



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

# Quantum Frontiers

Annual Report 22/23

# 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

**30** postdoctoral fellows

**100** graduate students

**31** undergraduate students

**35** invited talks at conferences/workshops including one plenary talk

**10** million dollars in research funds

**94** publications in refereed journal and conference proceedings including *Nature Communications* (1), *PRX Quantum* (2), *ACS Applied Materials and Interfaces* (1), *Physical Review Letters* (3), *Optica* (1), *ACS Energy Letters* (1) and *Nature Photonics* (1)

# Contents

<b>Director's Report</b>	<b>2</b>
<b>Message from the Chair</b>	<b>4</b>
<b>Research Highlights</b>	<b>5</b>
Research Achievements	5
Awards	6
<b>Key Performance Indicators</b>	<b>8</b>
<b>Research Groups</b>	<b>12</b>
<b>Management &amp; Membership</b>	<b>23</b>
Institute Structure	23
Governance	24
<b>Publications</b>	<b>29</b>
Refereed Journal Publications	29
Refereed Conference Proceedings	34
Books and Chapters	35
Student Theses	35
Intellectual Property	36
Invited Presentations at Workshops/Conferences	36
<b>Linkage</b>	<b>39</b>
Academic Collaborations	39
Industrial/Non-profit/Government Collaboration	40
Visitors	41
<b>Graduate Courses</b>	<b>42</b>
<b>Services and Outreach</b>	<b>43</b>
Conferences/Workshops	43
Professional Services	43
Outreach Lectures	45
Quantum Public Lecture	45
Media Coverage	45
<b>Research Grants</b>	<b>47</b>
<b>Objectives for Next Year</b>	<b>49</b>

# Director's Report

The Institute for Quantum Science and Technology hosts 21 research groups and about 170 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. University of Calgary researchers collaborate closely with counterparts at the Universities of Alberta and Lethbridge, and *Quantum Alberta* is the umbrella organisation for quantum activity in the Province with the Institute functioning as the Calgary branch.

The Institute is pleased to welcome new members Leonid Belostotski, Samira Siahrostami and Milana Trifkovic as Faculty members. Dr Belostotski is a Professor and Tier II Canada Research Chair in the Department of Electrical and Software Engineering. His research focuses on radio-frequency and millimetre-wave circuits and systems, including low noise amplifiers, digital-to-analogue converters, and unique beamforming solutions. Dr Siahrostami has been an Associate Professor in the Department of Chemistry since 2018, initially joining the Global Research Initiative in Sustainable Low Carbon Unconventional

Resources funded by a Canada First Research Excellence Fund (CFREF). She received the John Jeyes Award from the Royal Society of Chemistry in 2021, and the Tom Ziegler Award of the Chemical Institute of Canada in 2023. Her research focuses on theoretical and computational material design relating to electrocatalysis for sustainable energy and environmental protection applications. Dr Trifkovic is an Associate Professor in the Department of Chemical and Petroleum Engineering and works on quantum dots, in particular designing processes to convert asphaltene into graphene quantum dots. Milana is an expert in optimally designing, operating and controlling complex, non-linear engineering systems.

The Institute for Quantum Science and Technology has enjoyed a successful year of research and training during the 2022/2023 year. Members of the Institute had 94 papers published in refereed journals and proceedings including 10 papers appearing in the top-tier journals of *Nature Communications* (1), *PRX Quantum* (2), *ACS Applied Materials and Interfaces* (1), *Physical Review Letters* (3), *Optica* (1), *ACS Energy Letters* (1) and *Nature Photonics* (1). The Institute attracted 18 new students into quantum graduate studies

programs in 2022/2023. Eleven master's students graduated and five doctoral students completed their degrees. The Institute hosted 30 postdoctoral researchers with five being recipients of international, national and provincial postdoctoral fellowships including Swiss National Science Foundation Fellowship, e2i Fellowship, PIMS Postdoctoral Fellowship, Eyes High Postdoctoral Fellowship, Killam Postdoctoral Fellowship and MITACS Accelerate Entrepreneur Funds.

The Institute is home to the Alberta Government's Ministry of Technology and Innovation, whose predecessor the Ministry of Job, Economy and Innovation. The Ministry oversees the Major Innovation Fund allocation supporting quantum science and technology at the Universities of Calgary, Alberta and Lethbridge. The Institute continues to fulfill its mission as a Faculty of Science Institute and deliver outcomes matching Faculty expectations with respect to the Grand Challenge of "Unlocking Our Digital Future". 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.

