

2016
2017

ANNUAL
REPORT
QUANTUM
FRONTIERS



UNIVERSITY OF CALGARY
FACULTY OF SCIENCE
Institute for Quantum Science and Technology

VIS

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

VISION

MISSION

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

KEY FACTS

18

postdoctoral fellows

69

graduate students

17

undergraduate students

66

publications in refereed journal and conference proceedings including *Nature* (1), *Nature Communications* (3), *Nature Photonics* (1), *Nature Nanotechnology* (1), *Proceedings of the National Academy of Sciences of the United States of America* (2), *ACS Nano* (1), *Optica* (2), *Physical Review Letters* (3)

41

invited talks at national and international conference/workshops including 1 keynote

3.8

million dollars revenue

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DIRECTOR'S REPORT

The University of Calgary and the Province of Alberta have presciently invested in quantum science and technology from the early days of the field. Now quantum science and technology is a huge endeavour worldwide, with billions of dollars invested by governments. Hundreds of millions of dollars has recently been awarded by the Canadian government including three Canada First Research Excellence Fund (CFREF) awards of \$75m in federal funding made outside of Alberta.

At this critical stage of quantum science and technology, which is maturing from curiosity-driven foundational research to strategic knowledge-transfer activities, the University of Calgary is well poised to take a leadership role through its combined strengths in computer science, quantum information, nanoscience and quantum optics roots. Researchers at the University of Calgary have fortuitous linkage and collaboration with Alberta agencies CanmetENERGY and the National Institute for Nanotechnology plus companies such as Norcada, Resolved Instruments, FireWater Fuel, and Quantum Silicon.

The Institute for Quantum Science and Technology (IQST) in the Faculty of Science encompasses and represents quantum activities at the University of Calgary. IQST is a vehicle for providing a voice for the University of Calgary community of quantum researchers and technologists with the collective voice reaching stakeholders within and beyond the University. Organizationally, IQST operations have

been supported by Alberta Innovates Technology Futures, which has been subsumed into the single unified organization Alberta Innovates.

IQST hosts 14 research groups with a total of about 104 members including professors, research staff and students. The four themes of the Institute are (i) quantum optics, (ii) molecular modelling, (iii) nanotechnology, and quantum optics and quantum information. Although “quantum” is not explicitly stated in some themes, all four themes emphasize quantum aspects.

The strengths of the Institute for Quantum Science and Technology are exemplified by its accomplishments in research and training. The publication and graduate student metrics provide a quantitative summary of the achievements. The fourteen research groups within the Institute have had 66 papers published including 14 in the top-tier journals of *Nature*, *Nature Communications*, *Nature Photonics*, *Nature Nanotechnology*, *Proceeding of the National Academy of Sciences of the United States of America*, *ACS Nano*, *Optica*, and *Physical Review Letters*. Sixteen students enrolled in the graduate studies programs in 2016/2017. Five MSc students and seven PhD students completed their research and moved on to academic and industrial positions.

The quality of the students and postdocs in the Institute is excellent as evidenced by them winning awards and prizes. One postdoc received a postdoctoral fellowship from NSERC and one PhD student held NSERC Vanier Scholarship. Two PhD

students and one MSc student received NSERC graduate scholarships. Two postdocs obtained PIMS Postdoctoral Fellowships. Eight Alberta Innovates Graduate Scholarships were held by graduate students in the Institute. Seven postdocs were supported by Eyes High Postdoctoral Fellowships jointly funded by Alberta Innovates and the University of Calgary. One PhD student received the Arthur Bollo-Kamara Graduate Scholarship. Three undergraduate students had their summer research in the Institute under NSERC USRA awards and three international undergraduate students had their summer internships under MITACS Globalink.

Five graduate students held University of Calgary Queen Elizabeth II Graduate Scholarships, two PhD students were recipients of a University of Calgary Silver Anniversary Scholarships, and one PhD student was a recipient of the University of Calgary Chancellor's Graduate Medal. One PhD student received an Izaak Walton Killam Pre-doctoral Scholarship and two students obtained Eyes High Doctoral Recruitment Scholarships. Four students were awarded the Department of Physics and Astronomy Internal Award and one student received the Eric Milner Prize of the Department of Mathematics and Statistics.

The Institute's Director Barry Sanders received a Doctor of Science degree from the Imperial College London and he was awarded a Killam Annual Professorship. Gilad Gour received the University of Calgary's Student Union 2017 First and Second Year Teaching Excellence Award.

The Institute prioritizes outreach as well as research and training. Hosting conferences and holding Quantum Public Lectures serve as the main outreach instruments. In June 2016, the Institute was a partner of the deMon developers' conference in Calgary from 10 to 15 May 2017. The Workshop was successful and attracted 34 participants representing institutions from nine countries (Brazil, Canada, China, Czech Republic, France, Germany, Mexico, Sweden and USA).

The Quantum Public Lectures serve to convey leading breakthroughs in quantum science and technology to the public. Paul Corkum from the University of Ottawa delivered a public lecture titled "A molecule takes a selfie while creating the world's shortest light pulses" to 240 persons on 24 November 2016. This lecture was co-sponsored by Faculty of Science Alumni Relations team as a joint outreach event.

In summary IQST is performing splendidly in research, training and outreach. Furthermore, IQST is playing a leading role in developing the Quantum Alberta initiative. Globally, quantum science and technology has become increasingly popular as an interdisciplinary scientific endeavour and is now strategically important. IQST's reputation for breakthrough research results and outstanding training have made the University of Calgary a major player on the world's quantum stage.

Barry Sanders

Director, IQST

A MESSAGE FROM THE CHAIR

The Faculty of Science has been catalyzing change and inspiring discovery, creativity and innovation for over 50 years. In late September 2017, the Faculty launched its five-year strategic plan, “Curiosity Sparks Discovery!” where we outline a bold direction for our future. Science addresses many of the biggest challenges we face in society, and we are excited to be a part of creating solutions. (http://www.ucalgary.ca/science/strategic_plan)

As Dean of the faculty and Chair of the Board of Directors for the Institute for Quantum Science and Technology (IQST), I am pleased to see how IQST contributes to the faculty’s vision and acts as a catalyst for advancing the exciting multidisciplinary area of quantum science.

Strategically, IQST is a tangible example of the faculty’s evolving mission. This multidisciplinary group of researchers from computer science, mathematics and statistics, chemistry, and physics and astronomy come together because they are problem-solvers, keen to investigate solutions to key theoretical and experimental topics in quantum science and technology.

On behalf of the Board, we are continually impressed at how the IQST team brings a profound knowledge of quantum science and a deep commitment for how its applications can improve human existence and unlock our digital future. We see that in the quality of their students, postdoctoral researchers, faculty members, and their outreach activities.

In particular, I would like to commend IQST for engaging the public and many Faculty of Science alumni through the Annual Quantum Public Lecture. This much-anticipated event highlights how science can capture our curiosity and provide a window into how the world works.

The Faculty of Science, along with IQST, is part of a university that is one of Canada’s most dynamic and enterprising cities. Together, we will harness our current strengths, look to future opportunities and allow for the exploration of new discoveries. I encourage everyone to spend some time reviewing the annual report to learn more about IQST’s achievements this past year.

Lesley Rigg

Dean
Chair, IQST Board of Directors

RESEARCH HIGHLIGHTS

Research Achievements

Institute for Quantum Science and Technology members have made significant research achievements in the past year. The following exposition of achievements provides a sample of the kinds of activities and breakthroughs seen within Institute for Quantum Science and Technology.

Thompson is a member of the international ALPHA (Antihydrogen Laser PHysics Apparatus) collaboration based at CERN, which is the European Organization for Nuclear Research. ALPHA creates trapped antihydrogen atoms and performs precise comparison with hydrogen to study symmetries between matter and antimatter. This past year ALPHA reported, in *Nature*, the first observation of a spectral line in antihydrogen.

A collaboration between the groups of Tittel and Simon yielded a proof-of-principle demonstration of non-destructive detection of photonic qubits using a Tm:LiNbO₃ waveguide. This *Nature Communications* Paper suggests a new key component of quantum photonics based on rare-earth-ion-doped crystals.

In an *Optica* paper, Simon and Lvovsky proposed and demonstrated super-resolution imaging with linear optics and homodyne detection without any need for nonlinear optics or near-field imaging. Lvovsky's group also implemented a method for "breeding" the Schrödinger cat state, which is a superposition of two coherent light waves with opposite amplitudes. The group produce a large-amplitude Schrödinger cat state from two small-amplitude cat states. This result is described in their *Nature Photonics* article.

Gour co-authored an article, distinguished as an Editors' Suggestion, in *Physical Review Letters*. They critically examined physical consistency of quantum-coherence resource theories. Sanders was a co-author of a *Physical Review Letters* article as well: this article proposes an optical scheme, employing optical parametric down-converters interlaced with nonlinear sign gates, that completely converts a pump field in a photon-number state to an equal number of signal-idler photon pairs. The proof relies on amplitude amplification, analogous to that employed in Grover search.

In a *Proceedings of the National Academy of Sciences of the United States of America* paper, Kusalik and coworkers obtained evidence from mixed-hydrate nucleation for a funnel model of crystallization. Importantly, they show that the phenomenological similarities between crystallization and protein folding result from similarities between features of these microscopic ordering processes. In another work co-authored by Kusalik and published in *ACS Nano*, they provide molecular-level insights into self-assembly in metal-organic frameworks. Their molecular-dynamics simulations elucidate the early stages of the self-assembly mechanism for an important class of nanoporous materials.

These scientific achievements are significant to quantum science and published in top journals. Institute for Quantum Science and Technology is fortunate to have these scientists on board, and these achievements are not a complete list for Institute for Quantum Science and Technology but rather a representative sample of the activities and quality seen in the Institute's research.

