

# QUANTUM FRONTIERS

annual report 2015-2016



Institute for  
QUANTUM SCIENCE AND TECHNOLOGY  
at the University of Calgary

# 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

20

postdoctoral fellows

76

graduate students

23

undergraduate students

41

visiting researchers

76

publications in refereed journals and conference proceedings including *Nature* (1), *Nature Communications* (1), *Physical Review Letters* (8), *Physical Review X* (2), *Optica* (1), *Nano Letters* (1)

37

invited talks at national and international conference/workshops including 1 keynote and 2 plenary talks

4.572 million dollars

revenue

# contents

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executive director's report .....	4	linkage .....	34
a message from the chair .....	6	COLLABORATION .....	34
highlights of 2015/2016.....	8	VISITORS .....	36
RESEARCH ACHIEVEMENTS .....	8	AFFILIATION .....	37
AWARDS .....	9	teaching, training and education .....	38
KEY PERFORMANCE INDICATORS .....	10	GRADUATE COURSES .....	38
research groups .....	13	services and outreach .....	39
management and membership.....	20	CONFERENCES .....	39
INSTITUTE STRUCTURE .....	20	PROFESSIONAL SERVICES .....	39
GOVERNANCE .....	21	QUANTUM PUBLIC LECTURE .....	40
STUDENTS .....	23	OUTREACH LECTURES .....	40
POSTDOCTORAL FELLOWS .....	25	MEDIA COVERAGE .....	41
RESEARCH ASSOCIATES .....	25	finances .....	42
ADMINISTRATION AND SUPPORT .....	25	RESEARCH GRANTS (UNAUDITED) .....	42
publications and presentations.....	26	OPERATING ACCOUNT (UNAUDITED) .....	42
REFEREED JOURNALS .....	26	plans for next year .....	43
CONFERENCE PROCEEDINGS .....	30	appendices .....	46
BOOK CHAPTERS .....	30	APPENDIX 1: CHARTER OF THE INSTITUTE FOR	
INVITED CONFERENCE/ WORKSHOP PRESENTATIONS .....	31	QUANTUM SCIENCE AND TECHNOLOGY .....	47
STUDENT THESES .....	33	APPENDIX 2: IQST USE OF SPACE .....	50

## executive director's report



**BARRY C. SANDERS**

“The institute’s formidable presence on the international scene augurs well for Calgary and for the province of Alberta to benefit greatly from University and provincial investments in “quantum” over the past 13 years.”

The Institute for Quantum Science and Technology has enjoyed another year of excellence in research, training and outreach. The Highlights section of this Annual Report elaborates on some of the key achievements but I give an overview of the highlights here.

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*, *Physical Review Letters*, *Physical Review X*, *Optica*, *Nano Letters*. Eleven students enrolled in the graduate studies programs in 2015/2016. Three MSc students and nine 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. Hoan Bui Dang received a postdoctoral fellowship from NSERC, and two graduate students held NSERC Vanier Scholarships plus two Masters students received NSERC Canada Graduate Scholarships. Seven Alberta Innovates Graduate Student Scholarships were held by students in the Institute, and five postdocs were supported by Eyes High Postdoctoral Fellowships jointly supported by Alberta Innovates Technology Futures and the University of Calgary.

Four graduate students held University of Calgary Queen Elizabeth II Graduate Scholarships, and one graduate student was the recipient of a University of Calgary Silver Anniversary Scholarship. One student benefitted from the Dean’s International Doctoral Recruitment Scholarship and two graduate students obtained Eyes High Doctoral Recruitment Scholarships. One PhD student held a competitive award from Kuwait and a visiting graduate student was supported by a China Scholarship Council Award. Faculty member Gilad Gour was awarded

the Faculty of Science Early Career Research Scholarship Award.

The Institute prioritizes outreach as well as research and training. Hosting conferences and holding Quantum Public Lectures serve as the main outreach instruments. From 11 to 14 June 2016, the Institute hosted Theory Canada 10. Theory Canada is the annual conference for theoretical physics in Canada. Also the Institute hosted the annual Quantum Information Processing conference (QIP 2016), which is the leading theoretical conference in quantum information with strong computer science, mathematics and physics participation. QIP 2016 was held at the Banff Centre from 10 to 15 January 2016 preceded by tutorials at the University of Calgary on 9 and 10 January.

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. One of the Institute's Public Lectures was held in conjunction with the national conference Theory Canada 10: former University of Calgary postdoc Shohini Ghosh, who is now a Faculty Member of Wilfred Laurier University and a TED Fellow, gave a public lecture on "Seeing the Invisible: Journey into the Quantum World" on 11 June 2015 to an audience of 120.

Seth Lloyd from the Massachusetts Institute of Technology delivered a public lecture titled "Teleportation, Time Travel and Escape from Black Holes" to 320 persons on 18 November 2015, and this event was supported by the Faculty of Science Alumni Relations team as a joint outreach effort. In addition to this public lecture, a pan-Alberta public lecture, organized by the nascent Quantum Alberta initiative, was hosted at the University of Alberta and broadcasted by interactive video to the

Universities of Calgary and Lethbridge. Twenty persons in Calgary attended this Public Lecture by Nobel Laureate William Phillips. This Public Lecture is Quantum Alberta's first foray into province-wide outreach.

The Quantum Alberta initiative, which hosted the pan-Alberta Public Lecture by Phillips, is an AITF-sponsored effort to create a pan-Alberta network of academic and industry experts whose collective aim is to elevate Quantum Science research, development and commercialization in Alberta. Quantum Alberta's home page is <http://quantumalberta.ca/>. Ultimately the Institute for Quantum Science and Technology could become a branch of the Quantum Alberta umbrella if events unfold according to the Quantum Alberta plan.

The Institute operates efficiently with just one Administrator and a part-time webmaster. The Institute has been working on revamping its database and web presence by subsuming these information resources within the Quantum Alberta superstructure. The aim is to replace the Institute database and web pages by virtual pages that are served from the Quantum Alberta host but selected to show only the University of Calgary data.

In summary the Institute is performing well in research, training and outreach and taking new initiatives with respect to web page and database management and the development of the Quantum Alberta initiative. Quantum science and technology are becoming increasingly important for sensing, secure communication and computation, and the Institute's formidable presence on the international scene augurs well for Calgary and for the province of Alberta to benefit greatly from University and provincial investments in "quantum" over the past 13 years.

## a message from the chair



**LESLEY RIGG**

“In addition to the excellent science and training undertaken in the Institute, I applaud the Institute’s outreach effort.”

As the new Dean of the University of Calgary’s Faculty of Science, I also serve as the Chair of the Institute’s Board of Directors. This Board guides and assesses the performance of the Institute, which is one of two Institutes hosted within The Faculty of Science: the Institute for Quantum Science and Technology and the Institute for Security, Privacy and Information Assurance. The Faculty is also host to the University of Calgary branch of the Pacific Institute for the Mathematical Sciences. Each of these Institutes are strategically important to the Faculty of Science’s directions in research, training, and outreach.

The Institute for Quantum Science and Technology has put the University of Calgary firmly on the map of global leaders in quantum science and technology. The Institute has activities of excellence in each of four Science Departments: Chemistry, Computer Science, Mathematics and Statistics, and Physics and Astronomy. As quantum science is becoming increasingly important on the world stage, especially for potential applications to sensing, metrology, secure communication, and computing, this Institute ensures that the University of Calgary plays a key role in the advancements of this field and partners with other leaders.

In addition to the excellent science and training undertaken in the Institute, I applaud the Institute’s outreach effort. Members of the Institute are active in outreach efforts to schools nationally, and the Quantum Public Lectures draws large crowds each year to hear leaders in the quantum field. The Faculty of Science plays an important organizational role in facilitating the Quantum Public Lectures through the Faculty of Science Alumni Relations Office. Many Science alumni come each year to hear these popular lectures by leaders in the field of quantum science.

The Institute for Quantum Science and Technology is an exemplar within the Faculty for how an Institute should operate. In addition to the research, training, and outreach excellence, the Institute is managed well through its governance structure. The Board ensures strategic direction and accountability. The Executive Director and the Administrator ensure effective day-to-day management supported by an Executive Committee. The Council, which is convened thrice annually, is an integral part of ensuring a collegial and democratic approach to operations and planning. The long-standing success and growth of the Institute surely depend not only on the quality of its members but also the quality of its management. This Annual Report is an excellent document conveying the formidable achievements of the Institute, and I wish the Institute continued success in the coming year.

# highlights of 2015/2016

## RESEARCH ACHIEVEMENTS

The Institute has had a highly successful year of research outcomes. The chief highlights are reported here. In addition to these highlights, every research group continues to make great strides in research and has had substantial outcomes in the past year.

Gilad Gour and collaborators developed a general structure for quantum resource theories, which was published in *Physical Review Letters*. Another key result from Gour's group has been a model for quantum thermodynamics at low temperature; this result was published in *Nature Communications*. In a *Physical Review A* paper, promoted as an Editors' Suggestion and highlighted by MIT Technology Review, Christoph Simon and his group showed how to achieve entanglement over global distances based on quantum repeaters with satellite links. Barry Sanders and collaborators derive, in a *New Journal of Physics* paper, an asymptotically tight relation between average gate fidelity, favoured in experimental reporting of quantum gate performance, with an upper bound on the quantum gate error rate, which is the appropriate metric for assessing progress towards fault tolerant quantum computation.

Alex Lvovsky's group has addressed the challenge of sharing fragile N-photon "NOON" states between multiple particles. In their *Nature Photonics* paper, they explain their technique, which reverses the Hong-Ou-Mandel effect in order to prepare a high-fidelity two-photon NOON state shared between two parties connected by a lossy optical channel.

In a *Physical Review Letters* article promoted as an Editors' Suggestion, Wolfgang Tittel and his group demonstrated an atomic quantum memory that directly allows for reversible mapping of quantum states encoded in the polarization degree of freedom of a telecom-wavelength photon. Furthermore they showed that heralded polarization qubits at a telecom wavelength are stored and retrieved with near-unity fidelity by implementing the atomic frequency comb protocol in an ensemble of erbium atoms doped into an optical fiber.