In 2022, Quantum City, a partnership of the University of Calgary, Government of Alberta and a leading information technology company Mphasis, was established with over \$100 million in private and public investments. The Quantum City's mission is to capture the benefits of quantum technology by creating adoption pathways. Quantum City is merging as a global knowledge translation hub, bringing together researchers, quantum companies and early adopters of quantum technologies and services. IQST continues to represent the academics at the University of Calgary engaged in quantum science and technology and its adjacent areas, with Quantum City focused on creating a "quantum" ecosystem in Calgary. To realize the vision of being the place where quantum technology becomes quantum solutions, Quantum City is investing in multiple synergistic areas. One of these investments

is qLab, which is a quantum fabrication and characterization facility. Another investment is qHub, which is an incubation and ideas collision space. Other investments and support include training and upskilling programs and supporting the University of Calgary initiative to appoint new quantum faculty members as well as establishing the University of Calgary's Professional Master's in Quantum Computing program. Quantum City is led by Steering Committee Chair Dr Robert Thompson, Associate Vice-President (Research) and Executive Director of Research Services at the University of Calgary, Scientific Director Dr Barry Sanders, and Managing Director Dr Megan Lee, and is supported by a dynamic board of Steering Committee members representing research, academia, industry and community engagement.

**Dr. Barry C. Sanders**

Director



# Message from the Chair

There is no doubt about it: Calgary is emerging as an international high-tech hub. Increasingly, quantum science is a thread woven throughout our tech sector, bolstered by our robust infrastructure, talented workforce, and entrepreneurial spirit. From nanotechnology to biomedical engineering, the future of quantum in our city is bright.

In June 2022, the establishment of Quantum City—Calgary’s new quantum innovation hub—solidified that this type of technology is driving Alberta into the future. Quantum City is a collaboration between the University of Calgary, the Government of Alberta and Mphasis, a multinational IT solutions provider. The hub allows our city’s innovative minds to come together and find groundbreaking solutions to some of the world’s most complex problems. At IQST, we are honoured to be part of such a revolutionary initiative.

Some highlights from this year include:

- The establishment of Quantum City with over \$100 million in private and public investments, including \$23 million from the Government of Alberta. The hub is led by Steering Committee Chair Dr. Robert Thompson, Scientific Director Dr. Barry Sanders and Managing Director Dr. Megan Lee.

- In June, Quantum City partner Mphasis opened its Calgary headquarters. The global IT solutions provider specializes in cloud and cognitive services and has a strong emphasis on hiring local talent and students.
- Professor Peter Zoller from University of Innsbruck in Austria delivered a public lecture titled “A taste of quantum: A quantum leap in quantum information” at the TELUS Spark Science Centre in October. The lecture was part of the 2022 Quantum Summit organized by Quantum City, the Government of Alberta’s Quantum Technologies Major Innovation Project and Quantum Alberta.

This year has been truly exceptional when it comes to developing quantum technology in our city. Our success lies in strong partnerships, visionary minds, and a fearless approach to innovation. The future looks bright. I look forward to seeing it unfold.

**Dr. Kristin Baetz**  
Chair, IQST Board of Directors  
Dean, Faculty of Science  
University of Calgary

# Research Highlights

## RESEARCH ACHIEVEMENTS

The Institute for Quantum Science and Technology (IQST) has made 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.

Christoph Simon and his group are making great strides in exploring quantum phenomena in biology. They presented the case that many of the weak magnetic-field effects observed in biological systems could be due to a radical-pair mechanism, which has a quantum origin. Their highly cited work appeared in the *Journal of the Royal Society Interface*. Simon's collaboration with a group in France yielded a breakthrough on photon-number entanglement generated by sequential excitation of a two-level atom, published in *Nature Photonics*.

Samira Siahrostami advocated a rechargeable metal-hydrogen peroxide battery as a solution to improve metal-air battery performance, which was published in *ACS Energy Letters*. Her other discovery, in a collaborative effort, establishes that lanthanum aluminate is an efficient catalyst for two-electron water

electrolysis. This discovery advances the goal of producing hydrogen peroxide is important especially because hydrogen peroxide is an environmentally benign and powerful chemical oxidizer. This latter work was published in *Nature Communications*.

Paul Barclay and his group demonstrated high-frequency torsional motion transduction using optomechanical coupled oscillators, reported in a paper published in *Optica*. Erhan Saglamyurek collaborated on a University of Alberta experiment demonstrating superradiance-mediated photon storage for a broadband quantum memory, reported in *Physical Review Letters*. Barry Sanders collaborated on an experimental demonstration of topological spin texture of chiral edge states in photonic two-dimensional quantum walks, reported in *Physical Review Letters*.

