug 2013 – 31 Aug 2013.

27 Aug 2013, G. Gour, "Towards a complete classification of multipartite entanglement", Mathematical Challenges in Quantum Information, Isaac Newton Institute for Mathematical Sciences, Cambridge, United Kingdom, 27 Aug 2013 – 6 Sep 2013.

1 Sep 2013, T. Ziegler and M. Krykunov, "Excited state theories based on density functional theory" (plenary), Current Trends in Theoretical Chemistry –VI, Krakow, Poland, 1 Sep 2013 – 5 Sep 2013.

16 Sep 2013, N. Sinclair, E. Saglamyurek, H. Mallahzadeh, J. A. Slater, M. George, R. Ricken, M. Hedges, D. Oblak, C. Simon, W. Sohler and W. Tittel, "Quantum memories with read-out on demand for quantum repeaters", XV Feofilov Symposium, Kazan, Russia, 16 Sep 2013 – 20 Sep 2013.

10 Oct 2013, P. E. Barclay, "Nanocavity optomechanics for coupling to quantum systems", 97th Annual Frontiers in Optics 2013, Orlando, United States of America, 6 Oct 2013 – 10 Oct 2013.

15 Oct 2013, J. A. Slater, "Real-world proof-of-principle demonstration of measurement-device independent quantum key distribution", Single Photon Workshop 2013, Oak Ridge National Lab, United States of America, 15 Oct 2013 – 18 Oct 2013.

18 Oct 2013, B. C. Sanders, "Characterizing coherently-coupled dangling-bond dynamics", Progress towards practical quantum information processing: Meeting in honour of Dr. Sean Barrett, Royal Society, London, United Kingdom, 18 Oct 2013.

30 Oct 2013, B. C. Sanders, "Algorithmic quantum simulation", The 4th International Workshop on Quantum Optics, Jeju Island, South Korea, 30 Oct 2013 – 2 Nov 2013.

31 Oct 2013, B. C. Sanders, "Coherent and cooperative quantum optics in one dimension", The 4th International Workshop on Quantum Optics, Jeju Island, South Korea, 30 Oct 2013 – 2 Nov 2013.

11 Nov 2013, B. C. Sanders, "Quantum simulations of quantum channels", Workshop on Quantum Simulations and Quantum Walks, Pisa, Italy, 11 Nov 2013 – 15 Nov 2013.

16 Nov 2013, B. C. Sanders, "Efficient quantum simulation of a quantum channel", CIFAR: Quantum Information Science Program Meeting (QIP), Manoir des Sables, Orford, Canada, 13 Nov 2013 – 16 Nov 2013.

3 Dec 2013, B. C. Sanders, "On measuring coherence in coupled dangling-bond dynamics", EQuS 2013 Annual Workshop of the Australian Centre of Excellence for Engineered Quantum Systems, Mudjimba, Australia, 2 Dec 2013 – 4 Dec 2013.

8 Dec 2013, G. Gour, "Towards a complete classification of multipartite entanglement", 2013 Canadian Mathematical Society Winter Meeting, Ottawa, Canada, 6 Dec 2013 – 9 Dec 2013.

10 Jan 2014, T. Ziegler, “A variational derivation of the RPA equation” (plenary), CRC-EC Joint International Symposium on Chemical Theory for Complex Systems, Atlanta, United States of America, 9 Jan 2014 – 10 Jan 2014.

4 Feb 2014, P. E. Barclay, “Diamond nanostructures for optomechanics and quantum optics”, SPIE Photonics West, San Francisco, United States of America, 2 Feb 2014 – 7 Feb 2014.

20 Feb 2014, T. Ziegler, “CV-DFT theory developments”, SCM Developer Workshop, Amsterdam, The Netherlands, 17 Feb 2014 – 20 Feb 2014.

3 Mar 2014, G. Gour, “Universal uncertainty relations”, APS March Meeting 2014, Denver, United States of America, 3 Mar 2014 – 7 Mar 2014.

4 Mar 2014, N. Sinclair, E. Saglamyurek, H. Mallahzadeh, J. A. Slater, M. George, R. Ricken, M. Hedges, D. Oblak, C. Simon and W. Tittel, “Quantum memory for long-distance quantum communication based on spectral multiplexing”, APS March Meeting 2014, Denver, United States of America, 3 Mar 2014 – 7 Mar 2014.

Patent

A. M. Colcite, K. K. Gleason and Y. J. Shi, “Superhydrophobic and oleophobic functional coatings comprised of grafted crystalline polymers comprising perfluoroalkyl moieties, US patent application No: 13/784983, filed 5 March 2013.

Student Theses

A. G. D’Souza, “Quantum computation and many body physics” (PhD Thesis), 1 January 2014.

T. Friesen, “Probing trapped antihydrogen: in situ diagnostics and observations of quantum transitions” (PhD Thesis), 1 February 2014.

R. Ghobadi, “Towards macroscopic quantum effects using optomechanical and optical systems” (PhD Thesis), 1 November 2013.

K. Heshami, “Toward practical solid-state based quantum memories” (PhD Thesis), 1 May 2013.

C. Kupchak, “Complete characterization of quantum optical processes with a focus on quantum memory” (PhD Thesis), 1 April 2013.

B. Lavoie, “Slow light in metamaterial waveguides” (PhD Thesis), 1 December 2013.

J. Norooz Oliaee, “High-resolution infrared spectroscopy of van der Waals clusters of nitrous oxide, carbon dioxide and OCS-R complexes” (PhD Thesis), 1 May 2013.

E. Saglamyurek, “Broadband waveguide quantum memory for quantum communication” (PhD Thesis), 1 January 2013.

S. Sheybani-Deloui, “Observation of a planar isomer of the N2O – (C2H2)2 trimer” (MSc Thesis), 1 January 2014.

J. A. Slater, “Quantum correlations for fundamental tests and quantum communication” (PhD Thesis), 1 May 2013.

T. Stuart, “Probing the completeness of quantum theory with entangled photons” (MSc Thesis), 1 January 2013.

B. Toloui, “Quantifying the Asymmetry properties of quantum mechanical systems using entanglement monotones” (PhD Thesis), 1 March 2013.

R. Toukabri, “Gas-phase Chemistry on methyl-substituted silanes in hot-wire chemical vapor depositon” (PhD Thesis), 1 August 2013.

M. S. Underwood, “Quantum walk schemes for universal quantum computation” (PhD Thesis), 1 January 2013.

R. Zhang, “Multiscale simulation of mRNA synthesis by RNA polymerase II” (PhD Thesis), 1 December 2013.

H. R. Zhekova, “Density functional theory studies on the active site of the multicopper oxidases” (PhD Thesis), 1 December 2013.

Linkage

Collaboration Highlights

IQST and its members enjoy strong linkage with external organizations, research networks, and industry partners. Three members hold secondary positions at other institutes, and these linkages are valuable as they bring exchange opportunities.