Awards

International Awards

Imperial College London Doctor of Science Degree

Barry C. Sanders

National Awards

MITACS Globalink

Arun Rajendran
Rishabh Shukla
Xinxin Tang

NSERC Alexander Graham Bell Canada Graduate Scholarship – Doctoral

David Lake
Matthew Mitchell

NSERC Alexander Graham Bell Canada Graduate Scholarship – Master’s

Stephen Wein

NSERC Postdoctoral Fellowship

Hoan Bui Dang

NSERC USRA

Bipinmeet Chawla
David Gisu Ham
Aiden Huffman

NSERC Vanier Scholarship

Carlos Enriquez-Victorero

PIMS Postdoctoral Fellowship

Mehdi Ahmadi
Hoan Bui Dang

Provincial Awards

Alberta Innovates Graduate Students Scholarship

Chris Healey
Sourabh Kumar
David Lake
Hon-Wai Lau
Thomas Lutz
Tamiko Masuda
Stephen Wein
Parisa Zarkeshian

Arthur Bollo-Kamara Graduate Scholarship

Ebenezer Owusu-Ansah

University of Calgary Awards

Alberta Innovates Technology Futures (AITF)/Eyes High Postdoctoral Fellowship

Gabriel Aguilar (ended November 2016)
Ronnie Banerjee
John Patrick Hadden
Nikolai Lauk
Florian Senn
Namrata Shukla
Hristina Zhekova

Chancellor's Graduate Medal

Neil Sinclair

Department of Mathematics and Statistics Eric Milner Prize

Mark Girard

Department of Physics and Astronomy Internal Award

Abdullah Khalid
Pantita Palittapongarnpim
Shakib Vedaie
Yadong Wu

Eyes High Doctoral Recruitment Scholarship

Andrew Evans
Sourabh Kumar
Yasser Novo-Fernandez

Izaak Walton Killam Pre-Doctoral Scholarship

Mark Girard

Killam Annual Professor

Barry C. Sanders

Queen Elizabeth II Graduate Scholarship

Aaron Barclay
Alex Cameron
Keenan Fanning
Hamidreza Kaviani
Taozhe Wu

Silver Anniversary Graduate Fellowship

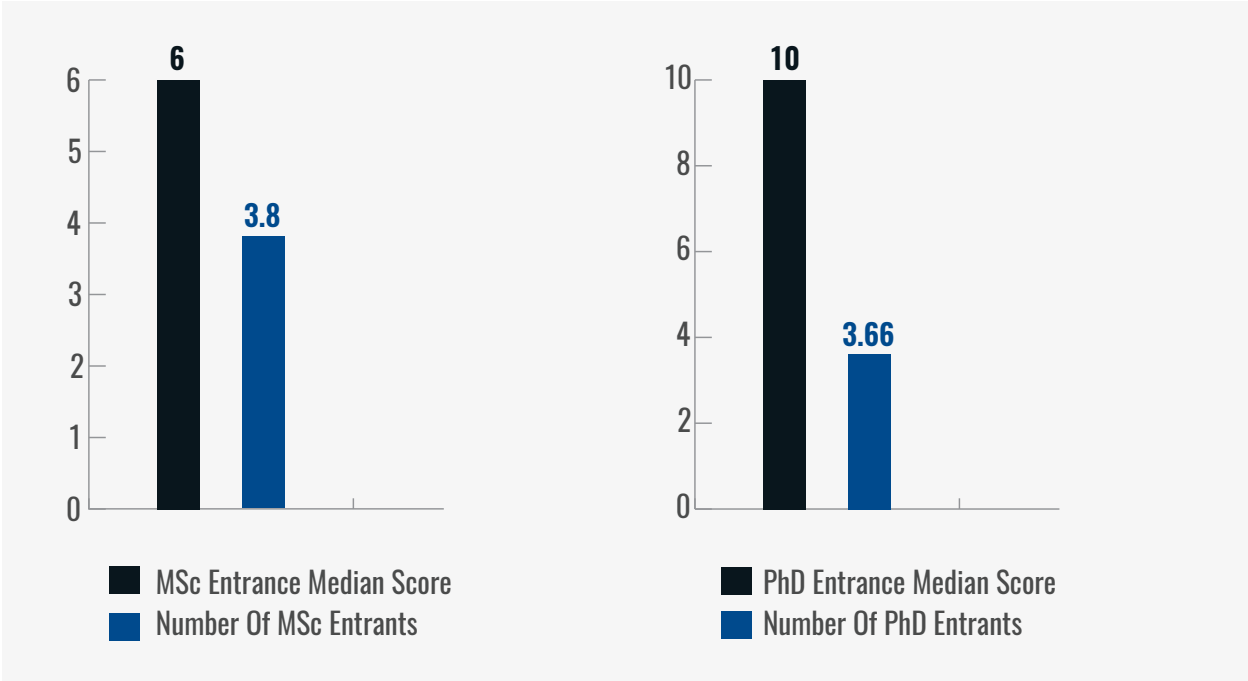
Kyle Hall
Marcelo Wu

The Student Union 2017 First and Second Year Teaching Excellence Award

Gilad Gour

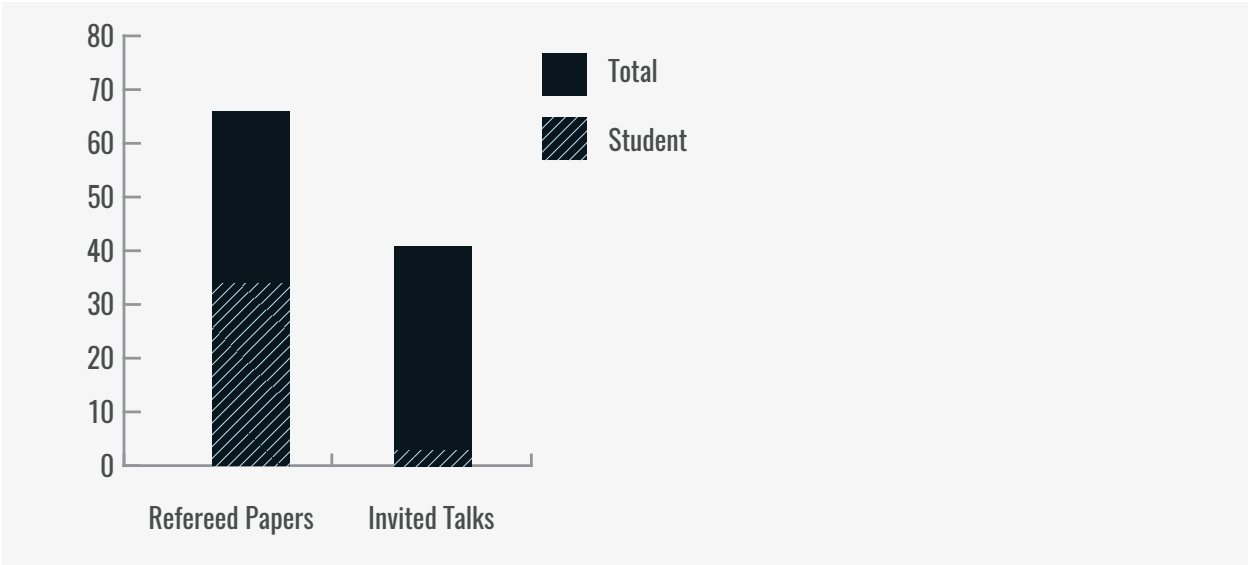
Key Performance Indicators

Graduate student enrolment and quality of entrants

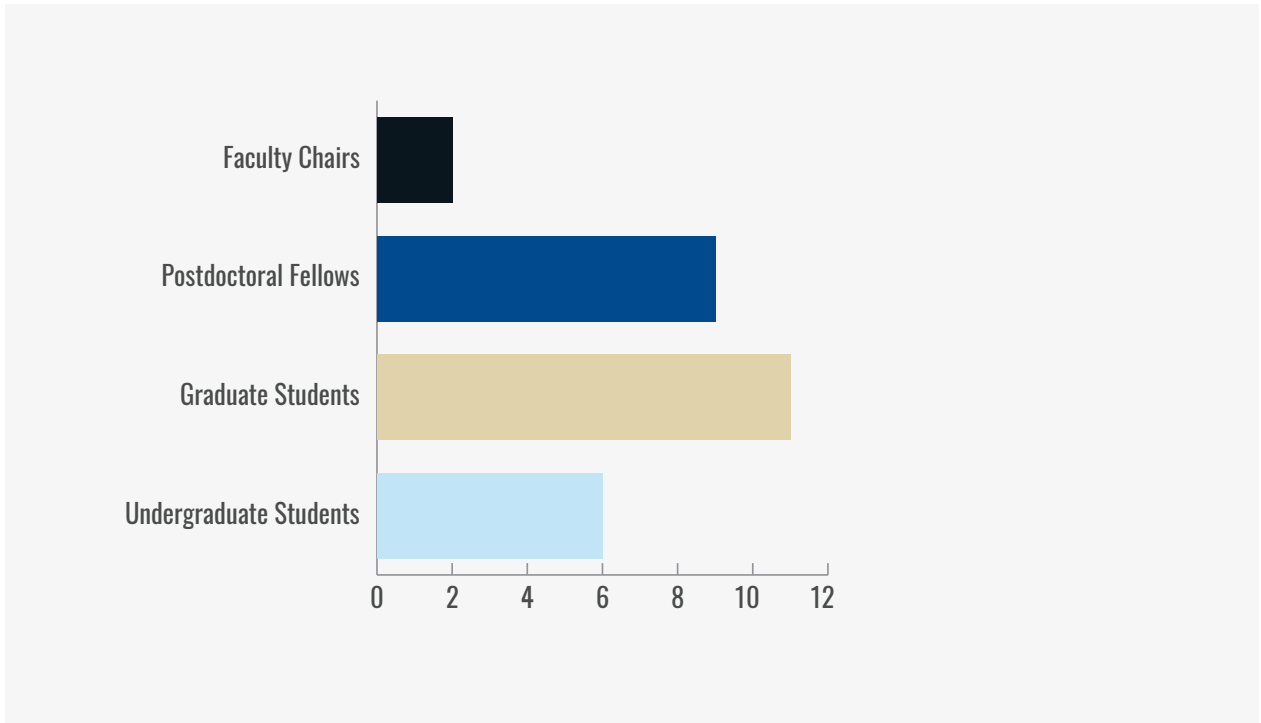


One MSc student from Ghana has second class upper division, so his GPA is not calculated.

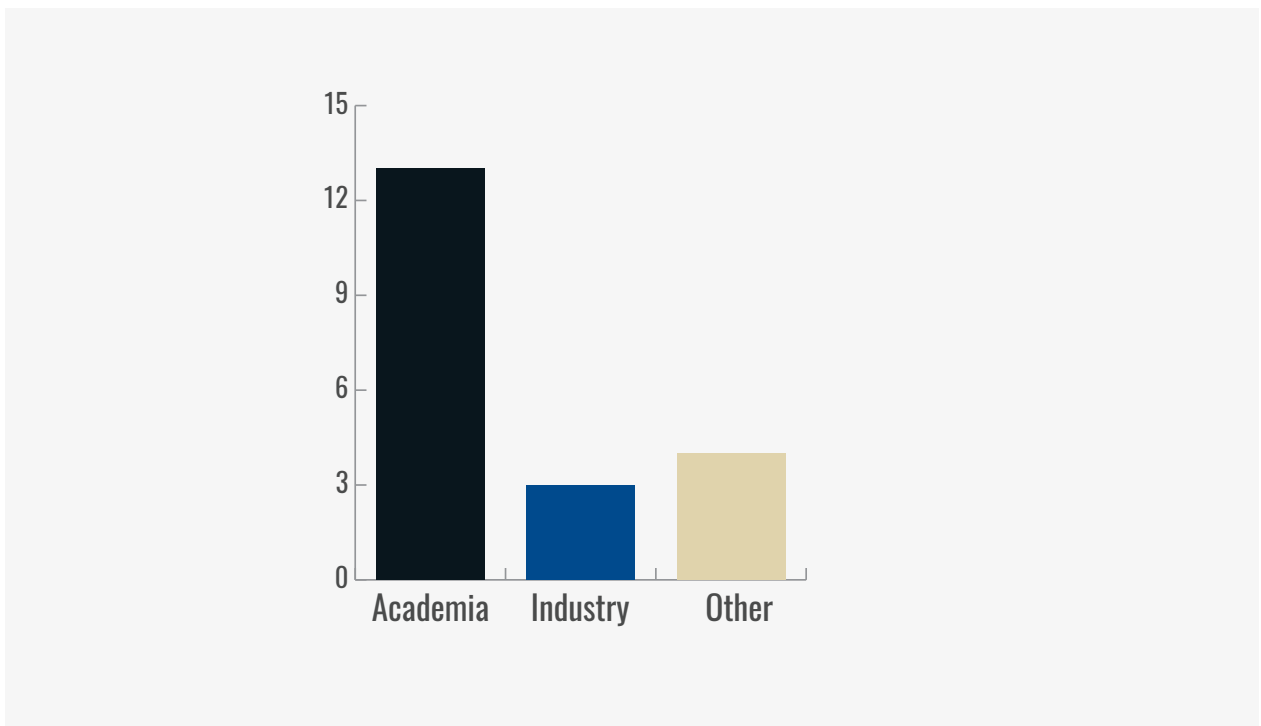
Publications and Presentations (highlighted portion with IQST student)