Peter Kusalik's group has contributed an important insight into crystal nucleation of gas hydrates by showing how specific defect (cage) structures can allow cross-nucleation of an otherwise structurally incompatible crystal on the surface of another. Yujun Shi's group has demonstrated efficient formation of Gold and Platinum nanoparticle arrays on organized dimpled tantalum substrates using the technique of pulsed laser dewetting of thin metal films. These results were published in *Physical Chemistry Chemical Physics* and in *Applied Physics Letters*, respectively.

In a *Nature* paper, Robert Thompson and collaborators bound the charge of the antihydrogen atom by applying stochastic acceleration to a near neutrality by a factor of 20 better than the best previous result. Robert Thompson, in a result reported in *Physical Review Letters*, measures single and double beta-decay Q Values among the Triplet  $^{96}\text{Zr}$ ,  $^{96}\text{Nb}$ , and  $^{96}\text{Mo}$  thereby providing valuable empirical results to such beta-decay models.

In *Nano Letters*, Paul Barclay's team describes how to fabricate easily single-crystal-diamond optical resonators whose wavelength-scale dimensions enable enhanced coupling between light and electron spins. In a *Physical Review X* publication, the team reports diamond devices with ultralow dissipation mechanical resonances that are coupled to an optical fiber and used to demonstrate one of the first instances optomechanics in diamond.

# AWARDS

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## INTERNATIONAL AWARDS

*China Scholarship Council Award  
(People's Republic of China)*

Wei-Wei Zhang (ended December 2015)

*PAAET Award (Kuwait)*

Hessa Muneef Alotaibi (ended August 2015)

## NATIONAL AWARDS

*MITACS Globalink*

Punit Kumar Jha  
Yeyu Tong  
Nguyen Dang Tran

*NSERC Canada Graduate Scholarships –  
Master*

Tamiko Masuda  
Stephen Wein

*NSERC Postdoctoral Fellowship*

Hoan Bui Dang

*NSERC USRA Program*

Xining Chen  
Celeb John  
Stephen Wein

*NSERC Vanier Scholarship*

Carlos Enriquez-Victorero  
Kyle Hall

*PIMS Postdoctoral Fellowship*

Hoan Bui Dang

## PROVINCIAL AWARDS

*Alberta Innovates Graduate Students  
Scholarship*

Chris Healey  
Sourabh Kumar  
Hon-Wai Lau  
David Lake  
Thomas Lutz  
Matthew Mitchell  
Stephen Wein

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

Gabriel Aguilar  
Ronnie Banerjee  
Joydip Ghosh  
John Patrick Hadden  
Florian Senn

## UNIVERSITY OF CALGARY AWARDS

*Dean's International Doctoral Recruitment  
Scholarship*

Sumit Goswami

*Eyes High Doctoral Recruitment Scholarship*

Andrew Evans  
Sourabh Kumar

*Faculty of Science Early Career Research  
Excellence Award*

Gilad Gour

*Faculty of Graduate Studies Travel Award*

Hamidreza Kaviani  
David Lake  
Thomas Lutz  
Matthew Mitchell

*Queen Elizabeth II Graduate Scholarship*

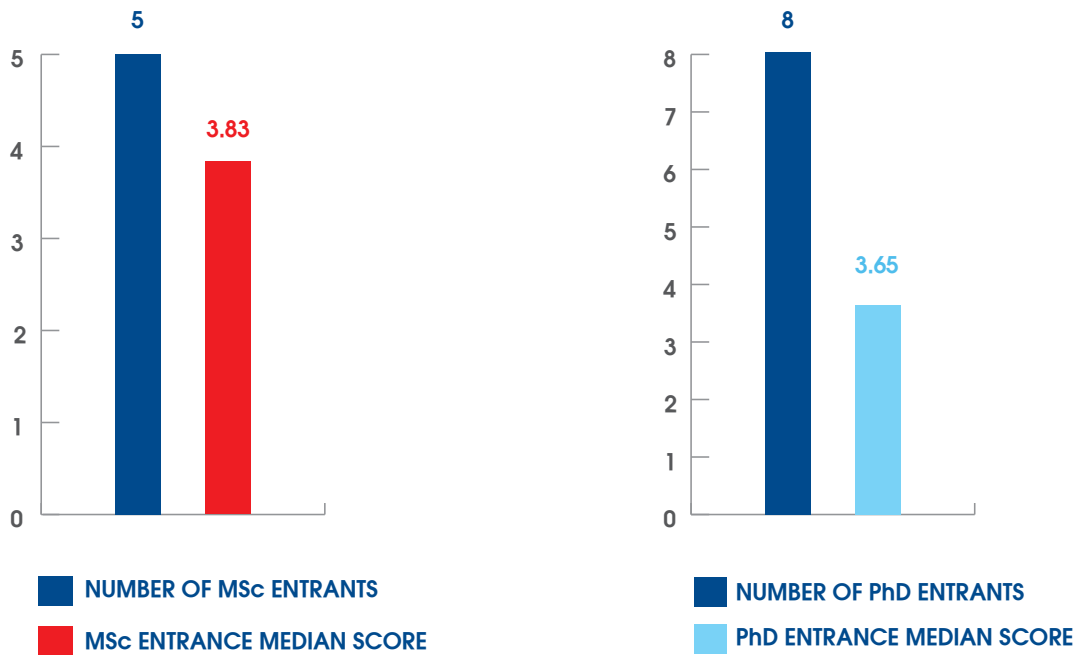
Alex Cameron  
Adam Mayer  
Sahar Sheybani-Deloui  
Neil Sinclair

*Silver Anniversary Graduate Fellowship*

Marcelo Wu

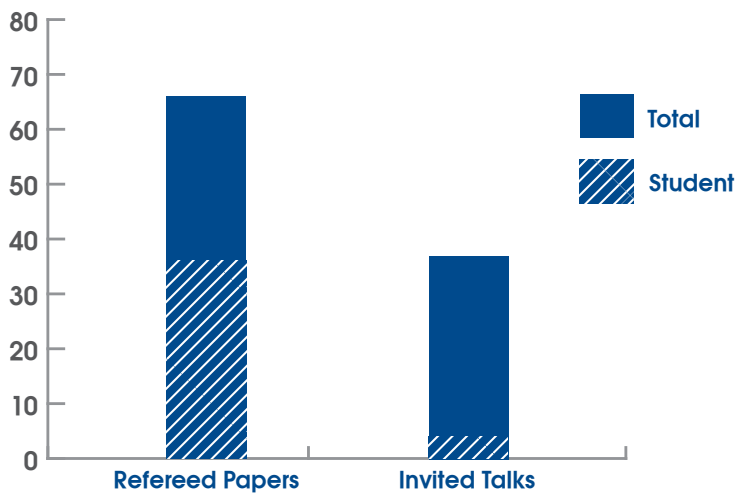
# KEY PERFORMANCE INDICATORS

## Graduate student enrolment and quality of entrants

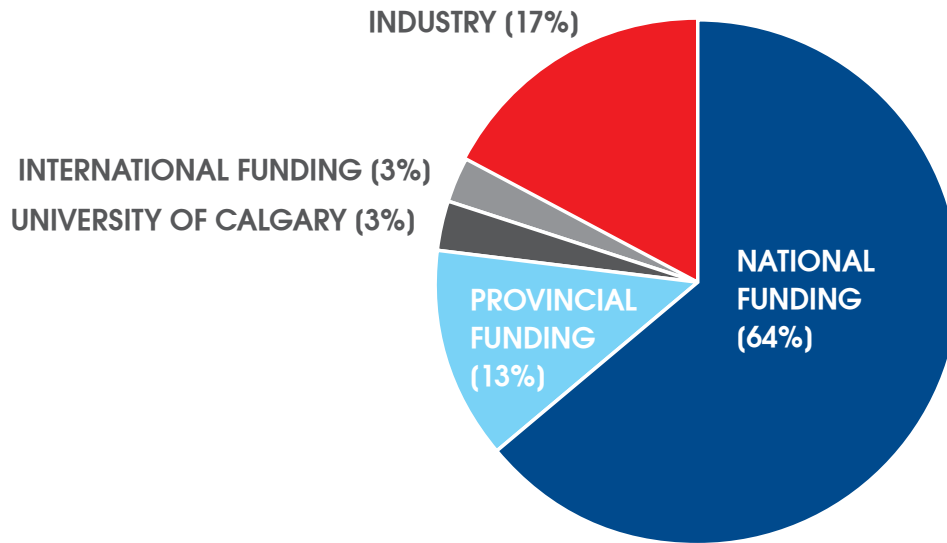


Note: Two PhD students were transferred from MSc program, so their GPAs were not calculated

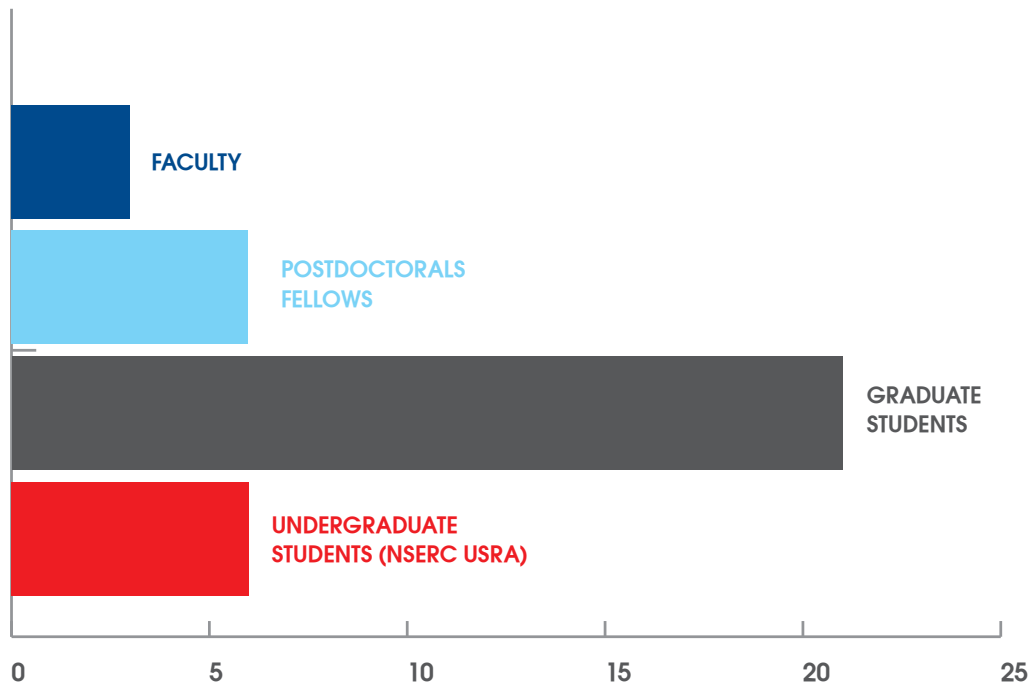
## Publications and Presentations (highlight portion with IQST student)