Postdocs Saubhik Sarkar and Abhijeet Alase collaborated on a project concerning exploitation of second-order quantum phase transitions for sensing at criticality. Specifically, they investigate phase transitions in free-fermionic topological systems that exhibit neither symmetry-breaking nor long-range entanglement and argue that gap closing is the main candidate for the ultimate source of

quantum enhanced sensing, paving the way for topological quantum sensors that are expected to be robust against local perturbations. The article was published in *Physical Review Letters*.

In the past year, Peter Kusalik and his collaborators explored molecular insights into the impacts of calcite nanoparticles on methane hydrate formation, published in *ACS Sustainable Chemistry*. Milana Trifkovic's group reported coupling particle ordering and spherulitic growth for long-term performance of nano cellulose/poly(ethyleneoxide) electrolytes, reported in *ACS Applied Materials and Interfaces*.

## AWARDS

### International Awards

#### SWISS NATIONAL SCIENCE FOUNDATION FELLOWSHIP

Sigurd Flågan

### National Awards

#### CANADIAN INSTITUTE OF NUCLEAR PHYSICS FELLOWSHIP

Adam Powell

#### MITACS ACCELERATE ENTREPRENEUR

Sourabh Kumar

#### MITACS-ACCELERATE GRADUATE RESEARCH INTERNSHIP PROGRAM

Sayed Shakib Vedaie

Robert Riley Nerem

#### NSERC CANADA GRADUATE SCHOLARSHIPS – MASTER'S PROGRAM

Elijah Adams

Abby Swadling

#### NSERC POSTGRADUATE SCHOLARSHIPS – DOCTORAL PROGRAM

Linh Ly

#### NSERC USRA

Mir Humayun

Hai Le

Mira Rupert