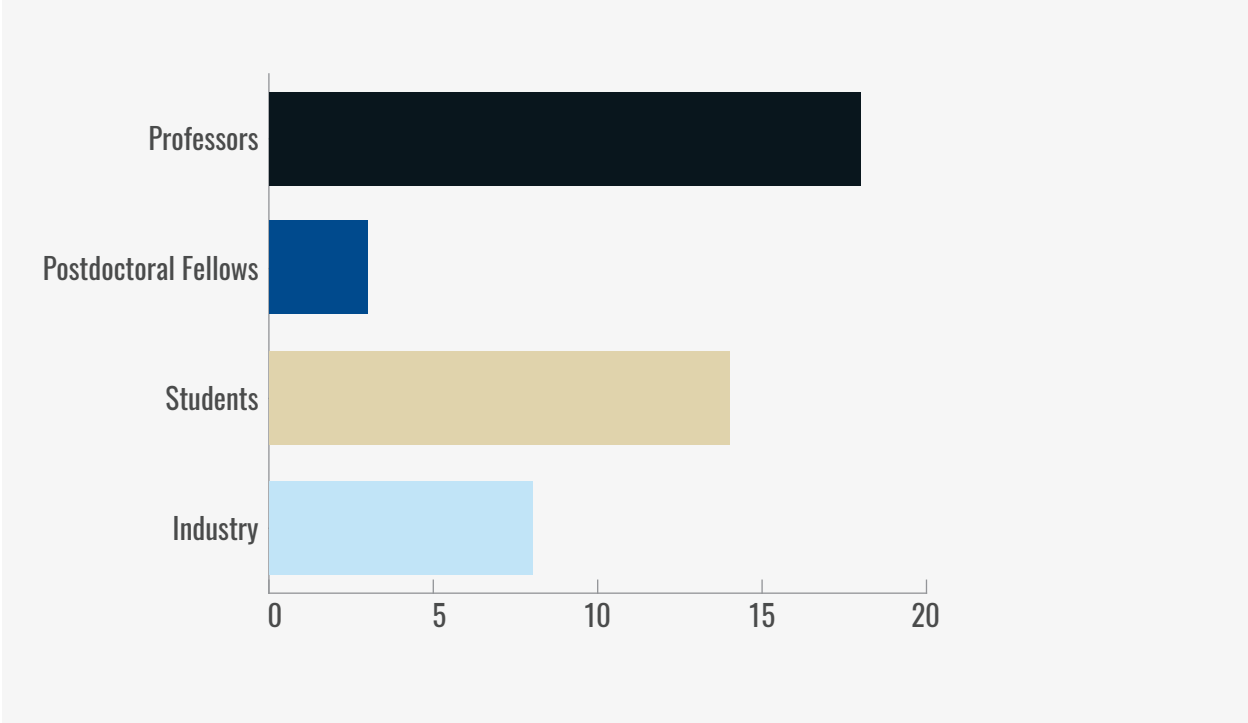
External Awards (Chairs, Fellowships and Scholarships)



Trainee Destinations after IQST



Visitors



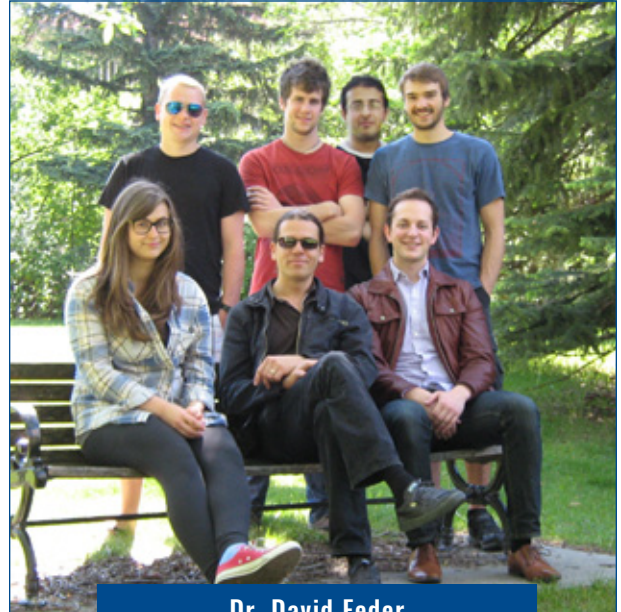
RESEARCH GROUPS



Dr. Paul Barclay

Nanoscale Optics

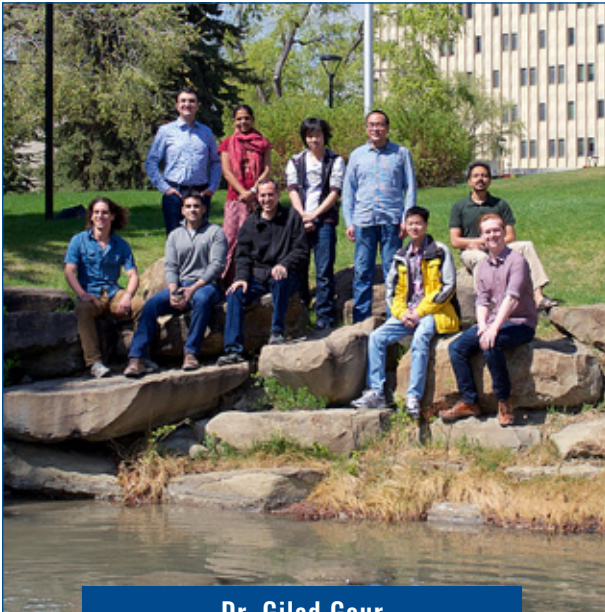
Explores interactions between light and nanoscale systems such as single atoms, electron spins and nanomechanical structures. Employs nanofabrication methods to engineer optical properties of these systems in order to enhance light-matter coupling. The current focus couples single quantum emitters, or “artificial atoms”, to optical nanocavities. The labs are at the University of Calgary and at the NRC National Institute for Nanotechnology in Edmonton, which has advanced nanofabrication tools plus leading quantum optics and nanotechnology researchers.



Dr. David Feder

Practical Quantum Computation

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.



Dr. Gilad Gour

Quantum Information Theory

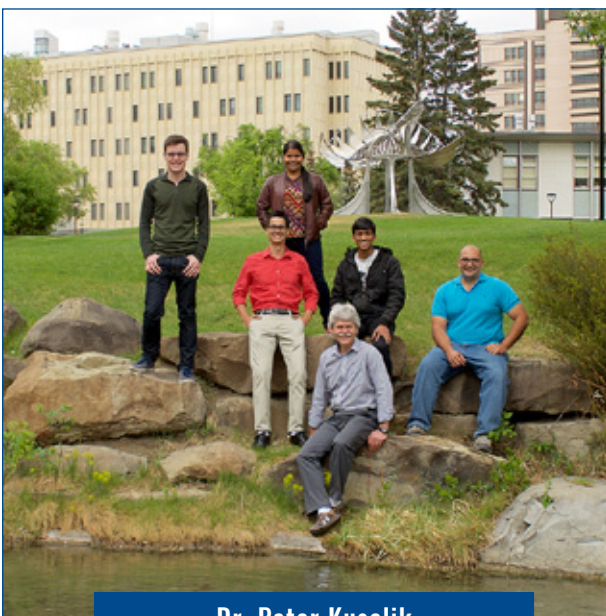
Employs sophisticated mathematical methods, such as algebraic geometry, matrix analysis, group theory and C^* -algebras, to solve core problems in quantum information science.



Dr. Peter Høyer

Quantum Computing

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.



Dr. Peter Kusalik

Molecular Simulations of Liquids & Solutions, Interfaces and Crystallization

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. Explores behaviour of the hydroxyl radical in various aqueous environments. Applications range from atmospheric and materials sciences to molecular biology and water treatment.



Dr. Alex Lvovsky

Quantum Information Technology with Light and Experimental Quantum Optics

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. We work on achieving sub-Rayleigh resolution of optical imaging using passive imaging devices.



Dr. Nasser Moazzen-Ahmadi

Spectroscopy of Hydrocarbons and Molecular Clusters and Complexes

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.



Dr. Dennis Salahub

Multiscale Modeling of (Bio)chemical Reactions in Complex Environments

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.



Dr. Barry Sanders

Quantum Information Science

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.



Dr. Yujun Shi

Chemical Vapor Deposition Chemistry

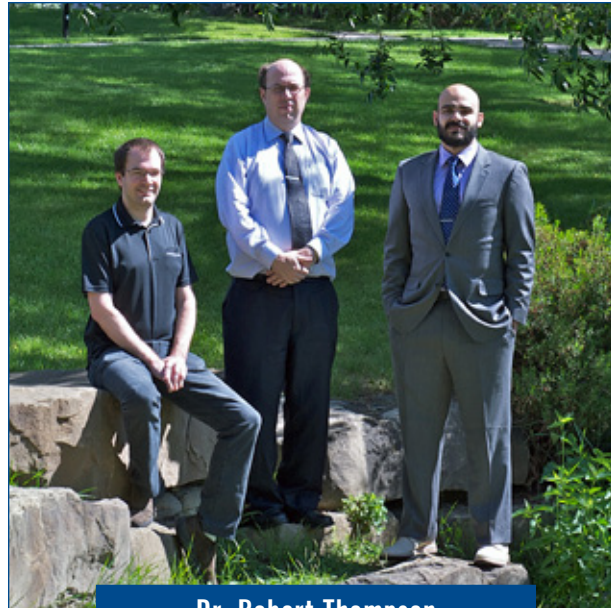
Focuses on chemical and physical processes underpinning the formation of silicon-containing semiconductor thin film materials using hot-wire chemical vapour deposition. Applies technically demanding laser ionization mass spectrometric and laser spectroscopic techniques to investigate this process at 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.



Dr. Christoph Simon

Theoretical Quantum Optics

We use quantum optical approaches to study potential applications of unique quantum phenomena such as superposition and entanglement (e.g. a future “quantum internet”), to probe whether these phenomena are universal, and to investigate whether they could play a role in biology (e.g. in neuroscience). Our theoretical research is often done in close collaboration with leading experimental groups.



Dr. Robert Thompson

Trapped Ion Physics with Atoms, Molecules, and Exotic Species

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.



Dr. Wolfgang Tittel

Quantum Cryptography and Communication

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.



Dr. Simon Trudel

Nanoscale Material

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.

