**Vision**

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

**Mission**

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

**Key Facts**

- 18 postdoctoral fellows
- 72 graduate students
- 26 undergraduate students
- 44 invited talks at national and international conference/workshops including three keynotes and two plenary talks
- 6.56 million dollars in research funds
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The Institute for Quantum Science and Technology hosts 15 research groups and about 130 academic members including professors, research staff and students. The Institute has four research themes: molecular modelling, nanotechnology, quantum information and computing, and quantum optics, across the four departments of Chemistry, Computer Science, Mathematics and Statistics, and Physics and Astronomy. In recent years, the Institute has effectively expanded to the provincial level through the growth of the Quantum Alberta initiative, which has three sites: the Universities of Alberta, Calgary and Lethbridge. The Institute for Quantum Science and Technology maintains a strong identity in Calgary but also exists as one of three Quantum Alberta branches.

The Institute is pleased to welcome Shabir Barzanjeh and Timothy Friesen as a Faculty member. Shabir moved from the Institute of Science and Technology Austria to the University of Calgary Institute for Quantum Science and Technology in 2020. Shabir’s main experimental research directions are exploring quantum coherence and quantum interfaces in electro-and optomechanical systems, and developing superconducting circuit quantum electrodynamics. Tim joins the Institute after having worked at the Antiproton Decelerator facility at the European Organization for Nuclear Research (CERN). Tim’s research focuses on trapping particle, microwave techniques, and annihilation detection for high-precision spectroscopy and gravitational mass measurements on antihydrogen.

The Institute for Quantum Science and Technology has enjoyed a successful year of research and training during the 2019/2020 year. Members of the Institute had 72 papers published in refereed journals and proceedings including seven papers appearing in the top-tier journals of Nature (1), Physical Review Letters (2), Nature Communications (1), Physical Review X (1), and Optica (2). The Institute attracted 21 new students into quantum graduate studies programs in 2019/2020. Seven masters students graduated and five doctoral students completed their degrees. The Institute hosted 19 postdoctoral researchers with four
being recipients of national and provincial postdoctoral fellowship including the NSERC Postdoctoral Fellowship (1), the Alberta Innovates Eyes High Postdoctoral Fellowship (2) and the Alexander von Humboldt Feodor Lynen Research Fellowship–Germany (1).

Success of the Institute is underpinned by support for training and infrastructure with especially notable support from the Natural Sciences and Engineering Research Council (NSERC) Collaborative Research and Training Experience (CREATE) Program called Quanta, which is headquartered at the University of Alberta. This program supports some University of Calgary graduate students. Furthermore, quantum activity is advanced significantly by a Canada Foundation for Innovation (CFI) grant for quantum technology, led by the University of Calgary. The Institute is home to the Alberta Government’s Ministry of Job, Economy and Innovation’s Major Innovation Fund, which supports quantum science and technology at the Universities of Calgary, Alberta and Lethbridge. This provincial funding supports 24 graduate students and six postdoctoral researchers at the University of Calgary.

The Institute continues to fulfill its mission as a Faculty of Science Institute and deliver outcomes matching Faculty expectations with respect to the quantum aspect of the Faculty’s Grand Challenge on “Unlocking Our Digital Future”. Furthermore, the Institute has a provincial leadership role through the Quantum Alberta initiative, which brings together the province’s quantum science and technology researchers under the umbrella of one consortium. As quantum research and development ramps up in Canada and globally, the Institute has a key role to play in ensuring that Calgary continues to be strong on the world stage for quantum science and technology.

Barry Sanders
Director, IQST
Message from the Incoming Chair

Since more than a decade, and currently accelerated because of COVID-19, the world is experiencing industrial revolutions powered by digital and advanced technologies. Social interactions, education, health, and transportation, just to name a few, are all being reshaped and transformed because of advanced technologies. Over the coming decade, how we live, work, and play will continue to rapidly evolve because of multiple technological revolutions.

While others will follow or be shaped by this tsunami of change, the University of Calgary’s digital initiative, including the research being done at the Institute for Quantum Science and Technology (IQST), will drive transformations though its transdisciplinary approach to developing advanced technologies in quantum science while growing the province’s research and innovation ecosystem.

The high value placed on quantum science and technology is evidenced in the Faculty of Science strategic plan, namely under the Unlocking Our Digital Future Grand Challenge. Furthermore, the new Growth through Focus plan of the University of Calgary has selected “Exploring Digital Worlds” as one of only four focus areas. This Annual Report highlights how the Institute for Quantum Science and Technology is at the forefront of making great strides towards achieving Faculty of Science and University of Calgary goals for a digital future.

The success of the work of IQST is in part evident in funding announcements such as the recent news of Barry Sanders being awarded $3 million through the Major Innovation Fund. This major financial support will help the University of Calgary’s Quantum Alberta network take advantage of the province’s academic strengths and investment opportunities to establish Alberta as a leader in quantum technologies.

The IQST team brings a deep commitment for advancing quantum science applications that improve human existence. Through their continued efforts of developing curiosity, critical thought and disciplinary excellence necessary to solve the challenges of the future, the IQST team is educating our students and alumni to bring positive impact to society. We are proud to have IQST as one of the research leaders in the Faculty of Science and congratulate them to another highly successful year.