Abby Swadling

#### PIMS POSTDOCTORAL FELLOWSHIP

Thomas Theurer

#### TOM ZIEGLER AWARD OF THE CHEMICAL INSTITUTE OF CANADA

Samira Siahrostami

### Provincial Awards

#### ALBERTA GRADUATE EXCELLENCE SCHOLARSHIP (AGES)

Katelynn Daly

Al-Waleed El-Sayed

Pirouz Kiani

Peyman Parsa

Anuj Sethia

Jordan Smith

Pooja Woosaree

#### ALBERTA INNOVATES GRADUATE STUDENTS SCHOLARSHIP

Al-Waleed El-Sayed

Linh Ly

### University of Calgary Awards

#### e2i FELLOWSHIP

Sourabh Kumar

#### EYES HIGH POSTDOCTORAL FELLOWSHIP

Majid Taghavi Dehaghani

Thomas Theurer

#### CANADIAN QUEEN ELIZABETH II DIAMOND JUBILEE SCHOLARSHIPS (ADVANCED SCHOLARS)

Nehad AttaElmanan AbdElrahim Mabrouk

#### EMERGING LEADERS IN THE AMERICAS SCHOLARSHIP

Dorcas Addo

#### EYES HIGH INTERNATIONAL DOCTORAL SCHOLARSHIP

Bishnupada Behera

#### FACULTY OF GRADUATE STUDIES DOCTORAL SCHOLARSHIP

Pragati Gupta

#### FACULTY OF SCIENCE AWARD OF EXCELLENCE

Simon Trudel

#### FACULTY OF SCIENCE GLOBAL OPEN DOCTORAL FELLOWSHIP

Pooja Woosaree



**FACULTY OF GRADUATE STUDIES INTRODUCTION TO  
ENTREPRENEURSHIP – HUNTER CENTRE**

Pragati Gupta

**KILLAM POSTDOCTORAL SCHOLARS**

Abhijeet Alase

**NOVA CHEMICAL GRADUATE SCHOLARSHIP**

Santiago Jimenez Villegas

Oliver Calderon

**PURE AWARD**

Lucas Brown

Shabaz Dhaliwal

Dareen Hallak

Simon Hu

Mobina Jamali

Marcus Kasdorf

Anthony Klevsky

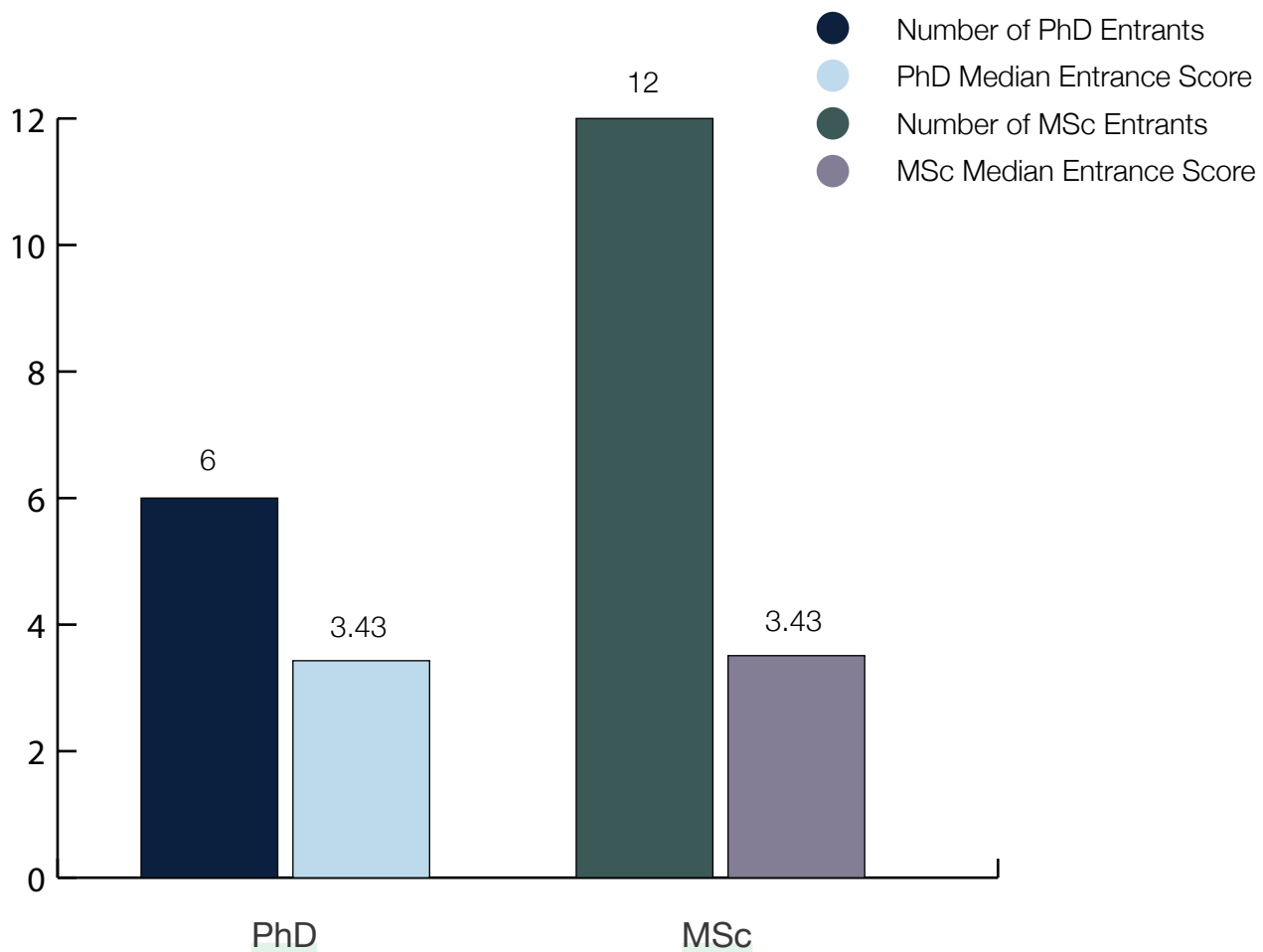
Sean Wilson

**SCHULICH SCHOOL OF ENGINEERING  
DEPARTMENTAL RESEARCH EXCELLENCE AWARD  
(DEPARTMENT OF CHEMICAL AND PETROLEUM  
ENGINEERING)**