In 2013 Barry Sanders was awarded a five-year China Thousand Talent Chair Professor part-time position at the University of Science and Technology of China. He is associated with the Department of Modern Physics as well as with the Shanghai-based Division of Quantum Physics and Quantum Information in the Hefei National Laboratory for Physical Sciences at Microscale.

Alex Lvovsky is a group leader at the Russian Quantum Center, with activities that are synergistic with his University of Calgary activities. Paul Barclay has a second position as a researcher at the National Institute for Nanotechnology based at the University of Alberta campus. Institute members are participants in collaborative research networks. Peter Høyer, Alex Lvovsky and Barry Sanders are members of the quantum information processing program within the Canadian Institute for Advanced Research.

Barry Sanders is the principal investigator of the Pacific Institute for the Mathematical Sciences Collaborative Research Group for the Mathematics of Quantum Information, which includes David Feder, Gilad Gour, Peter Høyer, Alex Lvovsky, Christoph Simon, and Wolfgang Tittel as members. As for new networks, Christoph Simon and Wolfgang Tittel are part of a United States Defense Advanced Research Projects Agency network supporting the effort to build a quantum repeater.

The Institute has strong industrial links. Dennis Salahub is a member of an European Union-funded network on Computer Simulations of Thermally Excited Materials by First Principles involving collaborations with Germany, France, Italy, Mexico and Japan. Tom Ziegler collaborates with Scientific Computing & Modeling (SCM) NV (www.scm.com) in Amsterdam. Tom Ziegler and SCM develop modeling software for implementation in their software ADF (Amsterdam Density Functional Theory package), which is sold worldwide.

Dennis Salahub is the leader of an international consortium called the deMon Developers which is dedicated to the development of the widely-used deMon computational chemistry software. Simon Trudel collaborates with FireWater Fuel, a startup company aiming to commercialize novel water-splitting electrocatalysis first developed at the University of Calgary.

Editorial activities are highly valued in the Institute. Alex Lvovsky is an associate editor of *Optics Express*, and Barry Sanders is an associate editor of *Physical Review A*. Dennis Salahub is an editor of *Advances in Physical Chemistry*, an academic editor of *PLOS ONE*, vice-chair of the Editorial Board for *Interdisciplinary Science: Computational Life Sciences* and an editorial board member of *Advances in Quantum Chemistry* and the *Journal of Computational Chemistry*.

Collaboration

International Institutions

Aarhus University, Denmark

Battelle Memorial Institute, United States of America

Catalan Institution for Research and Advanced Studies, Spain

Centre National de la Recherche Scientifique (CNRS), France

China Southeast University, People's Republic of China

College of William and Mary, United States of America

Data Storage Institute, Singapore

Delft University of Technology, Netherlands

École Normale Supérieure de Cachan, France

ETH Zürich, Switzerland

Federal University of Rio de Janeiro, Brazil

Free University of Amsterdam, Netherlands

Fritz Haber Institute of the Max Planck Society, Germany

Haverford College, United States of America

Indian Institute of Technology, Kharagpur, India

Institute for Molecular Science, Japan

Instituto Politécnico Nacional, Mexico

Jagiellonian University, Poland

Jacobs University, Germany

Jet Propulsion Laboratory, United States of America

Koç University, Turkey

Lebedev Physics Institute, Russia

Leiden University, Netherlands

Macquarie University, Australia

Massachusetts Institute of Technology, United States of America

Montana State University, United States of America

North Western University, United States of America

Nuclear Research Center, Israel

Oklahoma State University, United States of America

Old Dominion University, United States of America

Purdue University, United States of America

Saint Anselm College, United Kingdom

Shanghai Jiaotong University, People's Republic of China

South Illinois University, United States of America

Stockholm University, Sweden

Swansea University, United Kingdom

The Institute for Photonic Sciences, Spain

The Russian Quantum Centre, Russia

Tohuku University, Japan

Università Della Calabria, Italy

Università della Svizzera italiana, Switzerland

Universität Bonn, Germany

Universität Innsbruck, Austria

Universität Paderborn, Germany

Universität Potsdam, Germany

Université de Genève, Switzerland

Université Joseph Fourier, France

Université Pierre et Marie Curie, France

Universiteit van Amsterdam, Netherlands

Universidade Estadual de Campinas, Brazil

University College Dublin, Ireland

University of Arkansas, United States of America

University of Bristol, United Kingdom

University of California at Berkeley, United States of America

University of California at Davis, United States of America

University of California at San Diego, United States of America

University of California at Santa Barbara, United States of America

University of Illinois at Chicago, United States of America

University of Kentucky, United States of America

University of Liverpool, United Kingdom

University of Manchester, United Kingdom

University of New South Wales, Australia

University of Oulu, Finland

University of Queensland, Australia

University of Science and Technology of China, People's Republic of China

University of Utah, United States of America

Yale University, United States of America

Canadian Institutions

Lakehead University

National Institute for Nanotechnology

Queen's University

Simon Fraser University

Southern Alberta Institute of Technology

Steacie Institute for Molecular Sciences

TRIUMF

Université de Sherbrooke

University of Alberta

University of British Columbia

University of Saskatchewan

University of Waterloo

York University

University of Calgary

Institute for Security, Privacy and Information Assurance

Institute for Sustainable Energy, Environment and Economy

Industry & Government

City of Calgary

Hewlett-Packard Laboratories, United States of America

National Resources Canada's Canmet Energy

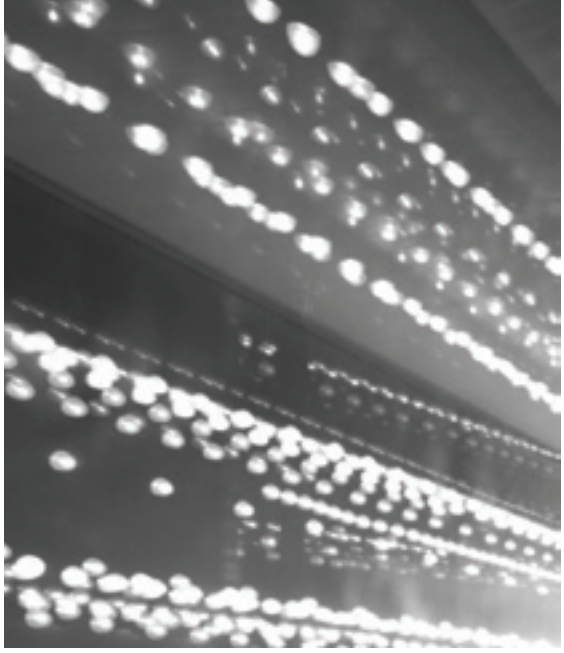
Raytheon BBN Technologies, United Sates of America

Visitors

Name	Institution Name
Guilherme Almeida	Universidade Federal de Sergipe
Eun-Ok Bae	Kyung Hee University
Angelo Bassi	University of Trieste
Dominic Berry	Macquarie University
Anne Broadbent	University of Ottawa
Harry Buhrman	University of Amsterdam
Carlton Caves	University of New Mexico
Dennis Clouthier	University of Kentucky
Saurya Das	University of Lethbridge
Nilanjana Datta	University of Cambridge
Paul Davies	Arizona State University
Gordon Drake	University of Windsor
Zachary Dutton	Raytheon BBN Technologies
Marie D'Iorio	National Institute for Nanotechnology (Edmonton)
Chip Elliott	Raytheon BBN Technologies
Mariagrazia Fortino	University of Calabria