Bernhard Mayer
Interim Dean
Chair, Board of Directors
RESEARCH ACHIEVEMENTS

The Institute for Quantum Science and Technology (IQST) has significant research achievements over the past year. The following exposition of achievements provides a sample of the kinds of activities and breakthroughs seen within IQST.

Nasser Moazzen-Ahmadi’s group has produced exciting results on the water-carbon monoxide dimer, including spectra and ab initio calculations, and introducing Coriolis interactions to explain certain anomalous energies, and this result was published in Physical Chemistry Chemical Physics. This article is an editor’s choice, signifying that the article is one of the journal’s outstanding publications.

Gilad Gour’s Physical Review Letters article on quantifying a dynamical quantum resource showed that generalizing relative entropy of a resource from states to channels has at least six generalizations with fascinating properties and involving a novel smoothing technique for channels that does not apply to states. Gour’s definitive review article on quantum resource theories was published in Reviews of Modern Physics, which is the top reviews journal in physics. Gour’s leadership in quantum resource theories was acknowledged through giving an invited tutorial at the 2020 Quantum Information Processing Conference, which is the top annual conference for theoretical quantum information.

Christoph Simon is the lead theorist on a collaboration that showed erbium ions, inserted into the best-known host crystal, have better spin coherence in the excited state compared to the ground state, which was published in Physical Review Letters, and they propose a type of quantum transduction that exploits this advantage. Simon’s collaboration with former Quantum Alberta member Alex Lvovsky led to an Optica paper reporting entanglement of distinct states of light, each containing over a hundred million photons.

Here the ALPHA project achieves a precise measurement of the anti-Hydrogen Lamb shift, which is fully consistent with quantum electrodynamics calculations for antimatter.

Paul Barclay’s group demonstrated optomechanically amplified wavelength conversion in diamond microcavities, with the results published in *Optica*, and this technique could enable interfacing quantum devices operating at different spectral wavelengths. Notably they report frequency up-conversion with 45% internal conversion efficiency and have successfully incorporated optical amplification.

Barry Sanders provided key theoretical input for two landmark experiments: an experimental demonstration of quantum fully homomorphic encryption published in *Physical Review X* and for emergent momentum-time skyrmions in parity-time-symmetric non-unitary quench dynamics published in *Nature Communications*.

**AWARDS**

**International Awards**

*Alexander von Humboldt Feodor Lynen Research Fellowship – Germany*

Martin Schon

*Study Abroad Studentship, Leverhulme Trust - United Kingdom*

Adam Powell

**National Awards**

*CAP Herzberg Medal 2019*

Paul E. Barclay

*MITACS Globalink*

Shudipto Kazi Amin

Bo Fu

Rajat Kumar

*NSERC Alexander Graham Bell Canada Graduate Scholarship – Doctoral*

Stephen Wein
NSERC Alexander Graham Bell Canada Graduate Scholarship – Master
Dante Renato Bencivenga
Janet Leahy

NSERC Postdoctoral Fellowship
Ghazal Haji Salem

NSERC USRA
Xining Chen
Nathan Fischer
Evan Johnson

Nova Chemicals Graduate Scholarship
Rishabh Shukla

Provincial Awards

Alberta Graduate Excellence Scholarship
Katelynn Daly
Alison Fulton
Salini Karuvade
Rishabh Shukla
Zhan Yu

University of Calgary Awards

Alberta Innovates Eyes High Postdoctoral Fellowship
Asha Yadav
Joseph Losby

Alberta Graduate Students Travel Incentive
Archismita Dalal

Canadian Queen Elizabeth II Diamond Jubilee Scholarships (Advanced Scholars)
Nehad AttaElmanan AbdElrahim Mabrouk

Department of Physics and Astronomy Graduate Student Excellence Award
Aaron Barclay

Eyes High International Doctoral Scholarship
Sumit Goswami

Faculty of Graduate Studies Travel Award – International Student
Gaurav Saxena
Parisa Zarkeshian

ii’taa’poh’to’p Graduate Scholarship
Katelynn Daly

Provost’s Doctoral Scholarship
Shudipto Kazi Amin
KEY PERFORMANCE INDICATORS

GRADUATE STUDENT ENROLMENT AND QUALITY OF ENTRANTS

PUBLICATIONS AND PRESENTATIONS
AWARDS (CHAIRS, FELLOWSHIPS AND SCHOLARSHIPS)

TRAINEE DESTINATIONS AFTER IQST
VISTORS

- Professors: 15
- Postdoctoral Fellows: 3
- Students: 9
Research Groups

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.

Integrated Hybrid Quantum Circuits
Focuses on the reversible quantum interface between the superconducting circuits and quantum optical systems. In our lab we develop quantum communication technology that is integrable with superconducting processors for building large-scale quantum networks.
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.

TESTING OF FUNDAMENTAL SYMMETRIES WITH ANTIMATTER
Experimental testing of symmetries between matter and antimatter primarily through study of (anti)hydrogen in collaboration with the ALPHA (Antihydrogen Laser Physics Apparatus) experiment at CERN. We focus on the development of particle traps, microwave techniques, and annihilation detection for high-precision spectroscopy and gravitational mass measurements on antihydrogen.
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.