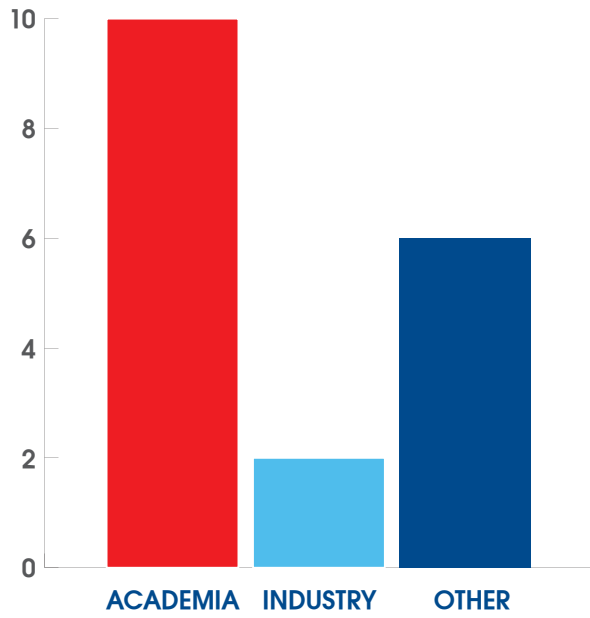
Revenue (unaudited)



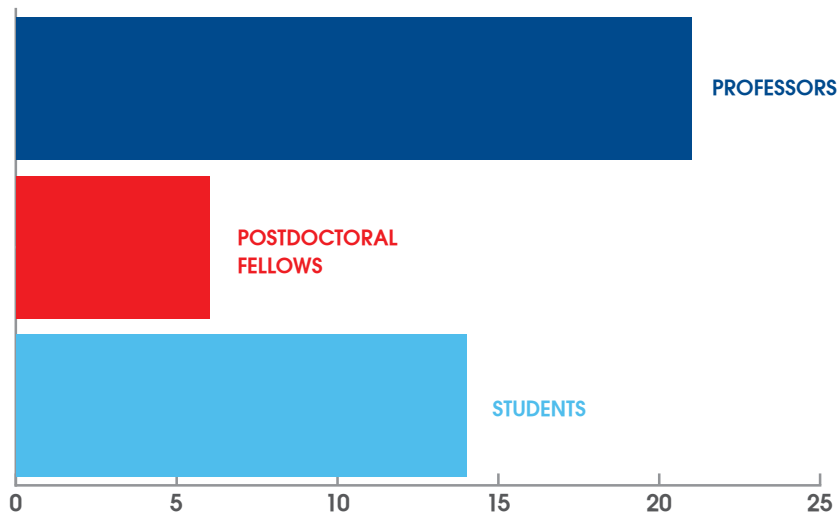
External Awards (Chairs, Fellowships and Scholarships)



*Trainee Destinations after IQST*



*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. 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.



### **PRACTICAL QUANTUM COMPUTATION**

*Dr. David Feder*

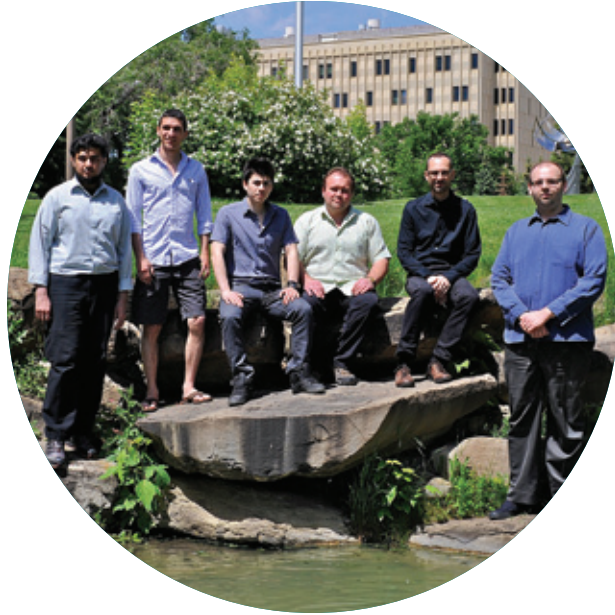
Focuses on understanding intrinsic properties of physical systems, such as ultracold atomic gases or spin lattices, can be employed to construct larger devices able to perform quantum computation. In addition, the group explores alternative models for the implementation of quantum logic, such as one-way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



## NANOSCALE 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.

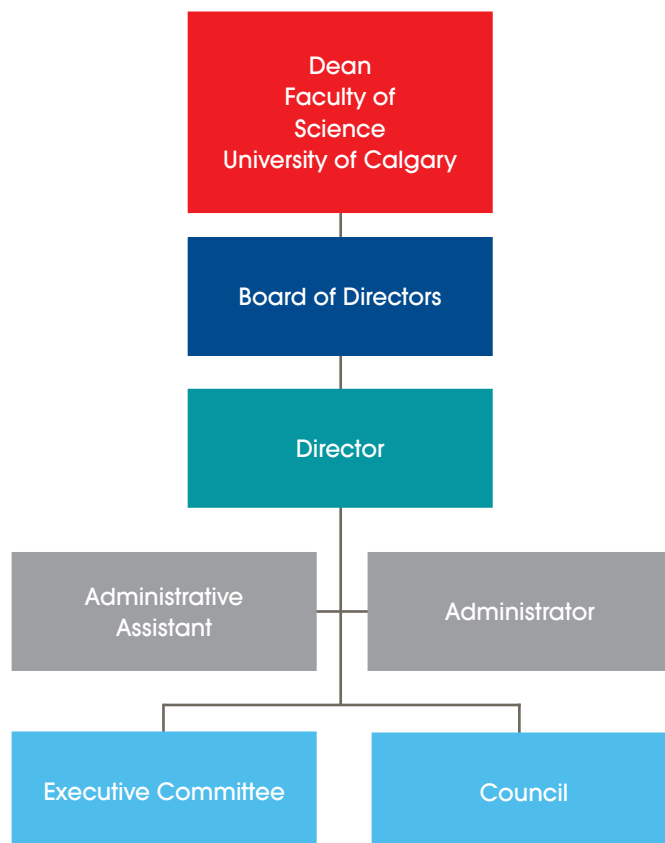
# management and membership

## 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

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### BOARD OF DIRECTORS

*Lesley Rigg*

Dean, Faculty of Science, University of Calgary

*Marie D'lorio*

Executive Director, National Institute for Nanotechnology (NINT)

*Chip Elliott*

Chief Engineer, Raytheon BBN Technologies

*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*

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*

*(on sabbatical leave from July 2015)*

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

*Gilad Gour*

Associate 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*

*(on sabbatical leave from July 2015)*

Professor, Department of Physics and Astronomy, University of Calgary

*Simon Trudel*

*(on leave from July 2015)*

Associate Professor, Department of Chemistry, 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*

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 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*

Associate 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

## STUDENTS

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### GRADUATE STUDENTS (PHD PROGRAM)

Hessa Muneef Alotaibi (completed August 2015  
Instructor → Public Authority for Applied Education  
and Training, Kuwait)

Mohsen Falamarzi Askarani

Nathan Babcock (completed April 2015 → Postdoc,  
Simon Fraser University)

Philip Chan

Ish Dhand (completed December 2015 → Postdoc,  
University of Ulm)

Harro Dittmar (completed August 2015 → Research  
Assistant, University of Calgary)

Catalin Dohotaru

Raphael Dong

Carlos Enriquez-Victorero

Andrew Evans

Akihiko Fujii

Mark Girard

Sumit Goswami

Kyle Hall

Chris Healey

Hamidreza Kaviani

Abdullah Khalid

Behzad Khanaliloo

Mohammad Khazali

Faezeh Kimiaee Asadi

Sourabh Kumar

David Lake

Hon-Wai Lau

Pascal Lefebvre

Xingchen Liu

Thomas Lutz

Armando Marengo

Adam Mayer

Matthew Mitchell

James Moncreiff

Farokh Mivehvar (completed February 2016 →  
Postdoc, University of Innsbruck)

Ali Mohandesi (completed November 2015)

Varun Narasimhachar

Ebenezer Owusu-Ansah

Pantita Palittapongarnpim

Marcel.lí Grimau Puigibert

Nafiseh Sang-Nourpour

Issaka Seidu

Sahar Sheybani-Deloui

Neil Sinclair

Mandana Sobhanzadeh (completed December  
2015 → Senior Laboratory Instructor, Mount Royal  
University)

Priyaa Varshinee Srinivasan

Arina Tashchilina

Venkata Ramana Raju Valivarathi

Shakib Vedaie

Dongsheng Wang (completed August 2015  
→ Postdoc, University of British Columbia)

Marcelo Wu

Yadong Wu

Navid Yousefabadi (on leave from January 2016)

Ehsan Zahedinejad (completed January 2016  
→ Postdoc, University of Calgary)

Parisa Zarkeshian

Rui Zhang

## GRADUATE STUDENTS (MSc PROGRAM)

Paul Anderson  
Aaron Barclay  
Di Chang (completed December 2015)  
Chetan Deshmukh  
Alison Fulton  
Jobin George  
Abhirup Goswami (on leave from May 2015)  
Masoud Habibi Davijani  
Daniel Hogg (terminated April 2015)  
Guosheng (Tom) Huo (on leave from September 2015)  
Jonathan Johannes (completed January 2016  
→ Software Developer, AppColony)  
Shreyas Jalnapurkar  
Abdullah Khalid (transferred January 2016 → PhD,  
University of Calgary)