Name	Institution Name
Motohisa Fukuda	Technische Universität München
Lambert Giner	École Normale Supérieure
Saikat Guha	Raytheon BBN Technologies
Daniel Hogg	McGill University
John Howell	University of Rochester
Stephen Hughes	Queen's University
Jietai Jing	East China Normal University
Gregory Kanter	Northwestern University
Todd Kemp	University of California, San Diego
Jeong San Kim	University of Suwon
Na Young Kim	Stanford University
Hari Krovi	Raytheon BBN Technologies
Sourabh Kumar	Indian Institute of Technology, Kharagpur
Yury Kurochkin	Russian Quantum Center
Alex Kuzmich	University of Michigan
Paul Kwiat	University of Illinois at Urbana-Champaign
David Lake	Dalhousie University
Aurélien de la Lande	Université Paris-Sud
Keith Lee	University of Waterloo
Arturo Lezama	Universidad de la República, Uruguay
Qin-Mei Liang	National University of Defense Technology of China
Qing Lin	Hua Qiao University
Jevon Longdell	University of Otago
Marko Lončar	Harvard University
Vinay A. Iyer	Indian Institute of Technology, Madras
Vadim Makarov	University of Waterloo
Francesco Marsili	National Institute of Standards and Technology (United States of America)
Roger Melko	University of Waterloo
Josh Mutus	University of California, Santa Barbara
Tayebeh Naseri	Sharif University of Technology
Yasser Novo-Fernandez	Institute of Technology and Advanced Science, Cuba
Joshua Nunn	University of Oxford
Marcos Cesar de Oliveira	Universidade Estadual de Campinas
Chris O'Brien	Texas A&M University
Paolo Piazzetti	University of Calabria
Arthur Pinon	École Normale Supérieure de Lyon
Joyce Poon	University of Toronto
Zhongzhong Qin	East China Normal Univeristy

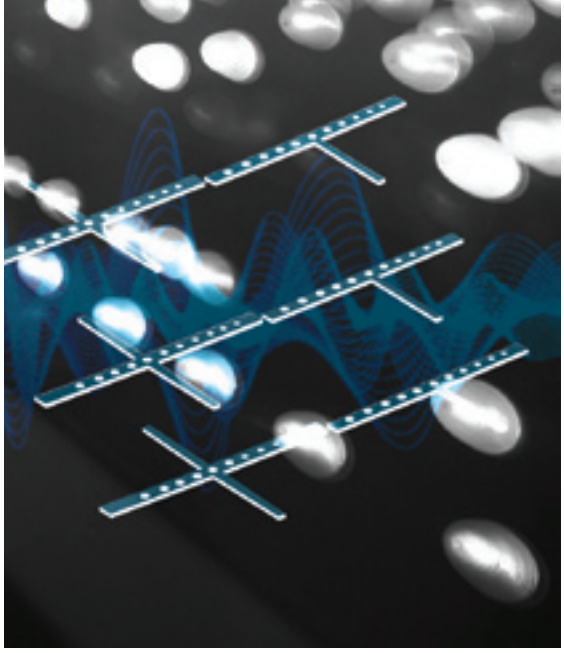
Name	Institution Name
Sadegh Raeisi	University of Waterloo
Nicolas Raoult	École Normale Supérieure de Lyon
Jibran Rashid	Università della Svizzera italiana
Bertrand Reulet	Université de Sherbrooke
Artur Scherer	Applied Communication Science
Gregory Scholes	University of Toronto
Krister Shalm	National Institute of Standards and Technology (United States of America)
Priyank Shyam	SRM University
Vijay Kumar Singh	Simon Fraser University
Urbasi Sinha	Raman Research Institute
John Sipe	University of Toronto
Aephraim Steinberg	University of Toronto
Sergie Studeniki	National Research Council (Ottawa)
Charles Thiel	Montana State University
Jack Tuszynski	University of Alberta
Varun Verma	National Institute of Standards and Technology (United States of America)
Nathan Wiebe	University of Waterloo
Carl Williams	National Institute of Standards and Technology (United States of America)
Dominic Williams	D-Wave Systems Inc.
Robert Wolkow	University of Alberta
Junying Wu	Beijing Institute of Technology
Babita Yadav	Indian Institute of Technology, Delhi
Yilin Zhao	Jilin University



Teaching, Training and Education

Quantum information graduate courses

Course Name	Instructor	Description
PHYS 673 Quantum and Nonlinear Optics	P. E. Barclay	Fundamentals of quantum and nonlinear optics including atom-photon interactions, coherence, electromagnetically induced transparency, open systems and decoherence, and applications to quantum information technology.
PHYS 615 Advanced Quantum Mechanics I	A. I. Lvovsky	Basic formalism of the theory and its interpretation, symmetry generators. Scattering theory. Bound states. Changed particles in electric and magnetic fields. Approximation methods.
CHEM 689 Modeling Multiscale Systems	D. R. Salahub	The course will build on a basic knowledge of classical and quantum mechanics to explore modern methods of simulating complex systems in chemistry, physics, biology and materials science. The student will acquire an understanding of the main approaches in quantum chemistry, molecular dynamics and the kinetics of coupled systems of chemical equations (e.g. the Kinetic Monte Carlo method). Hands-on experience with some of the techniques will be obtained and the student will be able to tailor the applications to his or her areas of interest, for example, heterogeneous, homogeneous or enzymatic catalysis, genetic regulatory networks, integrated nano-systems, etc.
CHEM 619 Advanced Mass Spectrometric Techniques	Y. J. Shi	The course will provide students with an understanding of theoretical and practical aspects of Mass Spectrometric techniques. Instrumentation design, method development and troubleshooting aspects will be considered in detail along with instrument maintenance. Students will be provided with hands on experience in Acquisition, Processing and Interpretation of experimental data. Applications in identification of unknown chemical compounds would be emphasized. Recent developments in the field of Mass Spectrometry Instrumentation including Hyphenated Techniques would be covered and their applications in multi-disciplinary fields will also be discussed.