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.
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.

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.
QUANTUM CLOUD LAB
Develops experimental capabilities that will lead to practical implementations of quantum links forming the basis of quantum networks that connect distant quantum devices. Research into quantum-key distribution over fibre and free-space channels, non-classical light sources, and quantum memory based on solid-state materials such as rare-earth ion doped crystals.

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 the context of high performance computing.
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.

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.
THEORETICAL QUANTUM OPTICS
Applies 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).

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.
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.
INSTITUTE STRUCTURE

The Institute is managed on a day-to-day level by the Institute Director and the Institute Administrator. 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 Scientist, Raytheon BBN Technology

Sir Peter Knight
Principal, The Kavli Royal Society International Centre

Barry C. Sanders
Professor, Department of Physics and Astronomy, University of Calgary

COUNCIL

Faculty Members

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

Shabir Barzanjeh
(joined January 2020) Assistant Professor, Department of Physics and Astronomy, University of Calgary

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

Timothy Friesen
(joined February 2020) Assistant Professor, Department of Physics and Astronomy, University of Calgary

Peter Kusalik
Professor, Department of Chemistry, University of Calgary

Nasser Moazzen-Ahmadi
Professor, Department of Physics and Astronomy, University of Calgary

Daniel Oblak
Assistant Professor, Department of Physics and Astronomy, University of Calgary

Barry C. Sanders
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

Dennis Salahub
Professor Emeritus, Department of Chemistry, University of Calgary

Robert I. Thompson
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

**Daniel Trad**  
Associate Professor, Department of Geoscience, University of Calgary

**Richard Zach**  
Professor, Department of Philosophy, University of Calgary

**Postdoctoral Fellows**

Abhijeet Alase  
Morteza Amirani  
Rogelio Delgado Venegas  
Jiri Hostas  
Vinaya Kumar Kavatamane Rathnakara  
David Lake  
Gustavo de Oliveira Luiz (completed June 2019 → researcher, nanoFAB)  
Joseph Losby  
Matthew Mitchell (resigned March 2020 → postdoc, University of British Columbia)  
Nicholas Randell  
Ghazal Haji Salem  
Carlo Maria Scandolo  
Martin Schon  
Denis Sukachev  
Maryam Taheri  
Yunlong Xiao (completed August 2019 → postdoc, Nanyang Technological University)  
Asha Yadav  
Jun Zhang (resigned September 2019 → postdoc, University of New South Wales)  
Wei Zhang (completed March 2020)

**Research Associates/Coordinators/Engineers**

Roollah Ghobadi (Research Associate)

**Graduate Students (PhD Program)**

Shudipto Kazi Amin  
Mohsen Bagherimehrab  
Aaron Barclay  
Bishnupada Behera  
Stephanie Bovincini  
Oliver Calderon  
Archismita Dalal  
Katelynn Daly  
Balarama Sridhar Dwadasi  
Carlos Enriquez-Victorero  
Andrew Evans  
Alison Fulton  
Sumit Goswami  
Masoud Habibi Davijani  
Chris Healey (graduated August 2019)  
Lizandra Barrios Herrera  
Jiawei Ji  
Hamidreza Kaviani  
Faezeh Kimiaee Asadi  
Sourabh Kumar  
Prasoon Kumar Shandilya  
Salini Karuvade  
David Lake (graduated December 2019 → postdoc, University of Calgary)  
Pascal Lefebvre  
Nehad AttaElmanan AbdElrahim Mabrouk
Institute for Quantum Science and Technology

Matthew Mitchell (graduated November 2019→postdoc, University of Calgary)
Eugene Moiseev
James Moncreiff
Mahmood Noweir
Eduardo Paez
Gaurav Saxena
Shahrzad Taherizadegan
Arina Tashchilina (graduated November 2019→postdoc, University of Alberta)
Seyed Shakib Vedaie
Lei Wang
Stephen Wein
Pooja Woosaree
Yadong Wu (graduated November 2019→postdoc, the University of Hong Kong)
Hadi Zadeh Haghighi
Parisa Zarkeshian

Graduate Students (MSc Program)
Omid Aligholamioskoee
Eric Ampong (graduated August 2019)
Dante Renato Bencivenga
Alex Cameron (graduated December 2019)
Anustup Das
Jake Flowerdew (graduated September 2019→PhD, University of Oxford)
Jianing Geng
Masoud Habibi Davijani (graduated August 2019→PhD, University of Calgary)
Mojtaba Komeili
Murali Krishna
Prasoon Kumar Shandila (transferred September 2019→PhD, University of Oxford)
Janet Leahy
Shang Li (graduated December 2019)
Pengcheng Liao
Zhuohao (Ray) Liu
Xinyuan Ma
Blaine Jeffrey McLaughlin
Robert Riley Nerem
Joan Ngure
Yasser Novo-Fernández
Kimberley Ann Owen
Adam Powell
Hamza Qureshi (graduated December 2019→quantum applications scientist, Agnostiq Labs)