David Lake (transferred September 2015 → PhD,  
University of Calgary)  
Tamiko Masuda  
Eugene Moiseev  
Alireza Poostindouz  
Lohrasp Seify  
Randy Squires (transferred September 2015 →  
part-time MSc, University of Calgary)  
Stephen Wein  
Venkata Ramana Raju Valivarathi  
Weihuang Xu  
Fan Yang  
Mahdi Yousefi Koopae (completed April 2015)

## UNDERGRADUATE STUDENTS

Paul Anderson (Research Assistant)  
Branko Bajic (Research Assistant)  
Logan Born (Research Assistant)  
Bhupinderjit Chana (CHEM 402)  
Xining Chen (NSERC USRA)  
Logan Cooke (PHYS 598)  
Davor Curic (PHYS 598)  
Adam Fazekas (Research Assistant)  
Alison Fulton (Research Assistant)  
Modan Han (Research Assistant)  
Nathan Harms (Research Assistant)  
Punit Kumar Jha (MITACS Globalink)

Celeb John (NSERC USRA)  
Jonathan Kung (CHEM 502)  
Robert Mereau (Summer Student)  
Kurtis Niedling (Research Assistant)  
Casey Platnich (CHEM 502)  
Delphine Prinnet (Research Assistant)  
Yeyu Tong (MITACS Globalink)  
Nguyen Dang Tran (MITACS Globalink)  
Wyatt Vine (CHEM 502)  
Jingyi Yuan (CHEM 402)  
Stephen Wein (NSERC USRA)

## POSTDOCTORAL FELLOWS

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Gabriel Aguilar  
Mehdi Ahmadi  
Morteza Amirani  
Ronnie Banerjee  
Hoan Bui Dang  
Mercedes Gimeno Segovia (visiting postdoc from University of Bristol)  
Joydip Ghosh (completed November 2015 → Postdoc, University of Wisconsin-Madison)  
Sandeep Goyal  
John Patrick Hadden  
Christopher O'Brien (resigned November 2015 → Senior Scientist, Lynntech)  
Daniel Oblak (completed April 2015 → Senior Research Coordinator, University of Calgary)  
Young Choon Park  
Erhan Saglamyurek (completed June 2015 → Postdoc, University of Alberta)  
Florian Senn  
Sriram Srinivasan (resigned November 2015)  
Rim Toukabri  
Lucile Veissier  
Nathanael Wu (resigned July 2015)  
Ehsan Zahedinejad  
Qiang Zhou

## RESEARCH ASSOCIATES

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Stephanie Bovincini  
Edelsys Codorniu-Hernandez (completed August 2015)  
Harro Dittmar  
Mykhaylo Krykunov (completed December 2015)  
Tamiko Masuda (completed August 2015 → MSc, University of Calgary)  
Daniel Oblak

## ADMINISTRATION AND SUPPORT

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Vladimir Kiselyov (Senior Electrical Engineer, part-time)  
Nancy Jing Lu (IQST Administrator)  
Trang Pham (part-time, resigned September 2015)  
Priyaa Varshinee Srinivasan (Webmaster, part-time)  
Lucia Wang (Administrative Assistant)

# publications and presentations

## REFEREED JOURNALS

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M. Ahmadi, M. Baquero-Ruiz, W. A. Bertsche, E. Butler, A. Capra, C. Carruth, C. L. Cesar, A. E. Charman, S. Eriksson, L. T. 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, S. A. Jones, S. Jonsell, L. Kurchaninov, N. Madsen, D. Maxwell, J. T. K. Mckenna, S. Menary, J. M. Michan, T. Momose, J. J. Munich, P. Nolan, K. Olchanski, A. Olin, A. Povilus, P. Pusa, C. Ø. Rasmussen, F. Robicheaux, R. L. Sacramento, M. Sameed, E. Sarid, D. M. Silveira, C. So, T. D. Tharp, R. I. Thompson, D. P. van der Werf, J. S. Wurtele, and A. I. Zhmoginov, "An improved limit on the charge of antihydrogen from stochastic acceleration", *Nature* **529**: 373-376, 20 January 2016.

M. Alanssari, D. Frekers, T. Eronen, L. Canete, J. Dilling, M. Haaranen, J. Hakala, M. Holl, M. Jeřkovský, A. Jokinen, A. Kankainen, J. Koponen, A. J. Mayer, I. D. Moore, D. A. Nesterenko, I. Pohjalainen, P. Povinec, J. Reinikainen, S. Rinta-Antila, P. C. Srivastava, J. Suhonen, R. I. Thompson, A. Voss, and M. E. Wieser, "Single and double beta-decay Q values among the triplet  $^{96}\text{Zr}$ ,  $^{96}\text{Nb}$ , and  $^{96}\text{Mo}$ ", *Physical Review Letters* **116**(7): 072501 (5 pp.), 17 February 2016.

H. M. Alotaibi and B. C. Sanders, "Slowing the probe field in the second window of double-double electromagnetically induced transparency", *Physical Review A* **91**(4): 043817 (18 pp.), 10 April 2015.

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I. Badran and Y. J. Shi, "Structure changes in tungsten and tantalum wires in catalytic chemical vapor deposition using 1,3-disilacyclobutane",

*Journal of Physical Chemistry C* **119**(3): 19134-19142, 31 July 2015.

E. Bae, G. Gour, S. Lee, J. Park and B. C. Sanders, "Stability theorem of depolarizing channels for the minimal output quantum Rényi entropies", *Journal of Physics A: Mathematical and Theoretical* **49**(11): 115304 (13 pp.), 2 February 2016.

H. Bassa, S. K. Goyal, S. K. Choudhary, H. Uys, L. Diosi and T. Konrad, "Process tomography via sequential measurements on a single quantum system", *Physical Review A* **92**(3): 032102 (6 pp.), 3 September 2015.

Z. H. Bian, J. Li, H. Qin, X. Zhan, R. Zhang, B. C. Sanders and P. Xue, "Realization of single-qubit positive operator-valued measurement via a one-dimensional photonic quantum walk", *Physical Review Letters* **114**(2): 203602 (5 pp.), 22 May 2015.

K. Boone, J. P. Bourgoin, E. Meyer-Scott, K. Heshami, T. Jennewein and C. Simon, "Entanglement over global distances via quantum repeaters with satellite links", *Physical Review A* **91**(5): 050201 (5 pp.), 26 May 2015.

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G. K. Brennen, E. Giacobino and C. Simon, "Focus on quantum memory", *New Journal of Physics* **17**(5): 050201 (3 pp.), 6 May 2015.

G. K. Brennen, P. Rohde, B. C. Sanders and S. Singh, "Multiscale quantum simulation of quantum field theory using wavelets", *Physical Review A* **92**(3): 032315 (11 pp.), 15 September 2015.

X. Chen, R. Merau and D. L. Feder, "Asymptotically perfect efficient quantum state transfer across uniform chains with two impurities", *Physical Review A* **93**(1): 012343 (10 pp.), 27 January 2016.

E. Codorniu-Hernández, K. Wm. Hall, A. D. Boese, D. Ziemianowicz, S. Carpendale and P. G. Kusalik, "Mechanism of O(<sup>3</sup>P) formation from a hydroxyl radical pair in aqueous solution", *Journal of Chemical Theory and Computation* **11**(10): 4740-4748, 28 August 2015.

A. de la Lande, V. Moliner and D. R. Salahub, "Editorial - Measurement and prediction of quantum coherence effects in biological processes", *Physical Chemistry Chemical Physics* **17**: 30772-30774, 17 September 2015.

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S. K. Goyal, F. S. Roux, A. Forbes and T. Konrad, "Implementation of multidimensional quantum walks using linear optics and classical light", *Physical Review A* **92**(4): 040302(R) (5 pp.), 15 October 2015.

S. Guha, H. Krovi, C. Fuchs, Z. Dutton, J. A. Slater, C. Simon and W. Tittel, "Rate-loss analysis of an efficient quantum repeater architecture", *Physical Review A* **92**(2): 022357 (24 pp.), 31 August 2015.

- H. de Guise, D. Spivak, J. Kulp and I. Dhand, "D-functions and invariants of unitary matrices and submatrices", *Journal of Physics A: Mathematical and Theoretical* **49**(9): 09LT01 (12 pp.), 21 January 2016.
- C. Healey, H. Kaviani, M. Wu, B. Khanaliloo, M. J. Mitchell, A. C. Hryciw and P. E. Barclay, "Design and experimental demonstration of optomechanical paddle nanocavities", *Applied Physics Letters* **107**(23): 231107 (6 pp.), 10 December 2015.
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- N*-methyl-Acetamide (NMA) as a model for understanding of Li<sup>+</sup> binding to amide plane”, *Physical Chemistry Chemical Physics* **18**: 4191-4200, 7 December 2015.
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- F. Mivehvar and D. L. Feder, “Enhanced stripe phases in spin-orbit-coupled Bose-Einstein condensates in ring cavities”, *Physical Review A* **92**(2): 023611 (14 pp.), 10 August 2015.
- V. Narasimhachar and G. Gour, “Low-temperature thermodynamics with quantum coherence”, *Nature Communications* **6**: 7689 (6 pp.), 3 July 2015.
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- E. Saglamyurek, T. Lutz, L. Veissier, M. Hedges, C. W. Thiel, R. L. Cone and W. Tittel, “Efficient and long-lived Zeeman-sublevel atomic population storage in an erbium-doped glass fiber”, *Physical Review B* **92**(24): 241111(R) (5 pp.), 14 December 2015.
- Y. R. Sanders, J. J. Wallman and B. C. Sanders, “Bounding quantum gate error rate based on reported average fidelity”, *New Journal of Physics* **18**(1): 012002 (13 pp.), 21 December 2015.
- M. Tillmann, S.-H. Tan, S. E. Stoeckl, B. C. Sanders, H. de Guise, R. Heilmann, S. Nolte, A. Szameit and P. Walther, “Generalized multi-photon quantum interference”, *Physical Review X* **5**(4): 041015, 27 October 2015.
- R. Toukabri and Y. J. Shi, “Hydrogen elimination from the dissociation of methyl-substituted silanes on tungsten and tantalum surfaces”, *Canadian Journal of Chemistry* **94**(4): 265-272, 7 July 2015 (Calgary Special Issue).
- A. E. Ulanov, I. A. Fedorov, A. A. Pushkina, Y. Kurochkin, T. C. Ralph and A. I. Lvovsky, “Undoing the effect of loss on quantum entanglement”, *Nature Photonics* **9**(11): 764-768, 12 October 2015.
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- T. Wang, H. W. Lau, H. Kaviani, R. Ghobadi and C. Simon, “Strong micro-macro entanglement from a weak cross-Kerr nonlinearity”, *Physical Review A* **92**(1): 012316 (6 pp.), 14 July 2015.
- S. Wang, B. S. Gelfand, P. C. Dong, S. Trudel and T. Baumgartner, “Tuning the aggregation-induced enhanced emission behavior and self-assembly of phosphole-lipids”, *Journal of Materials Chemistry C* **4**(14): 2936-2944, 18 December 2015.
- P. Xue, R. Zhang, H. Qin, X. Zhan, Z. H. Bian, J. Li and B. C. Sanders, “Experimental quantum-walk revival with a time-dependent coin”, *Physical Review Letters* **114**(14): 140502 (4 pp.), 6 April 2015.
- P. Xue, R. Zhang, Z. H. Bian, X. Zhan, H. Qin and B. C. Sanders, “Localized state in a two-dimensional quantum walk on a disordered lattice”, *Physical Review A* **92**(4): 042316, 30 September 2015.
- E. Zahedinejad, J. Ghosh and B. C. Sanders, “High-fidelity single-shot Toffoli gate via quantum control”, *Physical Review Letters* **114**(20): 200502 (5 pp.), 20 May 2015.
- X. Zhan, X. Zhang, J. Li, B. C. Sanders and P. Xue, “Realization of the contextuality-nonlocality tradeoff with a qubit-qutrit photon pair”, *Physical Review Letters* **116**(9): 090401 (4 pp.), 29 February 2016 (Editors’ Suggestion).