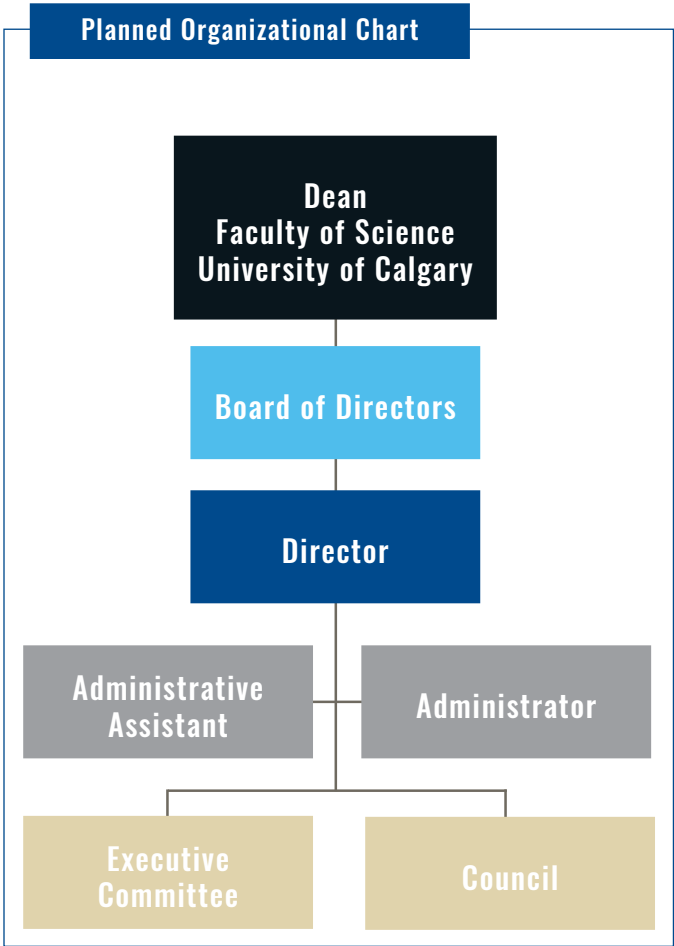
MANAGEMENT & MEMBERSHIP

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

Lesley Rigg

Dean, Faculty of Science, University of Calgary

Marie D'Iorio

Senior Strategy Advisor, University of Ottawa

Chip Elliott

Chief Technology Officer, Raytheon BBN Technology

John Kendall

Sir Peter Knight

Principal, The Kavli Royal Society International Centre

Barry C. Sanders

Professor, Department of Physics and Astronomy,
University of Calgary

Carl Williams

Deputy Director, Physical Measurement Laboratory
(PML), National Institute of Standards and Technology
(NIST)

Mark Williams

Executive Committee

Gilad Gour

Professor, Department of Mathematics and Statistics,
University of Calgary

Barry C. Sanders

Professor, Department of Physics and Astronomy,
University of Calgary

Yujun Shi

Associate Professor, Department of Chemistry,
University of Calgary

Wolfgang Tittel

Professor, Department of Physics and Astronomy,
University of Calgary

Council

Faculty Members

Paul Barclay

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

David Feder

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

Gilad Gour

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 C. Sanders

Professor, Department of Physics and Astronomy, University of Calgary

Yujun Shi

Associate Professor, Department of Chemistry, University of Calgary

Christoph Simon

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

Associate Professor, Department of Chemistry, University of Calgary

Affiliate Members

Robin Cockett

Professor, Department of Computer Science, University of Calgary

David Hobill

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

Sergei Noskov

Professor, Department of Biological Sciences, University of Calgary

Reginald Paul

Professor, Department of Chemistry, University of Calgary

Rei Safavi-Naini

Professor, Department of Computer Science, University of Calgary

Renate Scheidler

Professor, Department of Mathematics and Statistics, University of Calgary

Peter Tieleman

Professor, Department of Biological Sciences, University of Calgary

Richard Zach

Professor, Department of Philosophy, University of Calgary

Postdoctoral Fellows

Gabriel Aguilar (resigned November 2016 → Assistant Professor, Federal University of Rio de Janeiro)
Mehdi Ahmadi
Ronnie Banerjee
Hoan Bui Dang
Roohollah Ghobadi
Sandeep Goyal (completed May 2016 → Assistant Professor, Indian Institute for Science Education and Research, Mohal)
John Patrick Hadden
Nikolai Lauk
Young Choon Park
Florian Senn (completed October 2016)
Namrata Shukla
Mauricio Chagas da Silva (completed October 2016)
Neil Sinclair
Chukman So
Rim Toukabri (completed September 2016)
Lucile Veissier (resigned June 2016 → Postdoctoral Fellow, Université Paris-Sud Orsay)
Ehsan Zahedinejad (resigned August 2016 → Researcher, 1Qbit)
Qiang Zhou (completed March 2017 → Assistant Professor, University of Electronic Science and Technology)

Research Engineers & Research Assistants

Volodimir Kiselyov (resigned September 2016)
Daniel Oblak

Students

Graduate Students (PhD Program)

Mohsen Bagheri Mehrab
Stephanie Bovincini
Archismita Dalal
Katelynn Daly
Raphael Dong
Carlos Enriquez-Victorero
Andrew Evans
Mohsen Falamarzi Askarani
Akihiko Fujii

Mark Girard
Sumit Goswami
Kyle Hall
Chris Healey
Hamidreza Kaviani
Abdullah Khalid
Behzad Khanaliloo (graduated December 2016 → Engineer, Lumerical Inc.)
Mohammadsadegh Khazali (graduated December 2016 → Postdoctoral Fellow, Aarhus University)
Faezeh Kimiaee Asadi
Sourabh Kumar
David Lake
Hon-Wai Lau
Pascal Lefebvre
Thomas Lutz
Armando Marengo (graduated January 2017)
Adam Mayer
Matthew Mitchell
Ali Mohandesi
Eugene Moiseev
James Moncreiff
Yasser Novo-Fernandez
Varun Narasimhachar (graduated August 2016 → Postdoctoral Fellow, National University of Singapore)
Ebenezer Owusu-Ansah
Eduardo Paez
Pantita Palittapongarnpim
Alireza Poostindouz
Marcel.li Grimau Puigibert
Anastasia Pushkina
Nafiseh Sang-Nourpour
Issaka Seidu (graduated February 2017 → Postdoctoral Fellow, Carleton University)
Neil Sinclair (graduated May 2016 → Postdoctoral Fellow, University of Calgary)
Arina Tashchilina
Raju Valivarthi
Priyaa Varshinee Srinivasan
Seyed Shakib Vedaie
Marcelo Wu (graduated March 2017 → Postdoctoral Fellow, National Institute for Standards and Technology)
Taozhe Wu
Yadong Wu
Parisa Zarkeshian

Graduate Students (MSc Program)

Eric Ampong
Paul Anderson
Aaron Barclay
Alex Cameron
Jacob Davidson
Chetan Deshmukh (graduated February 2017 → PhD Student, Institute of Photonic Sciences, Barcelona)
Nuiok Dicaire
Alison Fulton
Abhirup Goswami (graduated September 2016 → PhD Student, Queensland University of Technology)
Masoud Habibi Davijani
Shreyas Jalnapurkar
Jiawei Ji
Mojtaba Komeili
Tamiko Masuda
Eugene Moiseev (transferred September 2016 → PhD Student, University of Calgary)
Aireza Poostindouz (graduated August 2016 → PhD Student, University of Calgary)
Mohammad Rahmati
Lohrasp Seify (graduated April 2016 → Trading Analyst, Parker Trading Corp.)
Stephen Wein
Wei Huang Xu
Fan Yang (graduated August 2016 → PhD Student, University of British Columbia)

Undergraduate Students

Burke Brockelbank (UofC PHYS598)
Alex Cameron (Summer Research)
Bipinmeet Chawla (NSERC USRA)
Leonardo Cotta (Research Assistant)
David Gisu Ham (NSERC USRA)
Aiden Huffman (NSERC USRA)
Jonathan Kung (UofC CHEM502)
Kimberley Owen (UofC PHYS598)
Arun Rajendran (MITACS Globalink)
Charmaine Sablay (UofC CHEM402)
Alexander Shook (UofC PHYS598)
Rishabh Shukla (MITACS Globalink)
Raunak Singh (UofC CHEM502)
James Stevenson (UofC CHEM402)
Xinxin Tang (MITACS Globalink)
Bryce Taylor (UofC PHYS599)
Tracy Tran (UofC CHEM299)

Administration

Jing (Nancy) Lu (Administrator)
Priyaa Varshinee Srinivasan (Part-Time Webmaster)
Lucia Wang (Administrative Assistant)

PUBLICATIONS

Refereed Journals

- M. Adcock, P. Høyer and B. C. Sanders, "Quantum computation with coherent spin states and the close Hadamard problem", *Quantum Information Processing* **15**(4): 1361-1386, April 2016.
- M. Ahmadi, B. X. R. Alves, C. J. Baker, W. A. Bertsche, E. Butler, A. Capra, C. Carruth, C. L. Cesar, M. Charlton, S. Cohen, R. Collister, A. Evans, N. Evetts, J. Fajans, T. Friesen, M. C. Fujiwara, D. R. Gill, A. Gutierrez, J. S. Hangst, W. N. Hardy, M. E. Hayden, C. A. Isaac, A. Ishida, M. A. Johnson, S. A. Jones, S. Jonsell, L. Kurchaninov, N. Madsen, M. Mathers, D. Maxwell, J. T. K. McKenna, S. Menary, J. M. Michan, T. Momose, J. J. Munich, P. Nolan, K. Olchanski, A. Olin, P. Pusa, C. Ø. Rasmussen, F. Robicheaux, R. L. Sacramento, M. Sameed, E. Sarid, D. M. Silveira, S. Stracka, G. Stutter, C. So, T. D. Tharp, J. E. Thompson, R. I. Thompson, D. P. van der Werf and J. S. Wurtele, "Observation of the 1S–2S transition in trapped antihydrogen", *Nature* **541**: 506-510, December 2016.
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Books and Chapters

P. Calaminici, A. Alvarez-Ibarra, D. Cruz-Olvera, V. D. Domínguez-Soria, R. Flores-Moreno, G. U. Gamboa, G. Geudtner, A. Goursot, D. Mejía-Rodríguez, D. R. Salahub, B. Zuniga-Gutierrez and A. M. Köster, "Auxiliary density functional theory: from molecules to nanostructures", section in book: *Handbook of Computational Chemistry*, J. Leszczynski, A. Kaczmarek-Kedziera, T. Puzyn, M. G. Papadopoulos, H. Reis, M. K. Shukla, eds. pp. 795–860, published by Springer in 2017.

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Student Theses

C. Deshmukh, "Towards non-destructive detection of photonic qubits using a rare-earth-ion doped crystal" (MSc Thesis), February 2017.

A. Goswami, "Analysis of a deterministic entangled photon pair source using single photons" (MSc Thesis), September 2016.

B. Khanaliloo, "Optomechanical crystals in single crystal diamond" (PhD Thesis), January 2017.

M. Khazali, "Applications of atomic ensembles for photonic quantum information processing and fundamental tests of quantum physics" (PhD Thesis), September 2016.

A. J. Marengo, "Origins of unconventional magnetism in coinage metal nanomaterials" (PhD Thesis), February 2017.

I. Seidu, "Excited-state studies with the constricted Variational Density Functional Theory (CV-DFT) method" (PhD Thesis), April 2016.

N. Sinclair, "Optical quantum memory and signal processing using a rare-earth-ion-doped waveguide" (PhD Thesis), April 2016.

M. Wu, "Nanophotonic optomechanical devices for torque magnetometry" (PhD Thesis), November 2016.

F. Yang, "Far-field linear optical superresolution via heterodyne detection in a higher-order local oscillator mode" (MSc Thesis), August 2016.