Kuntal Sengupta
Sara Shafiei Alavijeh
Rishabh Shukla
Deepesh Singh (transferred March 2020→PhD, University of Queensland)
Prathviraj Umesh (graduated October 2019→PhD, Institute for Quantum Optics and Quantum Information Austria)
Taozhe (Evan) Wu
Yufeng Wu
Yanjuan Xiong
Zhan Yu

Undergraduate Students
Benjamin Appleyard (PHYS598)
Hemanto Bairagi (PHYS598)
Karabee Batta (Summer Internship)
Xining Chen (NSERC USRA)
Kyle Ostrander (CHEM502)
Travis Gartner (PHYS599)
Ben Godwin (CHEM502)
Elliot Evans (CPSC502)
Nathan Fischer (NSERC USRA)
Bo Fu (MITACS Globalink)
Alex Hickey (NSERC USRA & PHYS598)
Evan Johnson (NSERC USRA)
Victoria Johnson (PHYS598)
Rajat Kumar (MITACS Globalink)
Janet Leahy (CPSC502)
Linh Ly (PURE Award)
Kyle Ostrander (Research Assistant)
Rana Pratap Simh Mukthavaram (Summer Internship)
Kenneth Sharman (Summer Student & PHYS599)
Jordan Smith (PHYS 598)
Antoine Stellino (Research Internship)
Zach Thomson (CHEM402)
Ruchir Tullu (Summer Undergraduate Student)
Camila Suarez Viltres (Summer Undergraduate student)
Yuxuan Wang (CHEM402)
Rana Zibakhshshabgahi (PHYS598)

Administration
Xining Chen (Part-time Webmaster)
Jing (Nancy) Lu (Administrator)
Publications

REFEREED JOURNAL PUBLICATIONS (PUBLISHED)


A. J. Barclay, A. R. W. McKellar and N. Moazzen-Ahmadi, “Spectra of the D2O dimer in the O-D fundamental stretch region:


M. K. Chini, S. G. Srinivasan, N. K. Tailor, Yukta, D. R. Salahub and S. Satapathi, “Lead-free, stable mixed halide double perovskites \( \text{Cs}_x\text{AgBiBr}_6 \) and \( \text{Cs}_x\text{AgBiBr}_6\text{-Cl}_x \): A detailed theoretical and experimental study”, *Chemical Physics* **529**(11): 110547 (8 pp.), January 2020.


REFEREEED CONFERENCE PROCEEDINGS


BOOKS AND CHAPTERS


STUDENT THESIS

E. Ampong, “Decomposition of hexamethyldisilazane on hot metal filaments and its gas-phase chemistry in a hot-wire chemical vapor deposition reactor” (MSc thesis), September 2019.

A. C. Cameron, “Quantum phase characterization via entanglement scaling in fermionic quantum wires” (MSc thesis), October 2019.
J. Flowerdew, “Optimising ion transport in a thermal ionisation mass spectrometer and plasma ion source using Monte Carlo simulations” (MSc thesis), September 2019.

M. Habibi Davijani, “Continuous-variable ramp quantum secret sharing with Gaussian states and operations” (MSc thesis), April 2019.


INVITED PRESENTATIONS AT WORKSHOPS/CONFERENCES


INTELLECTUAL PROPERTY

12 July 2019, F. Kimiae Asadi, “Rare-earth ions quantum networks”, SQUARE Summer School, Karlsruhe, Germany, 10-12 July 2019.
1 August 2019, B. C. Sanders, “Treasure hunt for computational problems that can be solved faster by quantum annealing”, 2019 Joint Statistical Meetings (JSM 2019), Denver, United States of America, 27 July-1 August 2019.
6 September 2019, B. C. Sanders, “Machine learning for quantum control”, Quantum Machine Learning and Data Analytics Workshop, Purdue University, United States of America, 5-6 September 2019.
2 December 2019, B. C. Sanders, “How to use a quantum computer II” (tutorial), International Workshop on Quantum Computing, Information Processing and Machine Learning, National Taiwan University, Taiwan, 2-4 December 2019.

2 December 2019, B. C. Sanders, “How to use a quantum computer I” (tutorial), International Workshop on Quantum Computing, Information Processing and Machine Learning, National Taiwan University, Taiwan, 2-4 December 2019.

3 December 2019, B. C. Sanders, “Learning for quantum control” (keynote), International Workshop on Quantum Computing, Information Processing and Machine Learning, National Taiwan University, Taiwan, 2-4 December 2019.