C. J. Zhang, C. P. Berlinguette and S. Trudel, "Water oxidation catalysis: an amorphous quaternary Ba-Sr-Co-Fe oxide as a promising electrocatalyst for the oxygen-evolution reaction", *Chemical Communications* **52**(7): 1513-1516, 26 November 2015.

## CONFERENCE PROCEEDINGS

A. Gutierrez, M. D. Ashkezari, M. Baquero-Ruiz, W. A. Bertsche, C. Burrows, E. Butler, A. Capra, C. L. Cesar, M. Charlton, R. Dunlop, S. Eriksson, N. Evetts, J. Fajans, T. Friesen, M. C. Fujiwara, D. R. Gill, 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, P. Pusa, C. Ø. Rasmussen, F. Robicheaux, R. L. Sacramento, E. Sarid, D. M. Silveira, C. So, S. Stracka, J. Tarlton, T. D. Tharp, R. I. Thompson, P. Tooley, M. Turner, D. P. van der Werf, J. S. Wurtele, A. I. Zhmoginov, "Antiproton cloud compression in the ALPHA apparatus at CERN", **235**(1): pp: 21-28, Proceedings of 6th International Conference on Trapped Charged Particles and Fundamental Physics (TCP 2014), Takamatsu, Japan, published by Springer.

K. Wm. Hall, E. Codorniu-Hernández, P. G. Kusalik and S. Carpendale, "ERICAs: Enabling insights into ab initio molecular dynamics simulations", pp.105-109, Proceedings of IEEE Pacific Visualization Symposium 2015, Hangzhou, P. R. China, 14 Apr 2015-17 Apr 2015, published by IEEE.

T. Hill, B. C. Sanders and H. Deng, "Dimensional dependence of cooperative emission", paper NW3A.3, Proceedings of Nonlinear Optics 2015, Kauai, United States of America, 26 Jul 2015-31 Jul 2015, published by Optical Society of America.

H. Jayakumar, B. Khanaliloo and P. E. Barclay, "Efficient fiber collection of nitrogen-vacancy center emission from diamond nano beams", FW1E.6, Proceedings of CLEO: QELS Fundamental Science 2015, San Jose, United States of America, 10 May 2015-15 May 2015, published by Optical Society of America.

H. Kaviani, C. Healey, M. Wu, P. E. Barclay and A. C. Hryciw, "Nonlinear optomechanical paddle nanocavities", pp.104-106, Proceedings of Photonics North 2015, Ottawa, Canada, 9 Jun 2015-11 Jun 2015, published by IEEE.

B. Khanaliloo, H. Jayakumar, D. Lake and P. E. Barclay, "Diamond manobeam waveguide optomechanics", STh31.3, Proceedings of CLEO: Science and Innovation 2015, San Jose, United States of America, 10 May 2015-15 May 2015, published by Optical Society of America.

D. Lake, M. J. Mitchell, A. C. Hryciw, H. Jayakumar and P. E. Barclay, "Resonant wavelength conversion in gallium phosphide nanostructures", STu21.5, Proceedings of CLEO: Science and Innovation 2015, San Jose, United States of America, 10 May 2015-15 May 2015, published by Optical Society of America.

M. J. Mitchell, B. Khanaliloo, A. C. Hryciw and P. E. Barclay, "Monolithic single crystal diamond high-Q optical microcavities", SF1H.3, Proceedings of CLEO: Science and Innovation 2015, San Jose, United States of America, 10 May 2015-15 May 2015, published by Optical Society of America.

W. Tittel, "A quantum repeater based on spectral multiplexing", FTh3D.1, Proceedings of Frontiers in Optics 2015, San Jose, United States of America, 18 Oct 2015-22 Oct 2015, published by Optical Society of America.

G. Vattay, D. R. Salahub, I. Csabai, A. Nassimi and S. A. Kauffman, "Quantum criticality at the origin of life", **626**: 012023 (10 pp.), Proceedings of 7th International Workshop DICE 2014 Spacetime - Matter - Quantum Mechanics, Castiglioncello, Italy, 15 Sep 2014-19 Sep 2014, published by IOP Publishing.

## BOOK CHAPTERS

X.-C. Liu, B. Zhou, F. Ahmed, A. Tkalych, A. Miyamoto and D. R. Salahub, "Multiscale modelling of in-situ oil sands upgrading with molybdenum carbide nanoparticles", section in book: *Quantum Modeling of Complex Molecular Systems*, volume **21**, J.-L. Rivail, X. Assfeld and Manuel Ruiz, eds. pp.415-416, published by Springer International Publishing, Switzerland in 2015 (Springer Series on "Challenges and Advances in Computational Chemistry and Physics).

## INVITED CONFERENCE/ WORKSHOP PRESENTATIONS

*(presenter is underlined)*

12 Apr 2015, M. Girard and G. Gour, “Quantum information theory and conversion witnesses”, The Sixth Northwest Functional Analysis Seminar, Banff, Canada, 10 Apr 2015–12 Apr 2015.

14 Apr 2015, A. I. Lvovsky, “Quantum technology of light as a harmonic oscillator” (keynote), EMN Meeting on Quantum Technologies, Beijing, People’s Republic of China, 14 Apr 2015–17 Apr 2015.

15 Apr 2015, W. Tittel, “Rare-earth-ion-based quantum technology: from quantum hard disks to single photon detectors”, ETH Symposium on Quantum Engineering, Zurich, Switzerland, 14 Apr 2015–15 Apr 2015.

8 May 2015, I. Dhand, H. de Guise, A. Khalid, H. Lu and B. C. Sanders, “Characterization and Simulation of Multi-Photon Interferometers”, Workshop on Multi-Photon Interferometry, Shanghai, People’s Republic of China, 7 May 2015–10 May 2015.

16 May 2015, W. Tittel and M. Afzelius, “Quantum repeaters based on multiplexed quantum memories and external photon pair sources”, First Workshop for Quantum Repeaters and Networks, Pacific Grove, United States of America, 15 May 2015–17 May 2015.

21 May 2015, C. Simon, “Towards global entanglement”, The International Conference on Quantum Physics of Nature 2015 (QuPoN 2015), Vienna, Austria, 18 May 2015–22 May 2015.

28 May 2015, D. R. Salahub, “deMon, quo vadis?”, 15th deMon Developers Workshop, Sofia, Bulgaria, 28 May 2015–31 May 2015.

29 May 2015, G. Gour, “The two bedrocks of quantum information science: Uncertainty and entanglement” (plenary), 12th Annual PIMS Young Researchers Conference in Mathematics and Statistics (PIMS YRC 2015), Calgary, Canada, 27 May 2015–29 May 2015.

9 Jun 2015, H. Kaviani, C. Healey, M. Wu, P. E. Barclay and A. C. Hryciw, “Nonlinear optomechanical paddle nanocavities”, Photonics North 2015, Ottawa, Canada, 9 Jun 2015–11 Jun 2015.

9 Jun 2015, P. G. Kusalik, “Explorations of the structure, mobility and reactivity of hydroxyl: Implications to biochemical systems”, 7th International Theoretical Biophysics Symposium, Cagliari, Italy, 8 Jun 2015–12 Jun 2015.

10 Jun 2015, C. Simon, “Towards global entanglement”, Photonics North 2015, Ottawa, Canada, 9 Jun 2015–11 Jun 2015.

11 Jun 2015, P. E. Barclay, “Nanophotonic optomechanical sensors: silicon and diamond devices”, Photonics North 2015, Ottawa, Canada, 9 Jun 2015–11 Jun 2015.

11 Jun 2015, W. Tittel, “How to build a quantum repeater”, Photonics North 2015, Ottawa, Ontario, Canada, 9 Jun 2015–11 Jun 2015.

15 Jun 2015, D. R. Salahub, “Introduction to density functional theory”, CECAM Workshop: deMon2k and deMonNano Tutorial, Orsay, France, 15 Jun 2015–20 Jun 2015.

16 Jun 2015, R. I. Thompson, “Project ALPHA: Applying AMO physics to antimatter and using antimatter to study AMO physics”, Canadian Association of Physicists Congress (2015 CAP Congress), Edmonton, Canada, 13 Jun 2015–19 Jun 2015.