Intellectual Property

T. W. Clements, C. Sarsons, P. Lai, E. J. Prenner, B. Blasiak, B. Tomanek, K. D. Rinker and S.

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Invited Presentations at Workshops/Conferences

29 Apr 2016, G. Gour, "On local multiplicativity of the L_p norms of a quantum channel", Alberta Mathematics Dialogue 2016, Calgary, Canada, 28 Apr 2016–29 Apr 2016.

4 May 2016, D. R. Salahub, "deMon quo vadis?", deMon Developer Workshop, Zhengzhou, People's Republic of China, 4 May 2016–7 May 2016.

13 May 2016, A. J. Mayer, D. Frekers, M. Wieser, R. I. Thompson and J. Dilling, "Gleaning the $\beta\beta$ decay half-life of ^{96}Zr from billion year old zircons", 17th Annual Meeting of the APS Northwest Section, Penticton, Canada, 12 May 2016–14 May 2016.

13 May 2016, W. Tittel, "Quantum networks: Merging quantum communication and computation", Quantum Alberta Workshop 2016, Banff, Canada, 13 May 2016.

23 May 2016, G. Gour, "Invariant polynomials in multipartite entanglement", Multipartite Entanglement Workshop, Benasque, Spain, 22 May 2016–27 May 2016.

26 May 2016, D. L. Feder, "The power of indistinguishable particles in quantum computation", Yukawa Institute for Theoretical Physics Long Term Workshop 2016: Quantum Information in String Theory and Many-Body Systems Meeting, Kyoto, Japan, 23 May–24 Jun 2016.

5 Jun 2016, D. R. Salahub, "Beyond structure – molybdenum carbide nanoparticles as catalysts for hydrogenation reactions - between clusters and the bulk", Canadian Society for Chemistry Symposium in Memory of Tom Ziegler, Halifax, Canada, 5 Jun 2016–9 Jun 2016.

5 Jun 2016, D. R. Salahub, "Humic and fulvic substances - beyond structure – a ReaxFF study", Canadian Society for Chemistry Symposium in Honour of Benoit Roux, Halifax, Canada, 5 Jun 2016–9 Jun 2016.

7 Jun 2016, S. Trudel, "Water oxidation catalysis: A new family of amorphous metal-oxide oxygen-evolution catalysts", 99th Canadian Chemistry Conference and Exhibition, Halifax, Canada, 5 Jun 2016–9 Jun 2016.

7 Jun 2016, M. Wu, N. L.-Y. Wu, T. Firdous, J. E. Losby, F. F. Sani, M. R. Freeman and P. E. Barclay, "Optomechanical torque magnetometry", Conference on Lasers and Electro-Optics (CLEO:2016), San

Jose, United States of America, 6 Jun 2016–10 Jun 2016.

9 Jun 2016, P. G. Kusalik, "Molecular simulations of crystallization: Past, present and future" (keynote), Multiscale Modelling of Materials and Molecules 2016 (eSENCE 2016), Uppsala, Sweden, 7 Jun 2016–9 Jun 2016.

19 Jun 2016, D. R. Salahub, "Towards multiscale modeling of (bio)catalysis", International Conference on the Theoretical Aspects of Catalysis (ICTAC), Zakopane, Poland, 9 Jun 2016–23 Jun 2016.

21 Jun 2016, Y. Shi, "Growth of crystalline metal carbides on the catalyst surface in hot wire chemical vapor deposition", Collaborative Conference on 3D & Materials Research (CC3DMR) 2016, Seoul, South Korea, 24 Jun 2016–26 Jun 2016.

22 Jun 2016, B. C. Sanders, "Precise space-time positioning for entanglement harvesting", Conference on Relativistic Quantum Information North (RQI-N2016), Waterloo, Canada, 21 Jun 2016–24 Jun 2016.

27 Jun 2016, A. E. Ulanov, I. A. Fedorov, D. Sychev, A. A. Pushkina, Y. Kurochkin, T. C. Ralph, P. Grangier and A. I. Lvovsky, "Two loss-tolerant protocols for quantum communications and metrology", 23rd Central European Workshop on Quantum Optics (CEWQO'16), Kolymabari, Greece, 27 Jun 2016–1 Jul 2016.

30 Jun 2016, G. Gour, "The conditional uncertainty principle", 3rd Seefeld Workshop on Quantum Information, Seefeld, Austria, 26 Jun 2016–1 Jul 2016.

30 Jun 2016, B. C. Sanders, "Accurate modelling of practical long-distance quantum and quantum key distribution through multiple entanglement-swapping stations", Trustworthy Quantum Information 2016, Shanghai, People's Republic of China, 27 Jun 2016–1 Jul 2016.

5 Jul 2016, D. R. Salahub, "Beyond structure – molybdenum carbide nanoparticles as catalysts for hydrogenation reactions – between clusters and the bulk", CECAM Workshop on Structure Prediction of Nanoclusters from Global Optimization Techniques: Computational Strategies and Connection to Experiments, Pau, France, 5 Jul 2016–8 Jul 2016.

8 Jul 2016, G. Gour, "The conditional uncertainty principle", The Life and Science of Jacob D. Bekenstein: A Celebration of His Life and Achievements in Science, Mitzpe Ramon, Israel, 3 Jul 2016–8 Jul 2016.

- 10 Jul 2016, [D. R. Salahub](#), “Multiscale modeling of chemical reactions in complex environments”, CSTCC – Canadian Symposium on Theoretical and Computational Chemistry, Regina, Canada, 10 Jul 2016–15 Jul 2016.
- 11 Jul 2016, A. E. Ulanov, I. A. Fedorov, A. A. Pushkina, D. Sychev, P. Grangier and [A. I. Lvovsky](#), “Loss-tolerant N00N states and hybrid quantum teleportation”, 25th Annual International Laser Physics Workshop (LPHYS’16), Yerevan, Armenia, 11 Jul 2016–15 Jul 2016.
- 18 Jul 2016, [A. I. Lvovsky](#), “Hybrid quantum optical technologies for communications and metrology”, 6th International Conference Frontiers of Nonlinear Physics (FNP 2016), Nizhny Novgorod, Russia, 17 Jul 2016–23 Jul 2016.
- 21 Jul 2016, [G. Gour](#), “Local additivity of minimum output entropies”, Beyond IID in Information Theory 4, Barcelona, Spain, 18 Jul 2016–22 Jul 2016.
- 21 Jul 2016, [Y. Shi](#), “Development of laser ionization mass spectrometric methods and its application to the investigation of chemical vapor deposition chemistry”, The 2nd International Conference on Current Trends in Mass Spectrometry, Chicago, United States of America, 20 Jul 2016–22 Jul 2016.
- 3 Aug 2016, [M. Wu](#), N. L.-Y. Wu, T. Firdous, J. E. Losby, F. F. Sani, M. R. Freeman and P. E. Barclay, “Optomechanical torque magnetometry”, International Conference on Optical MEMS and Nanophotonics (OMN 2016), Singapore, 31 Jul 2016–4 Aug 2016.
- 8 Aug 2016, [B. C. Sanders](#), “Learning in quantum control: High-dimensional global optimization for noisy quantum dynamics”, Quantum Machine Learning Conference, Perimeter Institute, Waterloo, Canada, 8 Aug 2016–12 Aug 2016.
- 6 Sep 2016, [Y. J. Shi](#), “Study of decomposition of methyl-substituted silane molecules on hot metal surfaces and in the gas phase”, The 9th International Conference on Hot Wire (Cat) and Initiated Chemical Vapor Deposition (HWCVD 9), Philadelphia, United States of America, 6 Sep 2016–9 Sep 2016.
- 18 Oct 2016, [D. R. Salahub](#), “Multiscale modeling of chemical reactions in complex environments”, Symposium in Honour of the 70th Birthday of Pavel Hobza, Prague, Czech Republic, 18 Oct 2016.
- 20 Oct 2016, R. Valivarthi, M. G. Puigibert, Q. Zhou, [G. Aguilar](#), D. Oblak, V. Verma, F. Marsili, M. Shaw and S. W. Nam, “Quantum teleportation across the Calgary fibre network”, Frontier in Optics 2016, Rochester, United States of America, 17 Oct 2016–21 Oct 2016.
- 23 Oct 2016, [A. I. Lvovsky](#), “Three ways to skin an optical Schrödinger cat”, Quantum Optics VIII, Maresias, Brazil, 23 Oct 2016–28 Oct 2016.
- 10 Nov 2016, [D. R. Salahub](#), “Multiscale modeling of chemical reactions in complex environments”, Symposium on Physical Chemistry for Energy and Medicine Research (American Chemical Society Southwest Regional Meeting), Galveston, United States of America, 10 Nov 2016–13 Nov 2016.
- 14 Nov 2016, [B. C. Sanders](#), “Spacetime replication of continuous-variable quantum information”, Conference on Coherent States and their Applications: A Contemporary Panorama, Marseille, France, 14 Nov 2016–18 Nov 2016.
- 3 Dec 2016, [G. Gour](#), “Semidefinite programming and quantum resource theories”, 2016 CMS Winter Meeting, Niagara Falls, Canada, 2 Dec 2016–5 Dec 2016.
- 20 Dec 2016, [B. C. Sanders](#), “Spacetime replication of continuous-variable quantum information”, The First International Conference on Topological Orders and Emergent Spacetime on Quantum Simulators, Fudan University, People’s Republic of China, 19 Dec 2016–23 Dec 2016.
- 5 Jan 2017, [B. C. Sanders](#), “Multiphoton multichannel interferometry for quantum information processing”, 2017 Zhejiang University Workshop on Tensor Networks and Related Topics in Quantum Information Theory, Hangzhou, People’s Republic of China, 4 Jan 2017–7 Jan 2017.
- 12 Jan 2017, F. Yang, A. Tashchilina, E. S. Moiseev, C. Simon and [A. I. Lvovsky](#), “Super-resolution microscopy utilizing heterodyne detection”, The 47th Winter Colloquium on the Physics of Quantum Electronics (PQE 2017), Snowbird, United States of America, 8 Jan 2017–13 Jan 2017.
- 29 Jan 2017, [D. R. Salahub](#), “Towards multiscale modeling of chemical reactions in complex environments – overview of the Salahub lab activities”, 8th Kananaskis Symposium on Molecular Simulation, Kananaskis, Canada, 29 Jan 2017–31 Jan 2017.
- 2 Feb 2017, [W. Tittel](#), “Rare-earth-doped crystals for quantum communications: How to store, and detect, a photon”, SPIE Photonics West, San Francisco, United States of America, 28 Jan 2017–2 Feb 2017.

21 Feb 2017, P. E. Barclay, “Nanophotonic optomechanical devices: Towards coupling photons, phonons and spins”, Spin Mechanics 4, Fairmont Château Lake Louise, Canada, 20 Feb 2017–25 Feb 2017.

7 Mar 2017, D. R. Salahub, “Beyond structure – molybdenum carbide nanoparticles as catalysts for hydrogenation reactions – between clusters and the bulk”, Intel Symposium on High-Performance Computing, Shanghai, People’s Republic of China, 7 Mar 2017.

18 Mar 2017, B. C. Sanders, “Machine learning for hard quantum control”, 12ème Colloque National de Recherche en Physique, Hammanet, Tunisie, 18 Mar 2017–21 Mar 2017.