COLLABORATIONS

International Institutions

Aarhus University, Denmark
Ben-Gurion University of the Negev, Israel
California Institute of Technology, United States of America
Centre national de la recherche scientifique, France
Centro de Investigación y de Estudios Avanzados (CINVESTAV), Mexico
Cockcroft Institute, United Kingdom
Colorado School of Mines, United States of America
Eastern Illinois University, United States of America
European Organization for Nuclear Research (CERN), Switzerland
Federal University of Rio De Janeiro, Brazil
Foshan University, People’s Republic of China
Grand Accélérateur National d’Ions Lourds, France
GSI Helmholtz Centre for Heavy Ion Research, Germany
Henan University of Technology, People’s Republic of China
Indian Institute of Technology – Roorkee, India
Korean Institute of Science and Technology, South Korea
Louisiana State University, United States of America
Marquette University, United States of America
Max Planck Institute for Nuclear Physics, Germany
Missouri University of Science and Technology, United States of America
Montana State University, United States of America
Nanyang Technological University, Singapore
Politecnico di Milano, Italy
Purdue University, United States of America
Qingdao Institute of Marine Geology, People’s Republic of China
Radboud University, the Netherlands
Raman Research Institute, India
Shandong University, People’s Republic of China
Sharif University of Technology, Iran
Soreq Nuclear Research Centre, Israel
Stockholm University, Sweden
Swansea University, United Kingdom
Tata Research Development and Design Centre, India
Technische Universität Dresden, Germany
Technische Universität München, Germany
The Russian Quantum Center, Russia
Università Ca’ Foscari Venezia, Italy
Université catholique de Louvain, Belgium
Université Paris Sciences et Lettres, France
Université Paris-Saclay, France
Université Paris-Sud, France
Université Paul Sabatier, France
University College Dublin, Ireland
University of California at Berkeley, United States of America
University of Electronic Science and Technology China, People’s Republic of China
University of Giessen, Germany
University of Groningen, Germany
University of Heidelberg, Germany
University of Oxford, United Kingdom
University of Science and Technology of China, People’s Republic of China
University of Science and Technology, South Korea
University of Technology Sydney, Australia
University of York, United Kingdom

National Institutions
Lakehead University
Queen’s University
TRIUMF
Simon Fraser University
University of Alberta
University of British Columbia
University of Manitoba
University of Victoria
University of Waterloo
York University

Industrial & Government
1QBit
City of Calgary
Hewlett-Packard
National Research Council of Canada (Ottawa)
### VISITORS

<table>
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<tr>
<th>NAME</th>
<th>INSTITUTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alán Aspuru-Guzik</td>
<td>University of Toronto</td>
</tr>
<tr>
<td>Karabee Batta</td>
<td>Birla Institute of Technology and Science (BITS Pilani)</td>
</tr>
<tr>
<td>Aritra Das</td>
<td>Indian Institute of Technology and Science (BITS Pilani)</td>
</tr>
<tr>
<td>Niel de Beaudrap</td>
<td>University of Oxford</td>
</tr>
<tr>
<td>Hubert de Guise</td>
<td>Lakehead University</td>
</tr>
<tr>
<td>André Fougères</td>
<td>National Optics Institute</td>
</tr>
<tr>
<td>Bo Fu</td>
<td>Shandong University</td>
</tr>
<tr>
<td>Xianxin Guo</td>
<td>Hong Kong University of Science and Technology</td>
</tr>
<tr>
<td>Karol Horodecki</td>
<td>University of Gdaňsk</td>
</tr>
<tr>
<td>Mahnaz Jafarzadeh</td>
<td>Urmia University</td>
</tr>
<tr>
<td>Kyle Jordan</td>
<td>University of Victoria</td>
</tr>
<tr>
<td>Sejeong Kim</td>
<td>University of Technology Sydney</td>
</tr>
<tr>
<td>Na Lin</td>
<td>Shandong University</td>
</tr>
<tr>
<td>Alberto Marino</td>
<td>University of Oklahoma</td>
</tr>
<tr>
<td>Hridya Meppully Sasidharan</td>
<td>S. V. National Institute of Technology</td>
</tr>
<tr>
<td>Varun Narasimhachar</td>
<td>Nanyang Technological University</td>
</tr>
<tr>
<td>Yi Peng</td>
<td>Institute of Physics, Chinese Academy of Sciences</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>NAME</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Haleema Sadia Qureshi</td>
<td>COMSATS University Islamabad</td>
</tr>
<tr>
<td>Jocelyn Read</td>
<td>California State University, Fullerton</td>
</tr>
<tr>
<td>Joe Salfi</td>
<td>University of British Columbia</td>
</tr>
<tr>
<td>Yuval Sanders</td>
<td>Macquarie University</td>
</tr>
<tr>
<td>Yi Shen</td>
<td>Beihang University</td>
</tr>
<tr>
<td>Barak Shoshany</td>
<td>Perimeter Institute for Theoretical Physics</td>
</tr>
<tr>
<td>Antoine Stellio</td>
<td>Institut national des sciences appliquées de Rouen</td>
</tr>
<tr>
<td>Shakir Ullah</td>
<td>COMSATS University Islamabad</td>
</tr>
<tr>
<td>Ming-Ming Wang</td>
<td>Xi’an Polytechnic University</td>
</tr>
<tr>
<td>Marcelo Wu</td>
<td>National Institute of Standards and Technology &amp; University of Maryland</td>
</tr>
<tr>
<td>Jianwei Xu</td>
<td>Northwest A&amp;F University</td>
</tr>
<tr>
<td>Siren Yang</td>
<td>Dalian University of Technology</td>
</tr>
<tr>
<td>Jeff Young</td>
<td>University of British Columbia</td>
</tr>
<tr>
<td>COURSE NAME</td>
<td>INSTRUCTOR</td>
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<tr>
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</tr>
<tr>
<td>CPSC601 Special Topics in Computer Science: Boolean Functions</td>
<td>P. Høyer</td>
</tr>
<tr>
<td>CPSC619 Quantum Computing</td>
<td>P. Høyer</td>
</tr>
<tr>
<td>PHYS617 Relativistic Quantum Mechanics</td>
<td>B. C. Sanders</td>
</tr>
<tr>
<td>CHEM 619.09 Advanced Mass Spectrometric Techniques</td>
<td>Y. J. Shi</td>
</tr>
</tbody>
</table>
## Services and Outreach