17 Jun 2015, B. C. Sanders, E. Zahedinejad and J. Ghosh, “High-fidelity single-shot Toffoli gate via quantum control”, Canadian Association of Physicists Congress (2015 CAP Congress), Edmonton, Canada, 13 Jun 2015–19 Jun 2015.

18 Jun 2015, P. E. Barclay, “Nanophotonic optomechanics in diamond”, Canadian Association of Physicists Congress (2015 CAP Congress), Edmonton, Canada, 13 Jun 2015–19 Jun 2015.

30 Jun 2015, A. E. Ulanov, I. A. Fedorov, A. A. Pushkina, Y. Kurochkin, T. C. Ralph, A. S. Prasad and A. I. Lvovsky, “Two ways to distill Einstein-Podolsky-Rosen entanglement”, 14th International Conference on Squeezed States and Uncertainty Relations, Gdansk, Poland, 29 Jun 2015–3 Jul 2015.

6 Jul 2015, G. Gour, “Conditional entropy, conditional majorization, and the conditional uncertainty principle”, Workshop on Foundations of Quantum Information, Lake Okanagan, Canada, 6 Jul 2015–10 Jul 2015.

9 Jul 2015, G. Gour, “The general structure of quantum resource theories”, Beyond I.I.D. in Information Theory, Banff, Canada, 5 Jul 2015–10 Jul 2015.

- 7 Aug 2015, [P. E. Barclay](#), “Diamond nanobeam waveguide optomechanics”, The 6th International Conference on Metamaterials, Photonic Crystals and Plasmonics (META ‘15), New York, United States of America, 4 Aug 2015–7 Aug 2015.
- 10 Aug 2015, [I. Dhand](#), A. Khalid, H. Lu and B. C. Sanders, “Accurate and precise characterization of linear optical devices”, Quantum Communication and Quantum Imaging XIII, San Diego, United States of America, 9 Aug 2015–13 Aug 2015.
- 13 Aug 2015, [I. A. Fedorov](#), A. E. Ulanov, A. A. Pushkina, A. K. Fedorov, Y. Kurochkin, T. C. Ralph and A. I. Lvovsky, “Quantum optics experiments at the Russian Quantum Center”, International Workshop on Quantum Optics, Troitsk, Russia, 11 Aug 2015–16 Aug 2015.
- 16 Aug 2015, X.-C. Liu and [D. R. Salahub](#), “Multiscale modeling of in situ oil sands upgrading with molybdenum carbide nanoparticles”, XXIV International Materials Research Congress, Cancun, Mexico, 16 Aug 2015–20 Aug 2015.
- 21 Aug 2015, A. E. Ulanov, I. A. Fedorov, A. A. Pushkina, Y. Kurochkin, T. C. Ralph and [A. I. Lvovsky](#), “Recovering the loss of continuous-variable entanglement”, 24th International Laser Physics Workshop (LPHYS’15), Shanghai, People’s Republic of China, 21 Aug 2015–25 Aug 2015.
- 4 Oct 2015, [P. G. Kusalik](#), “Molecular simulations of gas hydrate crystallization”, 65th Canadian Chemical Engineering Conference, Calgary, Canada, 4 Oct 2015–7 Oct 2015.
- 11 Nov 2015, [C. Simon](#), “Cross-phase modulation of a probe stored in a waveguide for non-destructive detection of photonic qubits”, Conference on Quantum Light-Matter Interactions in Solid State Systems (QLIMS 2015), Barcelona, Spain, 9 Nov 2015–13 Nov 2015.
- 11 Nov 2015, [L. Veissier](#) and W. Tittel, “Erbium-doped fiber: a new possibility for quantum storage at telecom-wavelength”, Conference on Quantum Light-Matter Interactions in Solid State Systems (QLIMS 2015), Barcelona, Spain, 9 Nov 2015–13 Nov 2015.
- 18 Nov 2015, [Y. J. Shi](#), “Formation of tungsten silicides using catalytic chemical vapor deposition”, Energy, Material and Nanotechnology Fall Meeting, Las Vegas, United States of America, 16 Nov 2015–19 Nov 2015.
- 26 Nov 2015, [B. C. Sanders](#), “High-fidelity single-shot multi-qubit gate via avoided level crossing”, The 3rd International Workshop on Frontiers in Quantum Optics and Quantum Information, Beijing, People’s Republic of China, 26 Nov 2015–28 Nov 2015.
- 14 Dec 2015, [B. C. Sanders](#), “Quantum computing with linear optics and single photons” (plenary), International Conference on Light Quanta: Modern Perspectives and Applications (ICLQMPA 2015), University of Allahabad, India, 14 Dec 2015–16 Dec 2015.
- 12 Jan 2016, [T. Lutz](#), L. Veissier, C. W. Thiel, R. L. Cone, P. E. Barclay and W. Tittel, “Modification of pho-non processes in nano-structured rare-earth-ion-doped crystals”, CEMS International Symposium on Dynamics in Artificial Quantum Systems, Tokyo, Japan, 12 Jan 2016–14 Jan 2016.
- 12 Jan 2016, [A. I. Lvovsky](#), “Undoing the effect of loss on quantum entanglement”, TAMU-PQE Follow-on Workshop, College Station, United States of America, 12 Jan 2016–13 Jan 2016.
- 18 Feb 2016, [P. E. Barclay](#), “Optomechanics in single crystal diamond”, SPIE Photonics West, San Francisco, United States of America, 13 Feb 2016–18 Feb 2016.
- 9 Mar 2016, [D. R. Salahub](#), “Beyond structure - molybdenum carbide nanoparticles as catalysts for hydrogenation reactions - between clusters and the bulk”, International Symposium on Clusters, Cluster-Assemblies and Nanomaterials (ISCAN 2016), Thiruvananthapuram, India, 9 Mar 2016–12 Mar 2016.
- 15 Mar 2016, [Y. R. Sanders](#), J. J. Wallman and B. C. Sanders, “Bounding quantum gate error rate based on reported average fidelity”, APS March Meeting 2016, Baltimore, United States of America, 14 Mar 2016–18 Mar 2016.
- 17 Mar 2016, [D. R. Salahub](#), “Beyond structure - molybdenum carbide nanoparticles as catalysts for hydrogenation reactions - between clusters and the bulk”, 12th International Conference of Computational Methods in Science and Engineering (ICCMSE 2016), Athens, Greece, 17 Mar 2016–20 Mar 2016.

## STUDENT THESES

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H. M. Alotaibi, “Double double electromagnetically induced transparency” (PhD Thesis), 1 September 2015.

N. S. Babcock, “Nonadiabatic control for quantum information processing and biological electron transfer” (PhD Thesis), 1 April 2015.

D. Chang, “Experiments towards the realization of a nanofiber guided dipole trap” (MSc Thesis), 22 December 2015.

I. Dhand, “Multi-photon multi-channel interferometry for quantum information processing” (PhD Thesis), 10 December 2015.

H. Dittmar, “Utilizing conjugate thermal fields to drive ordering processes in molecular dynamics simulations” (PhD Thesis), 1 September 2015.

F. Mivehvar, “Cavity-induced synthetic gauge potentials” (PhD Thesis), 1 January 2016.

A. Mohandesi, “Molecular-dynamics simulations of ice growth from the vapour phase: demonstration of proof of principle” (PhD Thesis), 1 October 2015.

L. Seify, “Evaporative cooling in electromagnetic radio frequency traps” (MSc Thesis), 1 February 2016.

D.-S. Wang, “Algorithmic quantum channel simulation” (PhD Thesis), 1 September 2015.

## COLLABORATION

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### INTERNATIONAL INSTITUTIONS

Aarhus University, Denmark

California Institute of Technology, United States of America

Chinese Academy of Sciences (Institute of Geology and Geophysics & Guangzhou Institute of Energy Conversion), People's Republic of China

CSIR National Laser Centre, South Africa

Durham University, United Kingdom

East China Normal University, People's Republic of China

École Normale Supérieure and CNRS, France

École Polytechnique Fédérale de Lausanne, Switzerland

Federal University of Rio de Janeiro, Brazil

Institut d'Optique, France

Institute of Physics, Bhubaneswar, India

Instituto per le Applicazioni del Calcolo, Italy

Jacobs University, Germany

Karl-Franzens-Universität Graz, Austria

Karlsruhe Institute of Technology, Germany

Kyung Hee University, South Korea

Macquarie University, Australia

Massachusetts Institute of Technology, United States of America

Montana State University, United States of America

Moscow Institute of Physics and Technology, Russia

National Institute for Standards and Technology, United States of America

National Institute for Theoretical Physics, South Africa

Negev Nuclear Research Centre, Israel

Pohang University of Science and Technology, South Korea

Politecnico di Milano, Italy

Purdue University, United States of America

Singapore University of Technology and Design, Singapore

linkage

Southeast University, People's Republic of China  
Stellenbosch University, South Africa  
Stokholm University, Sweden  
Swansea University, United Kingdom  
Technische Universität München, Germany  
The Russian Academy of Science (P. N. Lebedev Physical Institute & G. A. Krestov Institute for Solution Chemistry), Russia  
The Russian Quantum Center, Russia  
Università della Calabria, Italy  
Universität Heidelberg, Germany  
Universität Jena, Germany  
Universitat Jaume I, Spain  
Universität Leipzig, Germany  
Universität Münster, Germany  
Universität Potsdam, Germany  
Universität Wien, Austria  
Université Paris-Sud, France  
Universidade Estadual de Campinas, Brazil  
Universidad de la República, Uruguay  
University College Dublin, Ireland  
University College London, United Kingdom  
University of California at Berkeley, United States of America  
University of Chicago, United States of America  
University of Electronic Science and Technology, People's Republic of China  
University of KwaZulu-Natal, South Africa  
University of Liverpool, United Kingdom  
University of Manchester, United Kingdom  
University of New Mexico, United States of America  
University of Oregon, United States of America  
University of Queensland, Australia  
University of Rochester, United States of America  
University of Science and Technology of China, People's Republic of China  
University of Technology Sydney, Australia  
University of Washington, United States of America

University of Wisconsin – Madison, United States of America  
University of the Witwatersrand, South Africa  
Weizmann Institute of Science, Israel  
Wigner Research Center for Physics, Hungary