Services and Outreach

Conferences

Member(s)	Committee	Conference/Workshop	Location	Dates
A. I. Lvovsky	Chair, Subcommittee	CLEO: Quantum Electronics and Laser Science Conference (QELS) 2013	San Jose, United States of America	9 – 14 June 2013
B. C. Sanders	Chair	A New Quantum Era: Teachers Conference	Santa Barbara, United States of America	2 Mar 2013

Professional Services

Name	Role	Journal/Society/Institution
A. I. Lvovsky	Associate Editor	*Optical Express*
A. I. Lvovsky	Guest Editor	*Special Issue of Journal of Physics B* (The 20th anniversary of quantum state engineering)
A. I. Lvovsky	Member, Scientific Committee	The Russian Quantum Center
D. R. Salahub	Member, Editorial Board	*Advances in Physical Chemistry*
D. R. Salahub	Member, Editorial Board	*Advances in Quantum Chemistry*
D. R. Salahub	Member, NIC-National Initiative Committee	Compute Canada
D. R. Salahub	Member, Editorial Board	*International Journal of Quantum Chemistry*
D. R. Salahub	Co-chair, Editorial Board	*Interdisciplinary Science: Computational Life Science*
D. R. Salahub	Member, Editorial Board	*Journal of Computational Chemistry*
D. R. Salahub	Member, Editorial Board	*PLOS-One*
D. R. Salahub	Member, Editorial Board	*Research Letters in Physical Chemistry*
D. R. Salahub	Member, Executive Committee	WestGrid
B. C. Sanders	Peer Evaluator, Scientific Council	European Research Council
B. C. Sanders	Member	International Council for Quantum Electronics

Name	Role	Journal/Society/Institution
B. C. Sanders	Member, Editorial Board	*Mathematical Structures in Computer Science*
B. C. Sanders	Member, Research Associateship Panel	National Research Council (United States of America)
B. C. Sanders	Principal Coordinator, Collaborative Research Group for Mathematics of Quantum Information	Pacific Institute for the Mathematical Sciences
B. C. Sanders	Associate Editor	*Physical Review A*
Y. J. Shi	Associate Editor	*Canadian Journal of Chemistry*
C. Simon	Guest Editor	Special Issue on "Quantum Memories", *New Journal of Physics*
R. I. Thompson	Director, Student Affairs	Canadian Association of Physicists
R. I. Thompson	Secretary-Treasurer, Division of Atomic, Molecular and Optical Physics	Canadian Association of Physicists
R. I. Thompson	Member, Editorial Board	*Physics in Canada*
R. I. Thompson	University of Calgary Representative	TRIUMF Board of Management
R. I. Thompson	Member, Board of Governors	University of Calgary
S. Trudel	Secretary, Materials Division	Canadian Society for Chemistry

Outreach Lectures

19 Apr 2013, B. C. Sanders, "Quantum Information", Quantum Café Calgary.

26 Feb 2014, B. C. Sanders, "Re-shaping the technology landscape in Alberta, with help from global networks" (invited), Calgary Petroleum Club, Calgary, Canada.

Virtual Researcher on Call with Partners in Research: B. C. Sanders, Mentor for École Forest Trail, Oakville Ontario.

IQST Public Lecture

Each year the Institute holds a Public Lecture, which has been sponsored by Alberta Innovates Technology Futures. In 2013, about 750 participants enjoyed Paul Davies' wonderful lecture titled "Time travel: can it really be done?" Professor Davies is a renowned quantum physicist, author and Director of Arizona State University's Beyond Center. His prestigious awards include the Kelvin Medal, the Faraday Prize and the Templeton Prize. The Public Lecture is a crucial component of the Institute's outreach program.

Media Coverage

Source	Title of Article	Location	Date
Newsletter of 100th Indian Science Congress 2013	Quantum leap: Barry Sanders	http://goo.gl/g5xQA6	5 Jan 2013
UToday	Extending Einstein: Christoph Simon	http://goo.gl/ORui3I	9 Jan 2013
UToday	Extending the reach: Wolfgang Tittel	http://goo.gl/ar199d	15 Jan 2013
University Affairs	Video abstracts, the latest trend in scientific publishing: Barry Sanders	http://goo.gl/q8Bf71	6 Feb 2013
UToday	Researchers explore quantum entanglement: Christoph Simon	http://goo.gl/5mFP1h	12 Feb 2013
Snob	Cat, ATM, and the free: Alex Lvovsky	http://goo.gl/zUFVz	13 Feb 2013
Nature	Measuring twist with light: John Davis, Paul Barclay	http://goo.gl/JJTJIr	14 Feb 2013
Postnauka	Quantum technologies: Alex Lvovsky	http://goo.gl/iYdPIA	17 Feb 2013

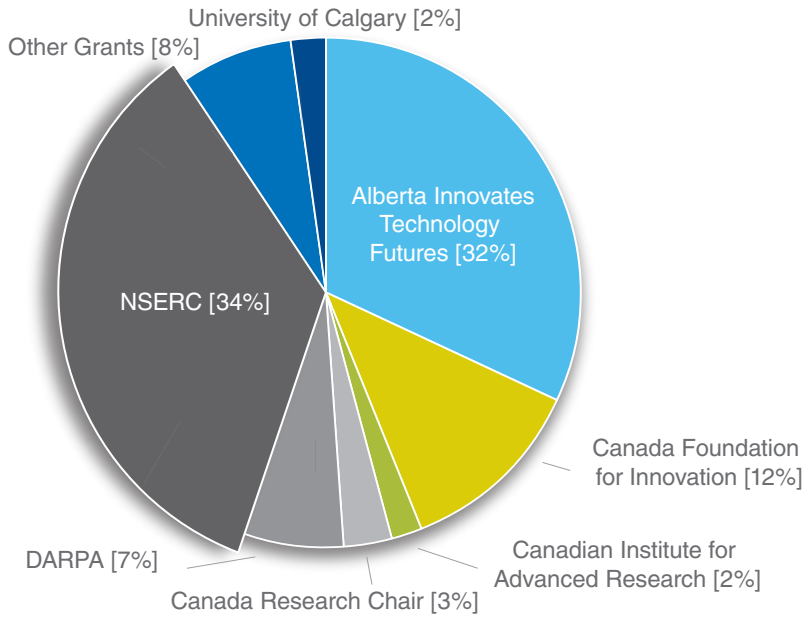
Source	Title of Article	Location	Date
Page42	Quantum computer: Alex Lvovsky	http://goo.gl/BRPhHP	20 Mar 2013
CTV Calgary	Harnessing the H in H2O: Simon Trudel, Curtis Berlinguette	http://goo.gl/B5Lfod	28 Mar 2013
The Global and Mail	How this device could revolutionize renewable energy: Simon Trudel	http://goo.gl/RfDgNF	28 Mar 2013
The Japan Times	Energy storage breakthrough relies on rust: Simon Trudel, Curtis Berlinguette	http://goo.gl/hZWD6H	31 Mar 2013
Novaya Gazeta	Not much longer to wait: Alex Lvovsky	http://goo.gl/2bDb9	5 Apr 2013
Science2.0	Teleportation: Alex Lvovsky	http://goo.gl/uWWgge	7 Apr 2013
Postnauka	Perspectives: quantum technologies: Alex Lvovsky	http://goo.gl/5dhEtO	11 Apr 2013
UToday	Researchers propose new test to learn whether antimatter falls down: Robert I. Thompson, Tim Friesen	http://goo.gl/BUbR8J	2 May 2013
Quirks and Quarks CBC Radio	Does antimatter have antigravity?: Robert I. Thompson	http://goo.gl/d4hav4	4 May 2013
UToday	Artificial intelligence used to tackle quantum-world problem: Barry Sanders	http://goo.gl/JLVFZ3	4 Jul 2013
33rd Square	Researchers use artificial intelligence to explore quantum problems: Barry Sanders	http://goo.gl/SnUkKS	5 Jul 2013
Lab Manager	Artificial intelligence used to tackle quantum-world problem: Barry Sanders	http://goo.gl/9GVJbR	5 Jul 2013
New Scientist	Schrödinger's 'kittens' made in the lab from photons: Alex Lvovsky	http://goo.gl/IoxtQC	24 Jul 2013
Science Media Centre	Taking the questions out of quantum: Barry Sanders	http://goo.gl/ZpcCBA	24 Jul 2013
UToday	Time travel: Can it really be done?: Professor Paul Davies	http://goo.gl/o6i80h	21 Aug 2013
University of Science and Technology of China News Center	Barry Sanders, Matthias Weidemüller were appointed "Qian Ren" Professor by USTC: Barry Sanders	http://goo.gl/2DerXP	31 Aug 2013
e! Science News	University research team's new approach enhances quantum-based secure communication: Wolfgang Tittel	http://goo.gl/dzy8q1	4 Sep 2013
Physorg.com	University research team's new approach enhances quantum-based secure communication: Wolfgang Tittel	http://goo.gl/pRKHVL	4 Sep 2013
Science Daily	University research team's new approach enhances quantum-based secure communication: Wolfgang Tittel	http://goo.gl/ZyBpCP	4 Sep 2013
ScienceNewsline	University research team's new approach enhances quantum-based secure communication: Wolfgang Tittel	http://goo.gl/wq1AJ4	4 Sep 2013
UToday	University research team's new approach enhances quantum-based secure communication: Wolfgang Tittel	http://goo.gl/2I6vTN	4 Sep 2013
Kurzweilai.net	Achieving quantum-based secure communication: Wolfgang Tittel	http://goo.gl/lc86J6	6 Sep 2013