### CONFERENCES/WORKSHOPS

<table>
<thead>
<tr>
<th>MEMBERS</th>
<th>COMMITTEE</th>
<th>CONFERENCE/WORKSHOP</th>
<th>LOCATION</th>
<th>DATES</th>
</tr>
</thead>
<tbody>
<tr>
<td>P. E. Barclay</td>
<td>Co-chair</td>
<td>CLEO Special Symposium on Coupling Artificial Atoms to Nano- and Opto-mechanical Systems</td>
<td>San Jose, United States of America</td>
<td>5-10 May 2019</td>
</tr>
<tr>
<td>B. C. Sanders</td>
<td>Organizer</td>
<td>BIRS Workshop on New Developments in Quantum Machine Learning</td>
<td>Banff, Canada</td>
<td>12-17 Jul 2020</td>
</tr>
</tbody>
</table>

### PROFESSIONAL SERVICES

<table>
<thead>
<tr>
<th>NAME</th>
<th>ROLE</th>
<th>JOURNAL/SOCIETY/INSTITUTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>P. E. Barclay</td>
<td>Associate Editor</td>
<td>Optics Letters</td>
</tr>
<tr>
<td>D. L. Feder</td>
<td>Member, Editorial Board</td>
<td>PLoS One</td>
</tr>
<tr>
<td>P. G. Kusalik</td>
<td>Member, Advisory Board, US Department of Energy Frontier Research Centre “Fluid Interface Reactions, Structures and Transport (FIRST)”</td>
<td>Oakridge National Laboratory</td>
</tr>
<tr>
<td>N. Moazzen-Ahmadi</td>
<td>Guest Editor, Special Issue “Spectroscopic Characterization of Noncovalent Interactions”</td>
<td>Journal of Molecular Spectroscopy</td>
</tr>
<tr>
<td>N. Moazzen-Ahmadi</td>
<td>Member, Editorial Board</td>
<td>Journal of Molecular Spectroscopy</td>
</tr>
<tr>
<td>D. R. Salahub</td>
<td>Member, Editorial Board</td>
<td>Advances in Quantum Chemistry</td>
</tr>
<tr>
<td>NAME</td>
<td>ROLE</td>
<td>JOURNAL/SOCIETY/INSTITUTION</td>
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</tr>
<tr>
<td>D. R. Salahub</td>
<td>College of Reviewers</td>
<td>Canadian Institutes of Health Research</td>
</tr>
<tr>
<td>D. R. Salahub</td>
<td>Member, Editorial Board</td>
<td>Computation</td>
</tr>
<tr>
<td>D. R. Salahub</td>
<td>Vice Chair, Editorial Board</td>
<td><em>Interdisciplinary Science: Computational Life Sciences</em></td>
</tr>
<tr>
<td>D. R. Salahub</td>
<td>Member, Editorial Board</td>
<td><em>Journal of Computational Chemistry</em></td>
</tr>
<tr>
<td>D. R. Salahub</td>
<td>Member, Academic Editorial Board</td>
<td><em>PLoS One</em></td>
</tr>
<tr>
<td>B. C. Sanders</td>
<td>Chief Scientist</td>
<td>Creative Destruction Lab (CDL) Toronto</td>
</tr>
<tr>
<td>B. C. Sanders</td>
<td>Lab Scientist</td>
<td>Creative Destruction Lab (CDL) Rockies</td>
</tr>
<tr>
<td>B. C. Sanders</td>
<td>Member, Editorial Board</td>
<td>IOP ebooks™</td>
</tr>
<tr>
<td>B. C. Sanders</td>
<td>Chair, Steering Committee</td>
<td>Quantum Africa Conference Series</td>
</tr>
<tr>
<td>B. C. Sanders</td>
<td>Editor-in-Chief</td>
<td><em>New Journal of Physics</em></td>
</tr>
<tr>
<td>Y. J. Shi</td>
<td>Associate Editor</td>
<td><em>Canadian Journal of Chemistry</em></td>
</tr>
<tr>
<td>Y. J. Shi</td>
<td>Guest Editor, Special Issue</td>
<td><em>Thin Solid films</em></td>
</tr>
<tr>
<td>C. Simon</td>
<td>Member, Physics Advisory Committee</td>
<td>Fermi National Accelerator Laboratory</td>
</tr>
<tr>
<td>S. Trudel</td>
<td>Director</td>
<td>Click Materials Corp.</td>
</tr>
<tr>
<td>S. Trudel</td>
<td>Chair, Materials Division</td>
<td>Chemical Institute of Canada</td>
</tr>
<tr>
<td>S. Trudel</td>
<td>Members, Scholarships and Fellowships Selection Committee for Chemical, Biomedical and Materials Science Engineering</td>
<td>Natural Sciences and Engineering Research Council of Canada</td>
</tr>
</tbody>
</table>
QUANTUM PUBLIC LECTURE

The Quantum Public Lecture serves 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 Alán Aspuru-Guzik from University of Toronto delivered a public lecture titled “Quantum algorithms for near-term quantum computers” to about 180 persons on 22 October 2019, and this event was supported by the Faculty of Science Alumni Relations team as a joint outreach effort. This public lecture was simulcasted at the Universities of Alberta and Lethbridge.