Collaborations

International Institutions

Aarhus University, Denmark
Beijing University of Posts and Telecommunications, People's Republic of China
Ben-Gurion University of the Negev, Israel
California Institute of Technology, United States of America
Centro de Investigación y de Estudios Avanzados del Instituto Politécnico Nacional (CINVESTAV), Mexico
Chinese Academy of Science's Institute of Geology and Geophysics, People's Republic of China
Chinese Academy of Science's Institute for Coal Research, People's Republic of China
Czech Academy of Sciences, Czech Republic
Durham University, United Kingdom
École Polytechnique Fédérale de Lausanne, Switzerland
European Organization for Nuclear Research (CERN), Switzerland
Hebei University of Technology, People's Republic of China
Henan University of Science and Technology, People's Republic of China
Imperial College London, United Kingdom
Indian Institute of Science Education and Research – Mohali, India
Institute of Nuclear Physics of Polish Academy of Science, Poland
Institute of Science and Technology Austria
Institute for Research in Fundamental Sciences (IPM), Tehran, Iran
Institut Charles Gerhardt (CNRS), France
Institut d'Optique, France
Institut de Ciències Fotòniques, Spain
Isfahan University of Technology, Iran
Istituto di Fotonica e Nanotecnologie (IFN-CNR), Italy
Istituto Italiano di Tecnologia, Italy
Jacobs University, Germany
Koç University, Turkey
Korea Basic Science Institute (Busan), South Korea
Kyoto University, Japan
Laboratoire de Chimie Physique (CNRS), France
Marquette University, United States of America
Massachusetts Institute of Technology, United States of America
Montana State University, United States of America
Moscow Institute of Physics and Technology, Russia
Nagoya University, Japan
Nanjing University of Science and Technology, People's Republic of China
National Centre for Spinal Disorders, Hungary
National Institute for Standards and Technology (Boulder), United States of America
National University of Sciences and Technology, Pakistan
National University of Singapore
P. N. Lebedev Physical Institute of the Russian Academy of Sciences, Russia

Politecnico di Milano, Italy
Public Authority for Applied Education and Training,
Kuwait
Purdue University, United States of America
Shanghai Jiao Tong University, People's Republic of
China
Soreq Nuclear Research Centre, Israel
Southern Illinois University, United States of America
Stanford University, United States of America
Stockholm University, Sweden
Swansea University, United Kingdom
The Cockcroft Institute, United Kingdom
The Russian Quantum Centre, Russia
Université Catholique de Louvain, Belgium
Universidade Federal do Rio de Janeiro, Brazil
Università della Calabria, Italy
Università di Pisa, Italy
University College Dublin, Ireland
University College London, United Kingdom
University of California at Berkeley, United States of
America
University of California at San Diego, United States of
America
University of Electronic Science and Technology,
People's Republic of China
University of Liverpool, United Kingdom
University of Leipzig, Germany
University of Manchester, United Kingdom
University of Michigan, United States of America
University of Minas Gerais, Brazil
University of Queensland, Australia
University of Science and Technology of China,
People's Republic of China
University of Tabriz, Iran
University of Tokyo, Japan
University of Wisconsin at Madison, United States of
America
University of Zurich, Switzerland
Vision Research Institute, Lowell, United States of
America
Weizmann Institute of Science, Israel

National Institutions

Canadian Institute for Advanced Research
McGill University
National Institute for Nanotechnology
National Research Council of Canada, Ottawa
Queen's University
Simon Fraser University
TRIUMF
University of Alberta
University of British Columbia
University of Lethbridge
University of Ottawa
University of Saskatchewan
University of Victoria
University of Waterloo
York University

Industrial & Government

BBN Raytheon Technologies
Lawrence Berkeley National Laboratory
Lawrence Livermore National Laboratory
NASA Jet Propulsion Laboratory
Natural Resources Canada CanmetENERGY

Visitors

Name	Institution	Name	Institution
Hessa Alotaibi	Public Authority for Applied Education and Training, Kuwait	Harish Kugel	University of British Columbia
Gustavo Amaral	Pontifical Catholic University of Rio de Janeiro	Arturo Lezama	Universidad de la República, Uruguay
Mohammad Amin	D-Wave Systems	Xiaohong Li	Henan University of Science and Technology
Simon Apers	Ghent University	Guilhem Madiot	Université Paris-Sud
Andrew Cameron	University of Prince Edward Island	Josh Mutus	Google
Paul Corkum	University of Ottawa	Matthew Posner	University of Southampton
Dan Dalacu	National Research Council of Canada	Liang Qiu	China University of Mining and Technology
Timothy Duty	University of New South Wales	Dongxiao Quan	Xidian University
Matthew Fisher	University of California at Santa Barbara	Arun Rajendran	Indian Institute of Technology, Madras
Greg Gabrenya	D-Wave Systems	Mark Saffman	University of Wisconsin at Madison
Mercedes Gimeno-Segovia	University of Bristol	Yuval Sanders	Macquarie University
Eduardo Guendelman	Ben Gurion University	Rishabh Skukla	Indian Institute of Technology, Guwahati
Yu Guo	Shanxi Datong University	Alp Sipahigil	Harvard University
Lizandra Barrios Herrera	Instituto Superior de Tecnologías y Ciencias Aplicadas, Cuba	Michail Skoteiniotis	Universitat Autònoma de Barcelona
Garrett Hickman	University of Maryland	Hennie Snyman	Nelson Mandela Metropolitan University
Jeremy Hilton	D-Wave Systems	Wanjun Su	Fuzhou University
Scott Hopkins	University of Waterloo	Xinxin Tang	University of Science and Technology of China
Said Jalife Jacobo	Centro de investigacion y de estudios avanzados (Cinvestav)	Hailin Wang	University of Oregon
David Jennings	Imperial College London	Nathan Wiebe	Microsoft Research
Ebrahim Karimi	University of Ottawa	Colin Williams	D-Wave Systems
Andrew King	D-Wave Systems	Haider Zia	University of Electronic Science and Technology of China
		Haimin Zheng	China University of Petroleum

Affiliation

Name	Title	Affiliation
A. I. Lvovsky	Quantum Optics Group Leader	The Russian Quantum Center
D. R. Salahub	Honorary Professor	Henan University of Technology
B. C. Sanders	“Qianren” Professor	University of Science and Technology of China
W. Tittel	Associated Professor	Montana State University

GRADUATE COURSES

Course Name	Instructor	Description
CHEM689 Molecular Driving Forces	P. G. Kusalik	In this introduction to statistical mechanics we will explore the basis from which to understand molecular driving forces. We will also examine how this formalism is applied within computer simulations of liquids, solids and solutions. The emphasis will be on physical models and interpretations, with applications to systems of chemical and biochemical interest. Selected topics from the recent literature will also be included. We will closely follow the required text, <i>Molecular Driving Forces</i> by Dill and Bromberg
CHEM689 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.
PHYS507 Solid State Physics	P. E. Barclay	Crystal structure. Classification of solids and their bonding. Fermi surface. Elastic, electric and magnetic properties of solids.
PHYS615 Advanced Quantum Mechanics	D. Feder	Formalism of quantum mechanics. Entangled systems and their applications. Quantum nonlocality, Einstein-Podolsky-Rosen paradox, Bell theorem. Interpretations of quantum mechanics. Second quantization. Quantum theory of the electromagnetic field. Addition of angular momenta, Clebsch-Gordan coefficients, Wigner-Eckart theorem.
PHYS543 Quantum Mechanics II	N. Moazzen-Ahmadi	Theory of angular momentum and applications, perturbation theory and applications. Identical particles. Introduction to relativistic wave equations.
PHYS677 Implementations of Quantum Information	B. C. Sanders	Proposals and realizations of quantum information tasks including quantum computation, quantum communication, and quantum cryptography in optical, atomic, molecular, and solid-state systems.

SERVICES AND OUTREACH

Professional Services

Name	Role	Journal/Society/Institution
P. E. Barclay	Chair, Division of Atomic, Molecular and Optical Physics	Canadian Association of Physicists
P. E. Barclay	Associate Editor	<i>Optics Express</i>
P. G. Kusalik	Chair, Chemistry/Biochemistry Resource Allocation Committee	Compute Canada
A. I. Lvovsky	Member, International Advisory Board	<i>Journal of Physics B</i>
A. I. Lvovsky	Member, NSERC Strategic Partnership Grants for Projects, Information and Communication Selection Panel	Natural Sciences and Engineering Research Council of Canada
A. I. Lvovsky	Deputy Editor	<i>Optics Express</i>
D. R. Salahub	Member, Editorial Board	<i>Advances in Physical Chemistry</i>
D. R. Salahub	Member, Editorial Board	<i>Advances in Quantum Chemistry</i>
D. R. Salahub	Member, Editorial Board	<i>Computation</i>
D. R. Salahub	Vice Chair, Editorial Board	<i>Interdisciplinary Science: Computational Life Sciences</i>
D. R. Salahub	Member, Editorial Board	<i>Journal of Computational Chemistry</i>
D. R. Salahub	Member, Academic Editorial Board	<i>PLOS-One</i>
B. C. Sanders	Member, Editorial Board	IOP eBooks™
B. C. Sanders	Chair, Steering Committee	Quantum Africa Conference Series
B. C. Sanders	Editor-in-Chief	<i>New Journal of Physics</i>
Y. J. Shi	Associate Editor	<i>Canadian Journal of Chemistry</i>
R. I. Thompson	Director, Student Affairs	Canadian Association of Physicists
R. I. Thompson	Member, Editorial Board	<i>Physics in Canada</i>
R. I. Thompson	University of Calgary Representative, Board of Management	TRIUMF National Laboratory
R. I. Thompson	General Faculties Council, Board of Governors	University of Calgary
R. I. Thompson	Chair, Graduate College Steering Committee	University of Calgary
W. Tittel	Member, Editorial Board	<i>Quantum Science and Technology</i>
S. Trudel	Chair, Materials Chemistry Division	Chemical Institute of Canada

Quantum Public Lecture

The Quantum Public Lectures serve to convey leading breakthroughs in quantum science and technology to the general public. The public appetite is indeed high for learning the latest advances in the quantum world. Professor Paul Corkum from University of Ottawa delivered a public lecture titled “A molecule takes a selfie while creating the world’s shortest light pulses” to about 200 persons on 24 November 2016, and this event was supported by the Faculty of Science Alumni Relations team as a joint outreach effort. The lecture was broadcast by interactive video to the University of Lethbridge.

Outreach Lectures

10 May 2016, [D. R. Salahub](#), “50 years of trying to understand natural and life sciences – learning from giants”, Faculty of Science, Henan University of Technology, People’s Republic of China (lecture to 250 undergraduate).

23 Aug 2016, [B. C. Sanders](#), “Building a quantum computer”, Russian Quantum Center Summer School 2016, Moscow, Russia, 22 Aug 2016–27 Aug 2016.

19 Nov 2016, [P. E. Barclay](#), “From engineering to physics: adventures in STEM,” Ignite 2016: Science Expo Alberta Conference, Calgary.

24 Nov 2016, [P. E. Barclay](#), “Quantum technology for fun, profit, and discovery,” Wild Rose Brewery Nerd Nite Calgary.

7 Feb 2017, [D. R. Salahub](#), “Computational chemistry at work in the oil sands”, Sir Winston Churchill High School (Chemistry Club), Calgary.