Source	Title of Article	Location	Date
Laboratory equipment.com	Scientists fix huge hole in secure communication: Wolfgang Tittel	http://goo.gl/jCYqlQ	6 Sep 2013
Govinfosecurity.com	Encryption: The next generation - research paves way for safer way to share keys: Wolfgang Tittel	http://goo.gl/XoH6iy	9 Sep 2013
Newstalk770	Rob Beakenridge Show: Paul Davies		18 Sep 2013
CBC Homestretch	Time travel: Paul Davies		20 Sep 2013
Physorg.com	University of Calgary launches Institute for Quantum Science and Technology	http://goo.gl/WsszSh	20 Sep 2013
UToday	Time travel looks like a one-way journey, renowned physicist Paul Davies says: Paul Davies	http://goo.gl/vqyiIu	23 Sep 2013
UToday	Institute for Quantum Science and Technology launched	http://goo.gl/ZIGBYv	23 Sep 2013
Radio Canada	New Institute for Quantum Science and Technology launched: Simon Trudel		24 Sep 2013
Gauntlet	New Institute for Quantum Science and Technology	http://goo.gl/IhjeyI	26 Sep 2013
Innovation.ca	Researchers at University of Calgary make storing energy cheaper and cleaner: Simon Trudel, Curtis Berlinguette	http://goo.gl/WqTiQ5	6 Nov 2013
Physorg.com	Distant artificial atoms cooperate by sharing light, physicists show: Barry Sanders	http://goo.gl/VKMW8U	14 Nov 2013
Photonics	Distant atoms cooperate by sharing light: Barry Sanders	http://goo.gl/4qDkqd	14 Nov 2013
Research & Development	Distant artificial atoms cooperate by sharing light: Barry Sanders	http://goo.gl/D2MFos	15 Nov 2013
Physics News	Distant artificial atoms cooperate by sharing light, physicists show: Barry Sanders	http://goo.gl/Y7xRnV	15 Nov 2013
Science Recorder	Distant artificial atoms cooperate by sharing light: researchers : Barry Sanders	http://goo.gl/9Tzobi	15 Nov 2013
UToday	Distant artificial atoms co-operate by sharing light, international research team shows: Barry Sanders	http://goo.gl/ky3sLf	15 Nov 2013
Canadian Institute for Advanced Research	Artificial atoms interact across a distance: Barry Sanders	http://goo.gl/dhw8KC	19 Nov 2013
UToday	Physicists earn university's first NSERC John C. Polanyi Award for breakthrough work on antimatter: Robert I. Thompson	http://goo.gl/1R9C0y	4 Feb 2014
MIT Technology Review	A cheaper way to make hydrogen from water: Simon Trudel, Curtis Berlinguette	http://goo.gl/iNylM	28 Mar 2014
Science Daily	Discovery opens door to efficiently storing and reusing renewable energy: Simon Trudel, Curtis Berlinguette	http://goo.gl/M4yIeC	28 Mar 2014
CBC News	Cheaper green energy storage solution invented by Calgary profs: Simon Trudel, Curtis Berlinguette	http://goo.gl/RK6GdH	29 Mar 2014
Discovery.com	Rust offers a cheap way to store wind, sun power: Simon Trudel, Curtis Berlinguette	http://goo.gl/9xoRCb	29 Mar 2014

Finances

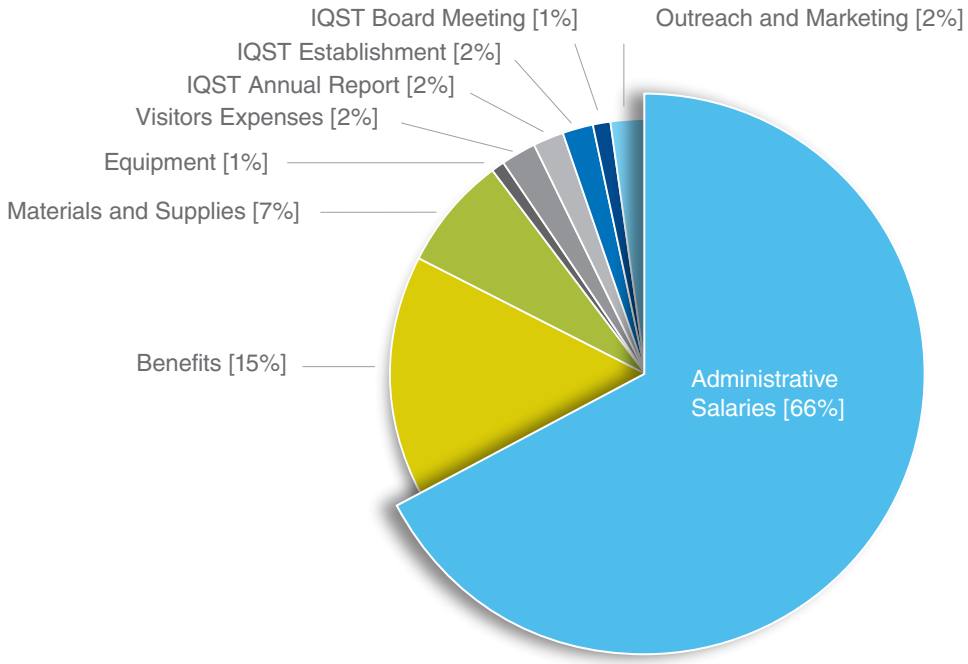
Research Grants (unaudited)