## **CANADIAN INSTITUTIONS**

Canadian Institute for Advanced Research  
Dalhousie University  
Lakehead University  
McMaster University  
National Institute for Nanotechnology  
National Research Council of Canada Ottawa  
Perimeter Institute for Theoretical Physics  
Simon Fraser University  
St. Francis Xavier University  
TRIUMF  
University of Alberta  
University of Waterloo  
York University

## **UNIVERSITY OF CALGARY**

Institute for Security, Privacy and Information Assurance  
Centre for Molecular Simulation

## **INDUSTRY & GOVERNMENT**

Battelle  
BBN Raytheon Technologies  
Canadian Microelectronics Corporation  
HP Labs  
Lumerical Solutions  
Microsoft Research  
NASA Jet Propulsion Laboratory  
Norcada

## VISITORS

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NAME	INSTITUTION NAME
Alexandre Blais	Université de Sherbrooke
Gavin Brennen	Macquarie University
Alex Brown	University of Alberta
Aharon Brodutch	University of Waterloo
Francesco Buscemi	Nagoya University
Louise Budzynski	École Normale Supérieure de Paris
Archismita Dalal	Indian Institute of Technology, Kharagpur
Andrzej Dragan	University of Warsaw
Shane Eaton	Politecnico di Milano
Dirk Englund	Massachusetts Institute of Technology
Andrei Faraon	California Institute of Technology
Kate Ferguson	Australian National University
Kai-Mei Fu	University of Washington
Raul Garcia-Patron	Université libre de Bruxelles
Mercedes Gimeno-Segovia	University of Bristol
Hubert de Guise	Lakehead University
Matin Hallaji	University of Toronto
Gaston Hornecker	Institut Néel (CNRS) France
Punit Kumar Jha	Homi Bhabha National Institute, India
Mária Kieferová	University of Waterloo
Jungsang Kim	Duke University
Lindsay LeBlanc	University of Alberta
Wenqing Li	Jacobs University
Xiaohong Li	Henan University of Science and Technology
Seth Lloyd	Massachusetts Institute of Technology
Guilhem Madiot	Université Paris-Sud
Duncan O'Dell	McMaster University
Liang Qiu	China University of Mining and Technology
Dongxiao Quan	Xidian University
Jibran Rashid	Habib University
Michael Revzen	Technion – Israel Institute of Technology
Grant Salton	Stanford University
Mohammad Shahid Shaikh	Habib University
Alexander Smith	University of Waterloo
Dean Southwood	Macquarie University
Joseph Thywissen	University of Toronto

NAME	INSTITUTION NAME
Yeyu Tong	University of Electronic Science and Technology of China
Nguyen Dang Tran	Ho Chi Minh City University of Science
Peter Wittek	ICFO – The Institute of Photonic Sciences
Wei-Wei Zhang	Beijing University of Posts and Telecommunications
Huangjun Zhu	University of Cologne

## AFFILIATION

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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

# teaching, training and education

## GRADUATE COURSES

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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.
MATH667 Introduction to quantum information	G. Gour	Focus on the mathematical treatment of a broad range of topics in quantum Shannon theory. Topics include quantum states, quantum channels, quantum measurements, completely positive maps, Neumarkis theorem, Stinespring dilation theorem, Choi-Jamiolkowski isomorphism, the theory of majorization and entanglement, the Peres-Horodecki criterion for separability, Shannon's noiseless and noisy channel coding theorems, Lieb's theorem and the strong subadditivity of the von Neumann entropy, Schumacher's quantum noiseless channel coding theorem, and the Holevo-Schumacher-Westmoreland theorem.
CPSC 601.92 Special Topics in Computer Science (Topics in Quantum Computing)	P. Høyer	Quantum algorithmics, algorithmics, random walks, quantum random walk, analysis, lower bounds, spectral analysis, duality, boolean functions, quantum information theory, graph theory, learning graphs, electrical networks, algorithmic problems such as triangle finding, mathematical software packages, eigenvectors and complex vector spaces, probabilistic arguments, asymptotic analysis
PHYS615 Advanced Quantum Mechanics	B. C. Sanders	Basic formalism of the theory and its interpretation, symmetry generators. Scattering theory. Bound states. Charged particles in electric and magnetic fields. Approximation methods.
CHEM 619.09 Advanced Mass Spectrometric Techniques	Y. J. Shi	Theoretical and practical aspects of mass spectrometric techniques, instrumentation design, method development and trouble-shooting aspects along with instrument maintenance, hands-on experience with the operation of different types of instruments in acquisition, processing and interpretation of experimental data, recent developments in mass spectrometry instrumentation including hyphenated techniques and their applications in multi disciplinary fields.

# services and outreach

## CONFERENCES

MEMBER(S)	COMMITTEE	CONFERENCE/ WORKSHOP	LOCATION	DATES
G. Gour	Co-Chair	Theory Canada 10	Calgary, Canada	11–13 Jun 2015
B. C. Sanders	Chair, Organizing Committee	Workshop on Multi-Photon Interferometry (MPI 2015)	Shanghai, P. R. China	7–10 May 2015
B. C. Sanders	Chair, Organizing Committee	The 19th Conference on Quantum Information Processing (QIP2016)	Banff, Canada	10–16 Jan 2016
W. Tittel	Co-Chair	Workshop for Quantum Repeaters and Networks	Pacific Cove, United States of America	15–17 May 2015
W. Tittel	Co-Chair	QCrypt 2015	Tokyo, Japan	28 Sept–2 Oct 2015

## PROFESSIONAL SERVICES

NAME	ROLE	JOURNAL/SOCIETY/INSTITUTION
P. E. Barclay	Vice-Chair, Division of Atomic, Molecular and Optical Physics	Canadian Association of Physicists
P. E. Barclay	Special Issue Editor	<i>Journal of the Optical Society of America B</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	Deputy Editor	<i>Optics Express</i>
A. I. Lvovsky	Member, Scientific Committee	The Russian Quantum Center
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	Vice Chairman, 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, Editorial Board	<i>PLOS-One</i>
B. C. Sanders	Member, Beijing Research Site Committee	Global Research Initiative in Unconventional Hydrocarbon Resources: Beijing Site
B. C. Sanders	Member, Editorial Board	IOP ebooks™

NAME	ROLE	JOURNAL/SOCIETY/INSTITUTION
B. C. Sanders	Associate Editor	<i>Physical Review A</i>
B. C. Sanders	Chair, Steering Committee	QIP Conference Series
B. C. Sanders	Chair	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	TRIUMF National Laboratory
R. I. Thompson	Vice-Chair, Environment, Health, Safety, and Sustainability Committee, Board of Governors	University of Calgary
R. I. Thompson	Chair, Graduate College Steering Committee	University of Calgary
R. I. Thompson	Academic Co-Chair, Academic Program and Planning Committee	University of Calgary
W. Tittel	Member, Editorial Board	<i>Quantum Science and Technology</i>
S. Trudel	Secretary, Materials Division	Canadian Society for Chemistry

## 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. One of the Institute's Public Lectures was held in conjunction with the national conference Theory Canada 10: former University of Calgary postdoc Shohini Ghosh, who is now a Faculty Member of Wilfred Laurier University and a TED Fellow, gave a public lecture on "Seeing the Invisible: Journey into the Quantum World" on 11 June 2015 to an audience of 120.

Seth Lloyd from the Massachusetts Institute of Technology delivered a public lecture titled "Teleportation, Time Travel and Escape from Black Holes" to 320 persons on 18 November 2015, and this event was supported by the Faculty of Science Alumni Relations team as a joint outreach effort. In addition to this public lecture, a pan-Alberta public lecture, organized by the nascent Quantum Alberta initiative, was hosted at the University of Alberta and broadcast by interactive video to the Universities of Calgary and Lethbridge. Twenty persons in Calgary attended this Public Lecture by Nobel Laureate William Phillips. This Public Lecture is Quantum Alberta's first foray into province-wide outreach.

## OUTREACH LECTURES

15 May 2015, [D. Oblak](#) and W. Tittel, "Let there be quantum light", Calgary High School Teachers - University of Calgary, Physics and Astronomy Professional Development Day, Calgary, Canada.

12 Jun 2015, [B. C. Sanders](#), "Abdus Salam: The grand unifier", Electrodynamics, Quantum Field Theory to Nobel Prize in Physics: Scientific Contributions of Professor Abdus Salam, University of Calgary, Canada, 12 Jun 2015 2015.

12 Jun 2015, [R. I. Thompson](#), “Understanding antimatter: The global connection”, Electrodynamics, Quantum Field Theory to Nobel Prize in Physics: Scientific Contributions of Professor Abdus Salam, University of Calgary, Canada, 12 Jun 2015.

21 Jan 2016, [B. C. Sanders](#), “Symmetries: Salam’s universe to quantum information technologies (Public Lecture)”, The Lahore University of Management Sciences, Lahore, Pakistan.