OUTREACH LECTURES


7 July 2019, B. C. Sanders, “Science through the lens of Imam Jafar al-Sadiq (as)”, 17th Annual Universal Muslim Association of America Conference (UMAA), Washington DC, United States of America, 5-7 July 2019.


21 January 2020, B. C. Sanders, “Our quantum century” (dinner speech), Creative Destruction Lab (CDL) Rockies, Calgary, Canada.
## MEDIA COVERAGE

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>TITLE OF ARTICLE</th>
<th>DATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Illinois.edu</td>
<td>CIRI physicists harness quantum computing to safeguard critical infrastructure: Barry C. Sanders</td>
<td>8 May 2019</td>
</tr>
<tr>
<td>CAP.ca</td>
<td>The 2019 CAP Herzberg Medal is awarded to Paul Barclay: Paul E. Barclay</td>
<td>8 May 2019</td>
</tr>
<tr>
<td>CCIDCOM.com</td>
<td>ITU Workshop on Quantum Information Technology (QIT) for Networks is Held in Shanghai: University of Calgary</td>
<td>5 Jun 2019</td>
</tr>
<tr>
<td>Edaily.co.kr</td>
<td>International Conference on Quantum Computing in Seoul from 11 to 12 July 2019: Barry C. Sanders</td>
<td>11 Jul 2019</td>
</tr>
<tr>
<td>The Science Monitor</td>
<td>International Conference on Quantum Computing in Seoul from 11 to 12 July 2019: Barry C. Sanders</td>
<td>12 Jul 2019</td>
</tr>
<tr>
<td>Geo Pakistan</td>
<td>Quantum Information Summer School (QISS) 2019 at Institute of Business Administration (IBA) Karachi (TV interview 1:16:10 - 1:21:54): Barry C. Sanders</td>
<td>18 Jul 2019</td>
</tr>
<tr>
<td>The Washington Post</td>
<td>The quantum revolution is coming, and Chinese scientists are at the forefront: Barry C. Sanders</td>
<td>18 Aug 2019</td>
</tr>
<tr>
<td>3CCorp.net</td>
<td>The quantum revolution is coming, and Chinese scientists are at the forefront: Barry C. Sanders</td>
<td>19 Aug 2019</td>
</tr>
<tr>
<td>NDTV</td>
<td>The quantum revolution is coming, and Chinese scientists are at the forefront: Barry C. Sanders</td>
<td>19 Aug 2019</td>
</tr>
<tr>
<td>Independent.co.uk</td>
<td>Trump administration nervous after China takes major step forward in quantum technology: Barry C. Sanders</td>
<td>19 Aug 2019</td>
</tr>
<tr>
<td>The Washington Post</td>
<td>China's top quantum scientist has ties to the country's defense companies: Barry C. Sanders</td>
<td>26 Dec 2019</td>
</tr>
<tr>
<td>Sudanese News Agency (SUNA)</td>
<td>A prominent Canadian physicist lecturing at Sudanese universities: Barry C. Sanders</td>
<td>14 Jan 2020</td>
</tr>
<tr>
<td>Wired</td>
<td>Physicists take their closest look yet at an antimatter atom: Timothy Friesen and Robert I. Thompson</td>
<td>19 Feb 2020</td>
</tr>
<tr>
<td>Physicsworld.com</td>
<td>Honeywell says it will soon release ‘the most powerful quantum computer yet’: Barry C. Sanders</td>
<td>20 Mar 2020</td>
</tr>
</tbody>
</table>
Research Grants
(UNAUDITED)

By funding agency

Total Revenue: $6.56M

- University of Calgary [8.33%]
- Natural Sciences and Engineering Research Council of Canada [14.43%]
- National Research Council Canada [2.41%]
- MITACS [2.02%]
- Other Grants [1.34%]
- Alberta Innovates [2.7%]
- Canada Foundation for Innovation [21.34%]
- Government of Alberta [47.44%]
By origin

Total Revenue: $6.56M

- Provincial Funding [58.46%]
- National Funding [40.52%]
- International Funding [1.02%]
Objectives for Next Year

Paul E. Barclay
- Demonstrate a tunable optomechanical memory based on “reservoir engineering” principle
- Measure spin-optomechanical coupling in diamond micodisk devices
- Develop diamond photonic crystal optomechanical devices

Shabir Barzanjeh
- Install Bluefors dilution refrigerators, microwave and optical components
- Write automation software for experiments with cavities, qubits and mechanical oscillators
- Design and fabricate silicon-on-insulator electro-optomechanical systems
- Measure the optomechanical resonator
- Complete sideband cooling of the mechanical resonator to its ground state