16 Feb 2017, [D. Oblak](#), R. Valivarthi, Q. Zhou, M. Grimau Puigibert, G. H. Aguilar and W. Tittel, “Quantum teleportation - What it is, what it’s not, and what it’s good for!”, Calgary Nerdnite Psi, Calgary, Canada.

21 Feb 2017, [W. Tittel](#), “Well connected”, PechaKucha Night, Calgary, Canada.

25 Mar 2017, [N. Sinclair](#), “Quantum technology- putting the weird to work”, University of Calgary, Rothney Astrophysical Observatory (public lecture).

29 Mar 2017, [D. R. Salahub](#), “50 years of trying to understand natural and life sciences – learning from giants”, Henan University of Technology, People’s Republic of China (lecture to 250 graduate students).

Media Coverage

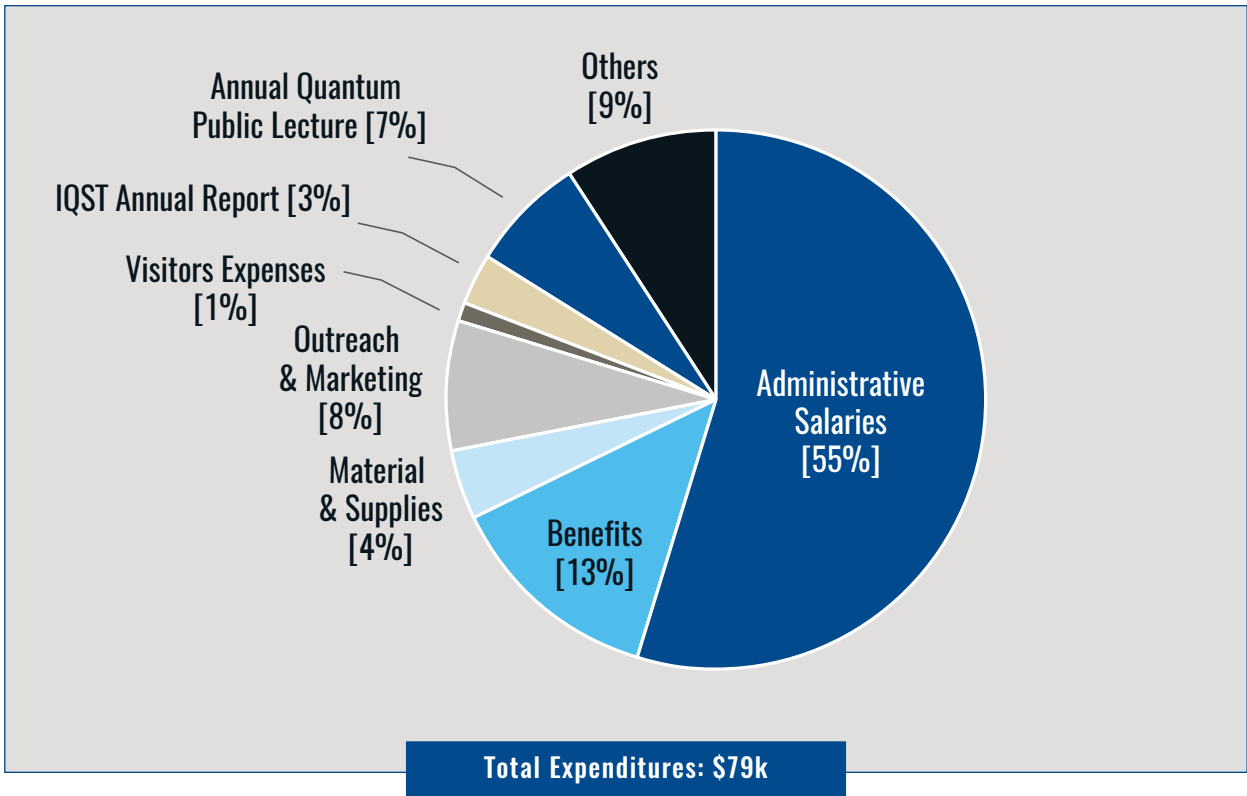
Source	Title of Article	Date
Maclean's	Trudeau versus the experts: Quantum computing in 35 seconds: Barry C. Sanders	19 Apr 2016
CBC News	The debate over preserving Calgary's architectural heritage: Barry C. Sanders	15 May 2016
Physicsworld.com	The June 2016 issue of Physics World is now out: Barry C. Sanders	1 Jun 2016
Eureka Alert	Russian physicists create a high-precision "quantum ruler": Alex Lvovsky	23 Jun 2016
Science Daily	Physicists create a high-precision "quantum ruler": Alex Lvovsky	23 Jun 2016
TASS.com	Russian physicists create highly precise "quantum ruler": Alex Lvovsky	23 Jun 2016
UToday	Physicist exploring new ways to think about science and how to teach it: Barry C. Sanders	8 Jul 2016
Lenta.ru	Environmentalists described the quantum tunnels in the human brain: Christoph Simon, Paul Barclay	19 Jul 2016
РИА Новости	Scientists spoke about the quantum tunnels in the human brain: Christoph Simon, Paul Barclay	20 Jul 2016
Capital TV	Dr. Barry Sanders' public lecture on Dr. Abdus Salam: Barry C. Sanders	30 Jul 2016
Daily Jehan-e-Pakistan	Habib University hosts Dr. Barry Sanders' public lecture: Barry C. Sanders	30 Jul 2016
Daily Ausaf	Habib University hosts Dr. Barry Sanders' public lecture: Barry C. Sanders	30 Jul 2016
Daily Jang	Habib University hosts four-day quantum information summer school: Barry C. Sanders	30 Jul 2016
Newa-e-Waqt	Habib University hosts four-day quantum information summer school: Barry C. Sanders	30 Jul 2016
Pakistanblogs.com	Habib University hosts QISS, aims for development of a national collaboration in Pakistan: Barry C. Sanders	30 Jul 2016
thenews.com.pk	Physicists laud Dr. Abdus Salam's contributions: Barry C. Sanders	31 Jul 2016
Pakobserver.net	Habib University hosts Summer School: Barry C. Sanders	5 Aug 2016
pstimes.com	Habib University hosts QISS, aims for development of a national collaboration in Pakistan: Barry C. Sanders	5 Aug 2016
CTV	Canadian researchers lead the way towards unhackable internet communication: Wolfgang Tittel	19 Sep 2016
Mail on Sunday	Quantum teleportation breakthrough as scientists send data across cities – and it could lead to UNBREAKABLE encryption for computer networks: Wolfgang Tittel	19 Sep 2016
BBC	Teleportation step toward quantum internet: Wolfgang Tittel	20 Sep 2016
Calgary Herald	University of Calgary manages to teleport photons, paving way for quantum Internet: Wolfgang Tittel	20 Sep 2016

Calgary Sun	How Calgary researchers solved a quantum conundrum using city hall and a photon: Wolfgang Tittel	20 Sep 2016
CBC Calgary	Teleportation across Calgary marks “major step” toward creation of “quantum internet”: Wolfgang Tittel	20 Sep 2016
Metronews.ca	U of C researcher teleports photons across Calgary: Wolfgang Tittel	20 Sep 2016
Motherboard	Scientists set a new distance record for quantum teleportation: Wolfgang Tittel	20 Sep 2016
The Christian Science Monitor	Could quantum teleportation help ensure online privacy?: Wolfgang Tittel	20 Sep 2016
UToday	Beam me up Scotty! Researchers teleport particle of light six kilometres: Wolfgang Tittel	20 Sep 2016
UToday	University of Calgary physicists create nano-sized device with huge potential in field of quantum computing: Paul Barclay	20 Sep 2016
CBC Homestretch	Calgary Jenny Howe gets to the bottom of teleportation: Wolfgang Tittel	21 Sep 2016
Global TV	Why teleportation could one day be a reality: Wolfgang Tittel	22 Sep 2016
The Loop	Moving around of information: Wolfgang Tittel	22 Sep 2016
CBC Radio: Quirks and Quarks	Quantum teleportation: Wolfgang Tittel	24 Sep 2016
Matter News	Quantum teleportation: It’s being in two places at once. Really: Wolfgang Tittel	24 Sep 2016
CIFAR	New distance record for quantum teleportation: Wolfgang Tittel	7 Oct 2016
UofA Faculty of Science News	Less is more when it comes to atomic-scale manufacturing: Robert Wolkow	28 Oct 2016
UToday	2016 Killam Scholars and award winners celebrated at annual reception: Barry C. Sanders	28 Oct 2016
The Globe and Mail	Tiny Alberta-made sensor may open door to hand-held drug tests: Paul Barclay, Mark Freeman	31 Oct 2016
UToday	PhD grad aims to take the mystery out of quantum science: Neil Sinclair, Wolfgang Tittel, Barry C. Sanders	14 Nov 2016
National Post	Does the mind use fibre optics? Calgary team floats “out-there” theory of light communication in the brain: Christoph Simon	20 Nov 2016
Calgary Herald	Does the mind use fibre optics? Calgary team floats “out-there” theory of light communication in the brain: Christoph Simon	21 Nov 2016
Newstlak770	Fibre optics and the brain: Christoph Simon	21 Nov 2016
UToday	A molecule takes a selfie: Paul Corkum	24 Nov 2016
Youtube: SciHerald	Brain optics, THz identification of cancer DNA, and “hairy” black holes: Christoph Simon, Paul Barclay, Sourabh Kumar	1 Dec 2016
The Wall Street Journal	After 1,000 year slumber, China vows to invent again: Barry. C. Sanders	6 Dec 2016
UToday	Researchers explore the possibility of a “fibre optic network” in the brain: Christoph Simon	7 Dec 2016
The Globe and Mail	Canadians solve key puzzle for future of encryption: Wolfgang Tittel	20 Dec 2016

UToday	Top research stories of 2016: Teleportation, bear attacks, and an app for people with celiac disease: Wolfgang Tittel	23 Dec 2016
UofA Faculty of Science News	What's cooler than being cool?: Lindsay LeBlanc	25 Jan 2017
UToday	International research team shines light on mystery of antimatter: Rob Thompson, Andrew Evans	3 Feb 2017
UToday	UCalgary researchers awarded NSERC Strategic Partnership Grants for high-priority impacts: Paul Barclay	15 Feb 2017
ScienceNews	Millions of atoms entangled in record-breaking quantum tests: Christoph Simon, Wolfgang Tittel	27 Mar 2017
UToday	Project expands research collaborations in Pan-Africa, Pakistan and Peru: Barry. C. Sanders	29 Mar 2017