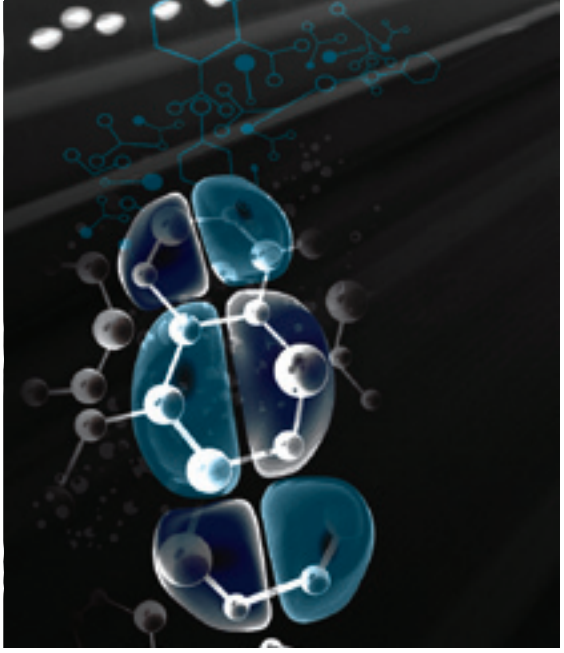
Total Revenue: $3,054 (in thousands)



Operating Account (unaudited)

Total Expenditures: $141 (in thousands)





Plans for Next Year

Dr. Paul Barclay

- Employ nanomechanical resonators fabricated from single crystal diamond to manipulate electron spins in nitrogen-vacancy centres in diamond.
- Demonstrate photon-pair generation using “doubly-resonant” down-conversion in gallium phosphide microcavities.
- Develop a nanocavity-based optomechanical magnetometer.
- Investigate modification of the phonon density of states in micro or nano-tailored crystals.
- Prepare three graduate students for the last phase of their degrees.
- Recruit a postdoctoral research associate.
- Train three undergraduate students.
- Collaborate with HP Labs in Palo Alto and with National Institute for Standards and Technology in Gaithersburg.

Dr. David Feder

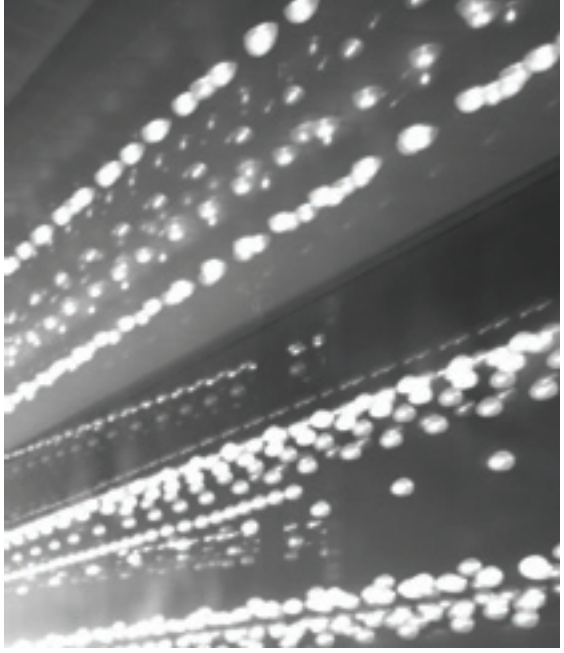
- Investigate graph transformations for enhancing fermionic quantum Monte Carlo algorithms.
- Study cavity-mediated interactions for neutral atoms, which could yield new quantum phases for ultracold Bose and Fermi gases.
- Explore interactions between ultracold atoms to accelerate implementations of quantum algorithms.

Dr. Gilad Gour

- Investigate establishing a shared reference frame for quantum networks.
- Explore nano-scale quantum thermodynamics.
- Advance multipartite entanglement theory.
- Develop protocols for quantum secret sharing schemes to reduce quantum-communication cost.
- Collaborate with Perimeter Institute in Waterloo, le Centre National de la Recherche Scientifique (CNRS) at Télécom ParisTech, University of Guelph, University College London, and Gdansk University in Poland.

Dr. Peter Høyer

- Develop simpler, provably secure primitives for incorporation into quantum cryptographic protocols such as quantum key distribution and quantum coin flipping and for experimental testing.
- Progress towards a scheme for using unreliable but practically feasible subroutines for driving quantum states with applications to quantum searches, walks and adiabatic computing.
- Instruct a course on quantum computing.
- Supervise two or more undergraduates on research in quantum computing.



Dr. Peter Kusalik

- Investigate homogeneous nucleation and heterogeneous growth of molecular crystals from pure liquids and from solutions emphasizing microscopic processes and structural and interface properties.
- Focus on water, ice, gas clathrate hydrates, and metal organic materials including probing quantum effects and key intermolecular interactions.
- Probe behaviour of the hydroxyl radical in various reactive aqueous environments.
- Develop new models and methods to study these systems and to provide training in standard approaches.

Dr. Alex Lvovsky

- Observe absorption and electromagnetically induced transparency due to the interaction between an optical field propagating through a nanofiber and surrounding atoms in a magneto-optical trap.
- Construct a setup with a magneto-optical trap and a high-finesse cavity to prepare and a characterize single-spin excitation of an atomic ensemble prepared by heralding on Raman-scattered photons followed by conversion to light, which is subjected to optical homodyne state tomography.

Dr. Nasser Moazzen-Ahmadi

- Record and analyze laboratory-based infrared spectroscopy of molecules relevant to the atmospheres of Titan and the Giant Planets.
- Deliver high-resolution infrared absorption cross sections for temperatures, pressures and compositions matching typical planetary atmospheric conditions.
- Make high-resolution spectroscopic observations of hydrocarbons using the French national synchrotron facility (Soleil), the Canadian Light Source Synchrotron, and the Jet Propulsion Laboratory.
- Construct accurate potential-energy surfaces for characterizing intermolecular forces.
- Obtain mid-infrared and millimetre-wave spectroscopic data of large-size clusters for determining non-additive effects in the interaction energy and elucidation of possible condensation pathways.
- Provide high-resolution spectroscopic data to test onset of superfluity in $CH_3COOH\text{-}(He)_4$ as the smallest superfluid cluster.
- Record spectra of H2- and He-hydrocarbons for elucidation of collisional processes between molecular hydrogen and rare-gas with hydrocarbon trace species.
- Collaborate with Indian Institute of Technology Bombay, Missouri University of Science and Technology, National Research Council of Canada, Queen's University, University of British Columbia University of Virginia, and University of Waterloo.