David L. Feder
- Determine the computational complexity of preparing and detecting topological states in qubits
- Investigate matrix product states characterized by degenerate singular values as universal resources for measurement-based quantum computation
- Explore the influence and power of particle interactions for characterizing and inducing topology in many body quantum systems
- Employ techniques in algebraic graph theory to determine the ground state and excitations of hard-core bosons on lattices
Timothy Friesen
- Improve in-situ magnetometry techniques for spectroscopy and gravity measurements on antihydrogen
- Complete upgrade and commission ALPHA-g apparatus at CERN
- Install and calibrate Time Projection Chamber annihilation detector in the ALPHA-g apparatus
- Develop a novel stripline resonator for excitation of anti-proton spin flip transitions in antihydrogen
- Develop new cylindrical Penning trap designs for antihydrogen formation and spectroscopy

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 quantum algorithms and prove bounds on sampling distributions
- Prove bounds on quantum walks for transitive graphs

Peter G. Kusalik
- Examine the factors important in the stability and mechanism of formation of aqueous nanobubbles
- Further develop and validate effective interaction potentials for hydroxide radical in water that faithfully reproduces the structural features observed from ab initio simulations
- Determine the stability and reactivity of hemi-bonded complexes of hydroxide radical with chloride or bromide anions
- Develop and test empirical and coarse grain potential models appropriate for simulations studies of self-assembly processes in zinc-/carboxylate metal-organic framework
- Use machine learning approaches to characterize formation of order during metal-organic framework self-assembly
- Develop Markov State models based on key structural events and their transitions during the nucleation processes of ice and gas clathrate hydrates
- Use novel molecular simulation approaches to identify nucleation pathways in mixed gas hydrates

Nasser Moazzen-Ahmadi
- Develop sensitive, compact, potable, and low-cost sensors for monitoring greenhouse gas emission
- Develop accurate global potential energy surfaces for molecular complexes
- Spectroscopic studies of microsolvation of carbon monoxide and carbon dioxide in water
- Develop quantum mechanical models of infrared band systems of ethane for remote sensing of terrestrial and planetary atmospheres
Daniel Oblak
- Commission quantum satellite ground station and establish quantum communication link to satellite
- Demonstrate novel quantum memory protocol using thulium-doped crystal
- Demonstrate two-photon interference with the aim of implementing measurement device-independent quantum key distribution using single photons from quantum dots
- Detect and characterize ultra-weak bio-photon emission from tadpole brain-tissue

Dennis R. Salahub
- Implement the combined method of density functional theory and Hubbard dynamics into deMon2k for strongly correlated systems
- Extend oil-sands upgrading simulations to molybdenum disulfide as the nanocatalyst
- Design new nanocatalysts
- Employ machine learning to identify collective-variable reaction coordinates for free-energy calculations
- Initiate collaborative research with NRC-Ottawa within their AI4D (Artificial intelligence for Design) program on design of new nanocatalysts

Yujun Shi
- Investigate chemical kinetics of nitrogen-containing organosilicon precursors in the chemical vapor deposition process
- Develop method of using chemical vapor deposition for the growth of gallium trioxide nanostructures
- Explain the process of pulsed laser dewetting for the formation of bimetallic nanoparticles on patterned and unpatterned substrates

Barry C. Sanders
- Formulate framework for intelligent search of computational problems showing a quantum speed up
- Devise a quantum algorithm for preparing the a free-field ground state with quasilinear scaling with respect to the number of modes
- Propose fast low-power pulse sequences for two-qubit gates for atomic quantum computing
- Assess potential benefits of quantum algorithms to surmount computational problems in metabolomics
- Develop a comprehensive framework for devising and assessing a quantum internet
- Install a functional quantum-satellite ground station in Calgary with Oblak
- Develop verification and validation protocols for quantum tasks
- Formulate quantum measurement as dual to quantum-state generation
Christoph Simon
- Explain the role of communication complexity and the potential for quantum communication complexity advantage in the brain
- Develop a transducer protocol based on opto-mechanical arrays
- Explain the potential for backpropagation of synaptic weight information through photonic channels in the brain
- Develop a proposal for quantum simulation with Rydberg excitons
- Develop a proposal for quantum repeaters with spins in quantum dots
- Develop a proposal for room-temperature quantum networks with nitrogen-vacancy centers in diamond
- Explain the radical pair mechanism as an explanation for electron spin resonance and isotope effects in Xenon-induced anesthesia
- Explain cavity-enhanced quantum memories in rare-earth ion doped crystals, including the atomic frequency comb and controllable dipole memories
- Explain optically active defects in hexagonal boron nitride as potential nodes for room-temperature quantum networks

Robert I. Thompson
- Complete upgrade and commission ALPHA-g apparatus at CERN
- Resolve atomic structures of antihydrogen
- Explore novel ion source options for TITAN

Simon Trudel
- Develop machine learning for the design of thin-film charge transport layers
- In operando investigation of catalysts using synchrotron methods
- Develop ferroelectric-nanomaterials bonds on a silicon surface
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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@iqstucalgary

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Fax: (403) 210-8876
Email: iqstinfo@ucalgary.ca

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University of Calgary
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