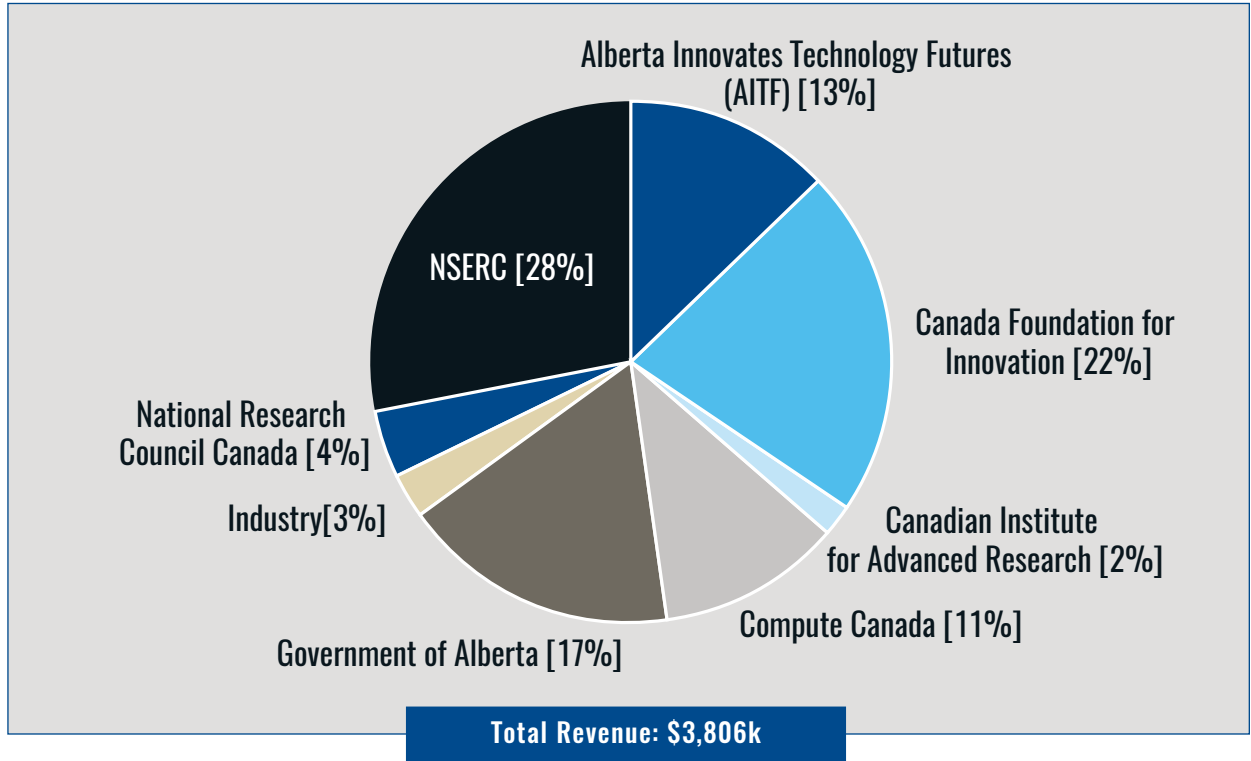
FINANCES

Operating Account (unaudited)

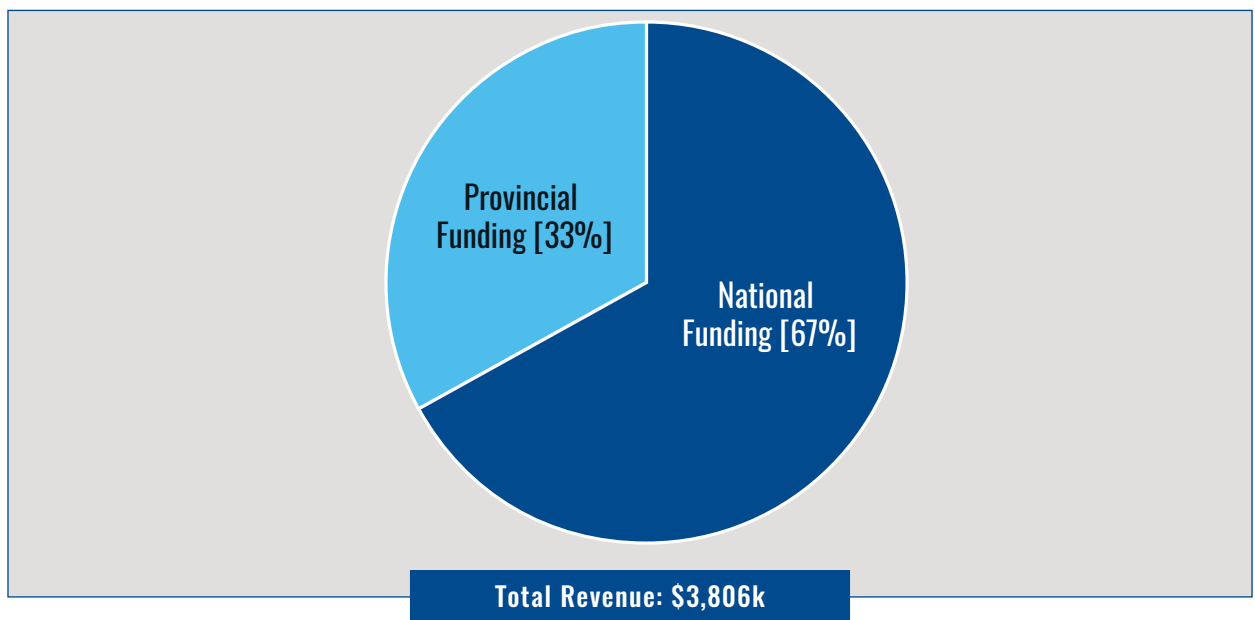


Research Grants (unaudited)

BY FUNDING AGENCY



BY ORIGIN



OBJECTIVES FOR NEXT YEAR

PAUL BARCLAY

- Demonstrate optomechanically induced transparency in a diamond device.
- Demonstration of optomechanical control of diamond spins.
- Evaluation of the possibility of observing room temperature quantum effects in diamond optomechanical devices.
- Demonstration of doubly resonant photon down-conversion from 780 nm band to the 1550nm band using a microcavity.
- Implant and characterize spectral properties of SiV defects in diamond chips.
- Together with Freeman and other NINT researchers, enhance sensitivity of silicon photonics nanocavity torque magnetometer technology.
- Publish proposal for detecting optical angular momentum states of light using optomechanical devices.

DAVID FEDER

- Explore how to perform universal measurement-based quantum computation with symmetry protected many-body states.
- Understand the violation of entanglement area laws in fermionic matter.

- Attempt to construct universal resources for measurement-based quantum computation with interacting fermionic particles on lattices.
- Explore novel phases for ultracold atoms confined in optical cavities and optical lattices.

GILAD GOUR

- Determine necessary and sufficient conditions for converting one state to another under symmetric operations.
- Derive necessary and sufficient conditions for converting an incoherent athermal state to an athermal state with coherence in the energy basis.
- Find an explicit example for non-additivity of the Holevo capacity of a quantum channel.
- Generalize the uncertainty principle from a lone system to a system entangled with quantum memory with applications to quantum cryptography.

PETER HØYER

- Develop algorithms for generalized quantum walks systems.
- Determine necessary and sufficient conditions for speed up of generalized quantum walks.

PETER KUSALIK

- Develop and test an effective interaction potential for OH radical in water that faithfully reproduces the structural features observed from ab initio simulations.
- Explore the behaviour of OH radical at the surfaces of water and ice.
- Determine the stability and reactivity of hemibonded complexes of OH radical with Cl⁻ or Br⁻ anions.
- Develop and test empirical and coarse-grain potential models appropriate for simulations studies of self-assemble processes in Zn/ carboxylate MOFs.
- Determine the key factors impacting the nucleation process of gas clathrate hydrates from gas mixtures of varying compositions.
- Examine influences of surfaces on the nucleation of gas hydrates from water-in-oil emulsions, in complimentary simulations and experimental studies.

ALEX LVOVSKY

- Build an entangled state between a Schrödinger cat and the polarization of a single photon.
- Obtain superresolution with pairs of point objects that are separated by a few tens of nm.
- Demonstrate complete reconstruction of an image with sub-diffraction resolution.

NASSER MOAZZEN-AHMADI

- Record and analyse laboratory infrared spectra of hydrocarbons relevant to the methane cycle in the atmospheres of Titan and the Giant Planets.
- Construct highly-accurate potential energy surfaces for characterization of intermolecular forces.
- Measure low-frequency intramolecular vibrational fundamentals of molecular clusters via combination bands.
- Provide high resolution spectroscopic data to test the onset of superfluidity in CH₃COOH-(He)₄ as the smallest superfluid cluster.
- Record and analyse laboratory spectra of H²- and He-hydrocarbons for elucidation of collisional processes between molecular

hydrogen and rare gas with hydrocarbon trace species for planetary applications.

- Perform structural determination of complexes formed from carbon monoxide and carbon dioxide.

DENNIS SALAHUB

- Advance multi-scale modelling methodologies and their implementation in efficient computer codes, with an immediate focus on and implementation of the GGA+U methodology for strongly correlated systems, dispersion corrections and quantum capping potentials for QM/MM calculations.
- Develop multiscale modelling of nanocatalysis for oil sands upgrading by extending our work on molybdenum carbide to include mixed-valence ceria-metal catalysts to split water, using the produced hydrogen for hydrocracking over molybdenum carbide.
- Perform multiscale QM/MM studies of the mechanism of action of important enzymes; continue studies of the heme peroxidases in order to verify, or falsify, the presence of electron density circuits.

BARRY C. SANDERS

- Develop a wavelet-based quantum algorithm for quantum computer simulation of a multi-scale renormalizable quantum field theory.
- Operationalize fundamental quantum protocols.
- Formalize the machine-learning description of quantum control.
- Determine how to postselect a controlled-controlled-not gate with ten-photon entangled state.
- With Wolkow at the University of Alberta and with Quantum Silicon Incorporated, design and test all-silicon proof of concept atom-scale circuitry for quantum adiabatic annealing.

YUJUN SHI

- Investigate chemical vapor deposition chemistry of silicon nitride using aminosilanes as novel precursors.
- Explore the pulsed laser dewetting method for the formation of bimetallic nanoparticles.

- Advance the development of a theoretical model in characterizing the temperature profile in the process of pulsed laser dewetting.
- Develop methods using chemical vapor deposition to form Si-based nanostructures.

CHRISTOPH SIMON

- Develop proposals for room-temperature quantum photonics involving defects in diamond and opto-mechanical systems.
- Work on quantum networks with rare-earth ions, pursuing both approaches based on single ions and on ensembles.
- Study transducers between superconducting qubits and photonic qubits, based on defects in solids and on opto-mechanical systems.
- Study potential sources of bio-photons in the brain, with a focus on singlet oxygen and the possible role of spin.
- Study entangled-photon microscopy, in particular using nano-diamonds.

ROBERT THOMPSON

- Observe optical transition in trapped atomic antihydrogen.
- Use geochemical techniques to determine double- β half-life for ^{96}Zr .
- Finalize design of the ALPHA-g apparatus.

WOLFGANG TITTEL

- Develop and demonstrate key components for quantum repeater-based quantum key distribution especially quantum memory for light, measurement-device-independent quantum key distribution, and quantum teleportation.
- Explore how to map quantum information between superconducting qubits and telecommunication-wavelength photons.

SIMON TRUDEL

- Investigate photochemical formation of nanoparticles for water electrolysis.
- Develop in situ and in oprando methods for x-ray based spectroscopy at the Canadian Light Source.
- Develop novel magnetic nanoparticles for magnetic resonance imaging.

APPENDICES

Appendix 1: 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.

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.

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

- 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.

Appendix 2: 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 320	13
MS 376	12
MS 436	13
SA 111	71
SB 117	45
SB 135	18
SB 301	12
SB 303	24
SB 306	54
SB 307	12
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

Room Number	Size (square meter)
SB 417	12
SB 427	25
SB 429A	12
SB 431	12
SB 508 (partial)	55
SB 512 (partial)	64
SB 525	16
SB 531	12
SB 535	12
SB 536 (partial)	33
SB 537	12
SB 605 (partial)	66

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 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 locally


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



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