Dr. Dennis Salahub

- Advance the development of multi-scale modeling methodologies, their implementation in efficient computer codes, and their application to catalytically-driven processes in complex biological and energy-related environments.
- Investigate electron transfer and quantum decoherence.
- Study biological networks and catalysis by the enzyme ribonucleic-acid polymerase.
- Develop multiscale modelling of nanocatalysis for oil sands upgrading.
- Explore quantum decoherence and the “poised realm”.
- Two PhD students to complete their degrees.
- Host two visiting scientists from China.
- Recruit a new postdoctoral fellow.
- Collaborate with Cinvestav (Mexico City), Centre Nationale de la Recherche Scientifique (Orsay), Federal University of Minas Gerais (Brazil), Jacobs University Bremen, and Shanghai Jiaotong University.
- Lead the 15th deMon Developers workshop in Sofia, Bulgaria in May 2015.

Dr. Barry Sanders

- Develop theories for slowing and storing electromagnetic fields in natural or artificial atoms.
- Devise enhanced quantum optical methods for solving the BosonSampling Problem involving non-simultaneous photons and compare to a fully classical treatment.
- Produce a quantum simulation algorithm for arbitrary qudit channels that is efficient with respect to permitted simulation error and with minimal spatial cost.
- Employ reinforcement learning algorithms for proposing high-fidelity multi-qubit gates especially for implementation in superconducting circuits.
- Improve quantum simulations of quantum field theories by superior techniques to prepare the input state for the algorithm.
- Determine means to improve quantum communication by extracting quantum channel parameters from quantum key distribution reconciliation protocols and update channel controls on-the-fly.
- Construct a full waveguide theory accommodating double-negative-index media and electromagnetic duality allowing for magnetic monopoles.
- Test the water-bridge hypothesis for electron transfer through a complicated protein complex.
- Complete experiment at University of Science and Technology of China and corresponding analysis of the coincidence rates for a beam splitter given one heralded photon at each of the two input ports.
- Three graduate students to complete degrees.
- Recruit two new graduate students and host two visiting students, one from India and one from South Korea.
- Establish, maintain and complete partnerships in research networks: Co-propose a France-Canada network on quantum communication security; continue in a United States Army-supported network on quantum algorithms and in the NSERC complete and in a Collaborative and Research Training Experience network “CryptoWorks21”; and close the successful Pacific Institute for Mathematical Sciences collaborative research network “Mathematics of Quantum Information Processing”.

- Collaborate with Friedrich-Schiller-Universität Jena, Harvard University, Lakehead University, Kyunghee University, Macquarie University, National University of Science and Technology Pakistan, Raman Research Institute, Saint Anselm College, Singapore University of Technology and Design, Southeast University of China, Swansea University, Universidade Federal de Sergipe, Universität Erlangen-Nürnberg, l'Université de Sherbrooke, University of Alberta, University of Guelph, University of Innsbruck, University of Michigan, University of Tabriz, University of Waterloo, and Xidian University.

Dr. Yujun Shi

- Explore chemical vapor deposition chemistry of silicon carbide using the four-membered-ring compound, (di)silacyclobutanes, as novel precursors.
- Commence studies of chemical vapor deposition chemistry for the formation of silicon nitride to study the role of chloro-substituted silylenes.
- Use resonance-enhanced multiphoton ionization techniques to characterize small silicon carbon clusters and hydrogenated silicon carbon species.
- Design resonance-enhanced multiphoton ionization schemes to detect jet-cooled species produced by pulsed discharge or by laser ablation.

Dr. Christoph Simon

- Collaborate on theory-experiment development of quantum repeaters based on satellite links.
- Collaborate on theory-experiment collaboration of quantum nondemolition measurements for photonic qubits in rare-earth doped waveguides.
- Propose photon-photon gates using Rydberg states.
- Study storage and processing of quantum states of light in Bose-Einstein condensates.
- Characterize entanglement created by weak cross-Kerr nonlinearities.
- Explore the creation of deterministic sources of entangled photons based on parametric down-conversion and quantum memories.
- Collaborate with the University of Waterloo.

Dr. Robert Thompson

- Commission and obtain first laser spectroscopy results from the upgraded Antihydrogen Laser Physics Apparatus (Alpha) at the European Organization of Nuclear Research (CERN).
- Develop and submit a Canadian Foundation for Innovation grant, jointly proposed by the University of Calgary, the University of British Columbia, Simon Fraser University, York University, and the Tri-University Meson Facility (TRIUMF) for the Alpha-g apparatus, which aims to carry out high-precision gravitational force and microwave spectroscopy measurements on trapped antihydrogen.
- Commence experiments with TRIUMF's Ion Trap for Atomic and Nuclear Science (TITAN), which is a multicomponent ion trapping system for storage, cooling, bunching, and study of stable and unstable isotopic species.

Dr. Wolfgang Tittel

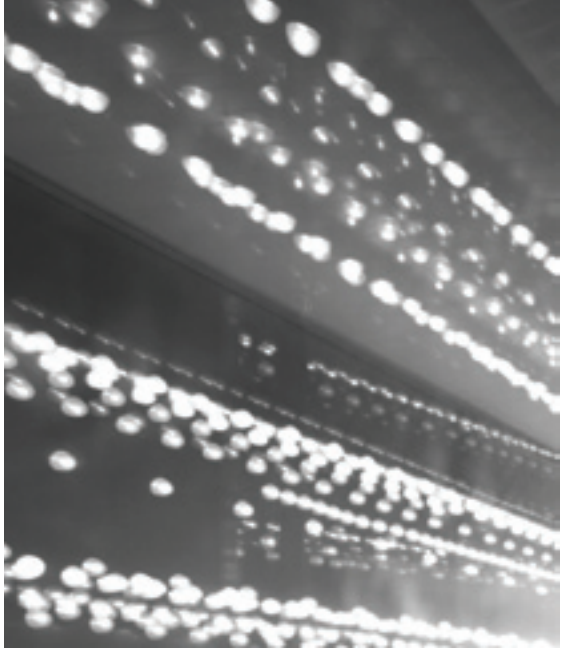
- Investigate quantum-secure communication for the City of Calgary.
- Collaborate with the Battelle Memorial Institute and others to obtain financial support for building the North American Quantum Network including quantum repeaters as well as measurement-device-independent quantum key distribution systems.
- Complete precise modelling of the group's quantum repeater architecture.
- Demonstrate high-efficiency optical memory with storage time sufficient for use in a quantum repeater, and capable of storing many spectrally multiplexed quantum states simultaneously.
- Seek to modify the phonon density of states in micro or nano-tailored crystals to improve spectroscopic parameters that determine the performance of a quantum memory.
- Develop practical measurement-device-independent quantum key distribution suitable for deployment under real-world conditions.

Dr. Simon Trudel

- Further investigation of water-splitting catalyst technology including spectroscopic investigation of the materials.
- Develop synthesis of cobalt-based Heusler compound nanowires using nanotemplating methods, and investigate their magnetic properties.
- Establish collaborations to further investigate spin dynamics and local ordering in Heusler compounds.
- Evaluate magnetoresistance in Heusler nanostructures.