## MEDIA COVERAGE

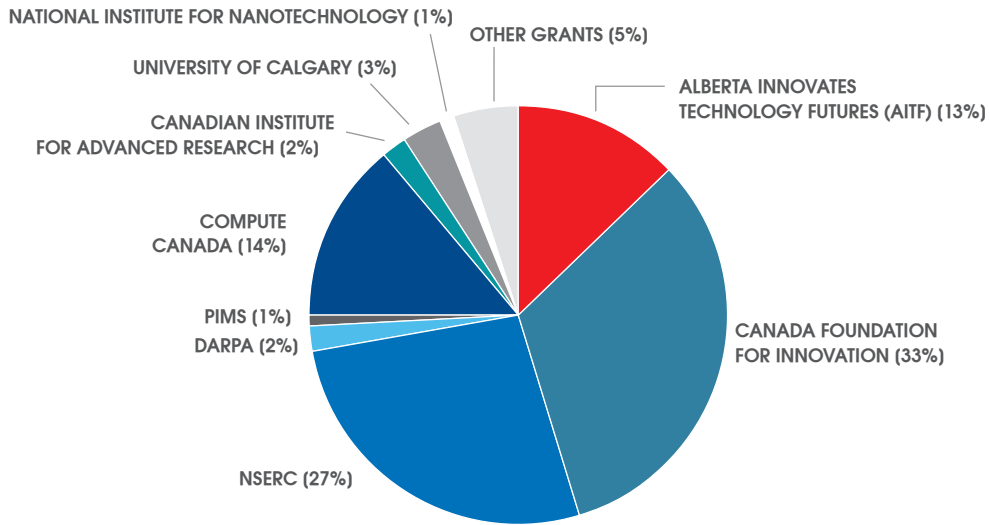
SOURCE	TITLE OF ARTICLE	LOCATION	DATE
UToday	Scientists push innovation frontier as part of \$333-million investment: Robert I. Thompson	online	29 May 2015
UToday	Symposium celebrates Nobel Prize-winning physicist Abdus Salam: Barry C. Sanders	online	12 Jun 2015
UToday	University awarded \$14.5 million in NSERC support: Christoph Simon	online	23 Jun 2015
Popular Science	The race to prove: Christoph Simon	online	29 Aug 2015
LaserFocusWorld.com	Russian physicists restore the entanglement of “untangled” quantum light: Alex I. Lvovsky	online	12 Oct 2015
Deepstuff.org	Physicists have learned how to restore the entanglement of “untangled” quantum light: Alex I. Lvovsky	online	13 Oct 2015
Offweek.com	Russian physicists restore the entanglement of “untangled” quantum light: Alex I. Lvovsky	online	13 Oct 2015
Physorg.com	Physicists have learned how to restore the entanglement of “untangled” quantum light: Alex I. Lvovsky	online	13 Oct 2015
PhotonicsOnline.com	Physicists have learned how to restore the entanglement of “untangled” quantum light: Alex I. Lvovsky	online	13 Oct 2015
Universities Canada	Christoph Simon and his quantum network research highlighted in Universities Canada Chair Elizabeth Cannon’s inaugural speech: Christoph Simon	online	28 Oct 2015
Newstalk770	Teleportation, time travel and escape from Black Holes: Seth Lloyd		18 Nov 2015
UToday	Teleportation, time travel and escape from Black Holes: Seth Lloyd	online	27 Nov 2015
IOPPublishing.org	New Editor-in-Chief for New Journal of Physics announced as Barry Sanders: Barry C. Sanders	online	9 Dec 2015
Toudiao.com	Pan team: Barry C. Sanders	online	8 Jan 2016
Globe and Mail	Antimatter experiment probes for cracks in nature’s mirror: R. I. Thompson	online	20 Jan 2016
Physicsworld.com	What it’s like collaborating with physicists in China: Barry C. Sanders	online	2 Feb 2016
Physicsworld.com	Shor’s algorithm is implemented using five trapped ions: Barry C. Sanders	online	4 Mar 2016

# finances

## RESEARCH GRANTS (UNAUDITED)

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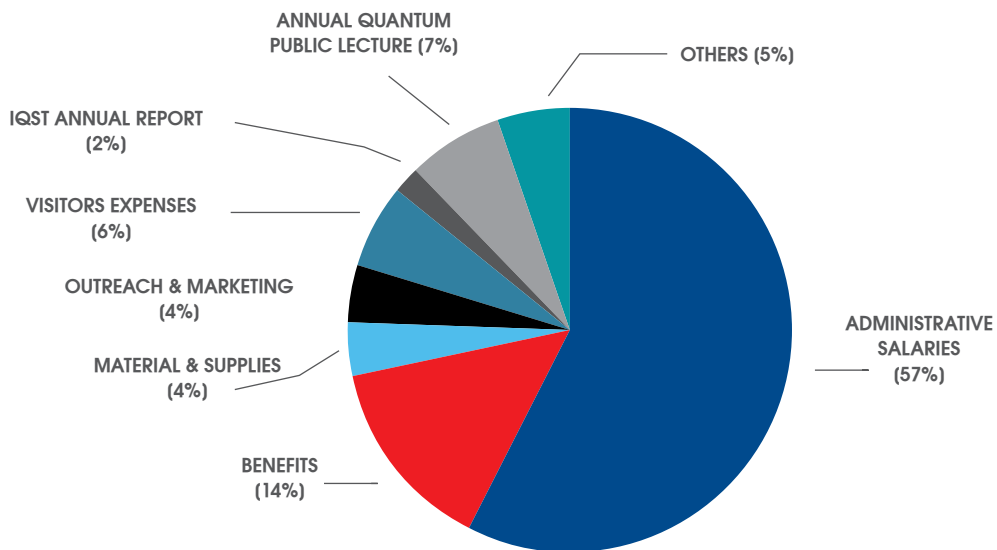
Total revenue: \$4,572K



## OPERATING ACCOUNT (UNAUDITED)

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Total expenditures: \$73K



## plans 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 1550 nm band using a microcavity.
- Implant and characterize spectral properties of SiV defects in diamond chips.
- Begin development of “next generation” optomechanical torque magnetometers based on silicon photonics technology.
- Publish proposal for detecting optical angular momentum states of light using optomechanical devices.

### DAVID FEDER

- Explore the possibility of performing measurement-based quantum computation on entangled resources in the form of symmetry-protected states.
- Study the properties of ultracold atomic gases in optical lattices and high-finesse optical cavities especially the emergence of spin-liquid and symmetry-protected phases driven by infinite cavity-mediated interactions and the potential realization extended Hubbard dynamics in one dimension.
- Completing work begun on continuous-time quantum walks in topologically ordered condensed matter systems.

## 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

- Determine the stability and reactivity of hemi-bonded complexes of OH radical and Cl<sup>-</sup> and Br<sup>-</sup> anions.
- Develop and test an effective interaction potential for OH radical in water that faithfully reproduces the key structural features observed in ab initio simulations.
- Explore the behaviour of OH radical in heterogeneous environments such as the surfaces of water and ice.
- Utilize advanced visualization techniques to explore various complex data sets arising from simulation trajectories, featuring atomic coordinates, electronics structure, and/or local parameters (e.g. particle mobility, energy, local structure).
- Determine the key features of the nucleation process of a clathrate hydrate crystal from a mixed CH<sub>4</sub> and H<sub>2</sub>S system of varying compositions.
- Test the reliability of empirical potential models against accurately determination of the potentials of mean force for the interaction of carboxylate ligands with Zn<sup>2+</sup> cations.

## ALEX LVOVSKY

- Employ a quantum-inspired technique to demonstrate resolution of an optical microscope beyond the Rayleigh limit.
- Use quantum conditional measurements to increase the size of a superposition of optical coherent states.
- Measure the optical mode of a spontaneously emitted photon.

## 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 CH<sub>3</sub>COOH-(He)<sub>4</sub> as the smallest superfluid cluster.
- Record and analyse laboratory spectra of H<sub>2</sub><sup>-</sup> 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 code for graphics processing units and implementation of the GGA+U methodology for strongly correlated systems.
- 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; complete work on artificial carbonic anhydrases for possible use in converting carbon dioxide to formic acid and initiate studies of the heme peroxidases in order to verify, or falsify, the presence of electron density circuits.

### **BARRY SANDERS**

- Develop a wavelet-based quantum algorithm for quantum computer simulation of a multi-scale renormalizable quantum field theory.
- Devise a feasible continuous-variable quantum optical realization of relativistic spacetime replication of quantum information.
- Construct quantum-control procedures for realizing a broad set of three-qubit gates for three-transmon systems in superconducting circuitry.
- Determine how to postselect a controlled-controlled-not gate with a ten-photon entangled state.
- Create a formal connection between reinforcement learning and a large class of quantum control and adaptive quantum metrology problems.

### **YUJUN SHI**

- Investigate chemical vapor deposition chemistry of silicon nitride using aminosilanes as novel precursors.
- Use resonance-enhanced multiphoton ionization techniques to characterize small silicon carbon clusters.
- Explore the pulsed-laser dewetting method for the formation of core-shell bimetallic nanoparticles.
- Advance the development of a theoretical model in characterizing the temperature profile in the process of pulsed laser dewetting.

### **CHRISTOPH SIMON**

- Derive conditions to create entanglement of many large atomic ensembles.
- Propose techniques to create cat states via quantum walks and Rydberg-state interactions in cold atoms.

- Determine how to implement non-destructive photon detection with single rare-earth ions and with rare-earth ion ensembles.
- Study the potential realization of room-temperature quantum repeaters based on nitrogen-vacancy centres in diamond.
- Explore the possibility of light conduction in axons.
- Propose the creation of chimera states in Bose-Einstein condensates.

### **ROBERT THOMPSON**

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

### **WOLFGANG TITEL**

- 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**

- Design experiments and specialized cells to pursue the characterization of amorphous metal-oxide catalysts in in-situ synchrotron x-ray absorption experiments.
- Characterization of semiconducting amorphous metal oxide for integration in photovoltaic devices.
- Pursue the development of nanoscale magnetic nanoparticles for magnetic resonance imaging applications.

# appendices

# APPENDIX 1: CHARTER OF THE INSTITUTE FOR QUANTUM SCIENCE AND TECHNOLOGY

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## 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.

## APPENDIX 2: IQST USE OF SPACE

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### OFFICES

ROOM NUMBER	SIZE (SQUARE METER)	ROOM NUMBER	SIZE (SQUARE METER)
BI 555	16	SB 314	34
BI 556	17	SB 315	16
BI 557	17	SB 316	32
BI 558	17	SB 317	9
ICT 625A	13	SB 318	53
ICT 627	13	SB 319	19
ICT 653	13	SB 323	12
MS 374	13	SB 417	12
MS 376	12	SB 427	25
MS 436	13	SB 429A	12
SA 111	71	SB 431	12
SB 117	45	SB 508 (partial)	55
SB 135	18	SB 512 (partial)	64
SB 301	12	SB 525	16
SB 303	24	SB 531	12
SB 306	54	SB 535	12
SB 307	12	SB 536 (partial)	33
SB 312	56	SB 537	12
SB 313	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 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



# UNIVERSITY OF CALGARY INSTITUTE FOR QUANTUM SCIENCE & TECHNOLOGY

[iqst.ca](http://iqst.ca)

t: +1 403 220 4403

f: +1 403 210 8876

e: [iqstinfo@ucalgary.ca](mailto:iqstinfo@ucalgary.ca)

UNIVERSITY OF CALGARY

SCIENCE B BUILDING

ROOM 307

2500 UNIVERSITY DRIVE NW

CALGARY, AB T2N 1N4