Dr. Tom Ziegler

- Develop a beta version of computer code for executing constricted variational density functional theory to describe the electronic structure of excited states.



Appendices

Charter of the Institute for Quantum Science and Technology

Name and Affiliation

1. The name of the organization shall be the Institute for Quantum Science and Technology (hereinafter referred to as "Institute"). The Institute formally reports to the Faculty of Science and is governed by the Faculty of Science Research Institutes Policy (hereinafter referred to as "Policy").

Reporting Structure

2. The Institute reports to the Dean, Faculty of Science (s. 4.7).

Approval and Review Bodies

3. The body responsible for approving, reviewing, and renewing the Institute under the Policy (s. 5.1) is the Faculty of Science Executive Committee.

Term of the Institute

4. Under the Policy Institutes are normally established for a five (5) year term (s. 4.3). The current term of the Institute ends 31 December 2018. The Institute is eligible for renewal upon favourable review (s. 4.4).

Goals

5. In keeping with the Policy (s. 4.1) the goals of the Institute shall be:
   a) to conduct leading research in key theoretical and experimental topics of quantum science and technology;
   b) to provide excellent education and training in quantum science and technology and cognate areas;
   c) to foster linkage between the Institute and other quantum science and technology institutes and with industrial partners.

Schedule of Review

6. The review process is specified in the Faculty of Science Research Institutes Procedures (hereinafter referred to as: "Procedures"). Reviews will occur as specified in the Procedures (s. 2.6). The Procedures call for notice of review to be given no later than 9 months before the end of term of the Institute, with a decision no later than 3 months before the end of the term.

The Institute shall submit an annual report (July 15) on its activities to the Dean of the Faculty of Science.

Institute Board of Directors

7. a) The governing body of the Institute shall be referred to as the "Board of Directors" (hereinafter "Board").

   b) Membership of the Board shall comprise:

      i. The Dean of Science (or designate) will Chair the Board and appoint a Vice Chair from among other board members;

      ii. At least 4 "members at large," drawn from or nominated by

      - companies whose primary operations are synergistic with quantum information science
      - agencies that provide funding for quantum information science research in Alberta; and
      - leading members of the quantum information science academic community.

      At least one (1) "member at large" shall be appointed from each of these three categories.

   c) The Dean of Science shall appoint "members at large". Terms of appointment, commencing on April 1, shall normally be for three years. This length of appointment may be varied to ensure an appropriate staggering of terms. Members of the Board shall be eligible for re-appointment for consecutive terms of office.

   d) The Board shall be responsible for the overall success and governance of the Institute. More particularly, its responsibilities include:

      i. approving and/or amending this Charter under the provisions of clause 10 below

      ii. ensuring that relevant University policies are respected (see section 9 below)

      iii. appointing a Director for the Institute

      iv. approving the Institute's budget and strategic plans

      v. determining membership categories and requirements for the Institute

      vi. determining the procedures and requirements of general meetings of institute members (with at least one such meeting required annually)

      vii. helping to create opportunities for the Institute

      viii. facilitating the periodic reviews and external assessments of the Institute, as required by the Policy and Procedures of the Faculty of Science.

   e) The Board shall appoint a Secretary of the Board for a three-year term. The Board can revoke such appointment at any time. The Secretary is not a Board Member and is not eligible to vote.

   f) The Board shall meet not less than once in each calendar year, prior to the annual general meeting of Institute members. Special Meetings of the Board shall be convened by the Chair of the Board or upon the written request of at least two (2) members of the Board addressed to the Chair.

      i. At least thirty days notice of any meeting shall be given in writing to each member of the Board. Such notice shall specify the time, place and agenda of the meeting.

      ii. At any meeting of the Board 50 percent of members, present physically or via teleconference, shall constitute a quorum.

   g) The cost for Board members of attending Board meetings (annual and special) will be incurred by the Institute.

Director

8. a) The Director reports to the Board and to the University through the Dean of the Faculty of Science (who, directly or through a designate, chairs the Board).

   b) The Director exercises a general superintendence over the operational affairs of the Institute in accordance with the goals of the Institute, and within Board-approved budgets and strategic plans.

c) The duties of the Director shall include, but not be limited to, the following:

i. preparing an annual budget and strategic plan for consideration and approval by the Board;

ii. preparing periodic financial updates for consideration by the Board;

iii. ensuring that all Institute policies and procedures adopted by the Board are made widely known among Institute members and stakeholders, including the broader University of Calgary community;

iv. preparing an annual report on the Institute's affairs, which shall include reporting on measures of success;

v. making any additional submissions or reports, as appropriate or requested, to the Board or the University of Calgary on any matter affecting the Institute;

vi. facilitating the periodic reviews and external assessments of the Institute required by the Policy and Procedures of the Faculty of Science.

Policies and Procedures

9. The Institute will operate in accordance with all applicable University of Calgary policies and procedures.

Amendments

10. Amendments to this Charter shall require approval by the Dean and two-thirds of the Board. The Dean will refer proposed amendments to the Faculty of Science Executive Committee.

IQST Use of Space

Offices

Room Number	Size (square meter)
BI 555	16
BI 556	17
BI 557	17
BI 558	17
ICT 625A	13
ICT 627	13
ICT 653	13
MS 374	13
MS 376	12
MS 436	13
SA 111	71
SB 115A	10
SB 115B	10
SB 115C	9
SB 117	12
SB 117A	11
SB 118	5
SB 135	18
SB 301	12
SB 303	24
SB 306	54
SB 307	12

Room Number	Size (square meter)
SB 312	56
SB 313	12
SB 314	34
SB 315	16
SB 316	32
SB 317	9
SB 318	53
SB 319	19
SB 323	12
SB 325	12
SB 326	44
SB 333	16
SB 417	12
SB 427	25
SB 429A	12
SB 431	12
SB 508 (partial)	55
SB 512 (partial)	64
SB 525	16
SB 535	12
SB 605C	19

Labs

Room Number	Size (square meter)
ES 04	248
SA 113	95
SB 03A	39
SB 08 & 09	61
SB 126	61
SB 304	83
SB 416	62
SB 418	47
SB 432	21

IQST adds value to the University of Calgary in the following ways:

Enables a multidisciplinary research through financial and logistical support

Builds a quantum science and technology community through visitor, seminar, and colloquium programs

Assists new faculty members to becoming productive researchers rapidly

Publishes reports and web pages that showcase the Institute as a leader in quantum information science

Supports recruitment of outstanding faculty, researchers, and graduate students

Sponsors and supports leading conferences held in Calgary/Banff

Partners with other quantum institutes

Enhances the University's reputation by delivering outstanding research results

Benefits the wider community by contributing new knowledge in a strategic area

www.iqst.ca

University of Calgary
Science B Building, Room 307
2500 University Drive NW
Calgary, AB T2N 1N4

t: +1 403 220 4403
f:+1 403 210 8876
e: iqstinfo@ucalgary.ca