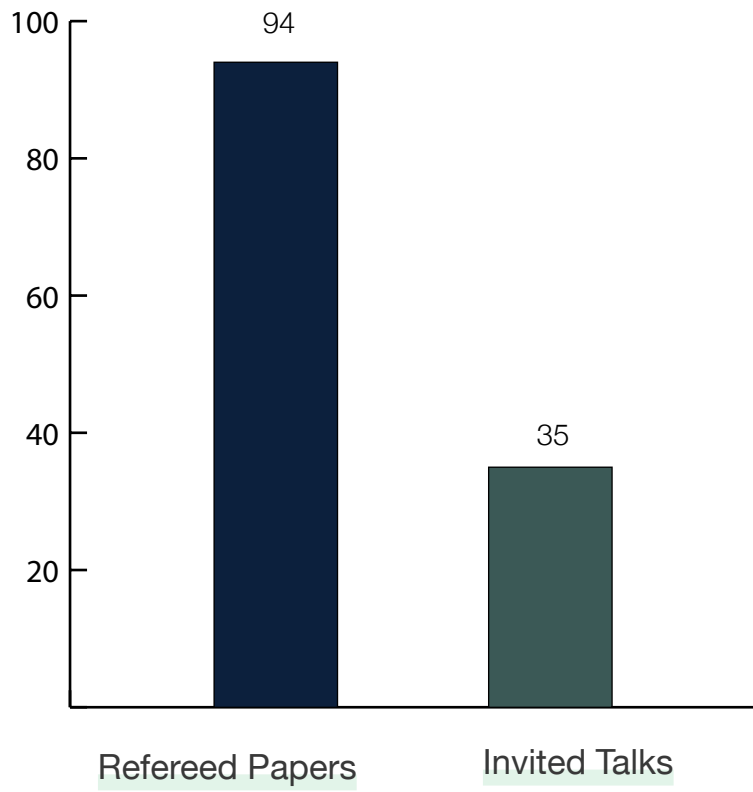
Milana Trifkovic

# Key Performance Indicators

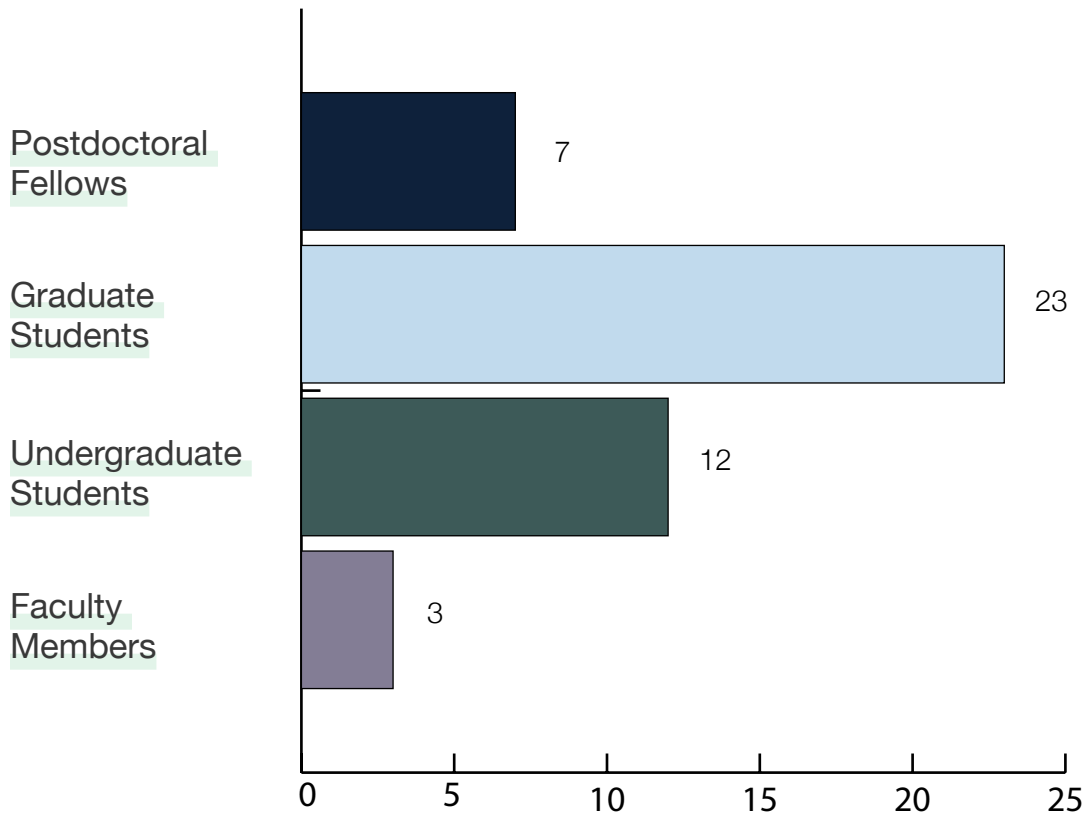
## GRADUATE STUDENTS ENROLMENT AND QUALITY OF ENTRANTS



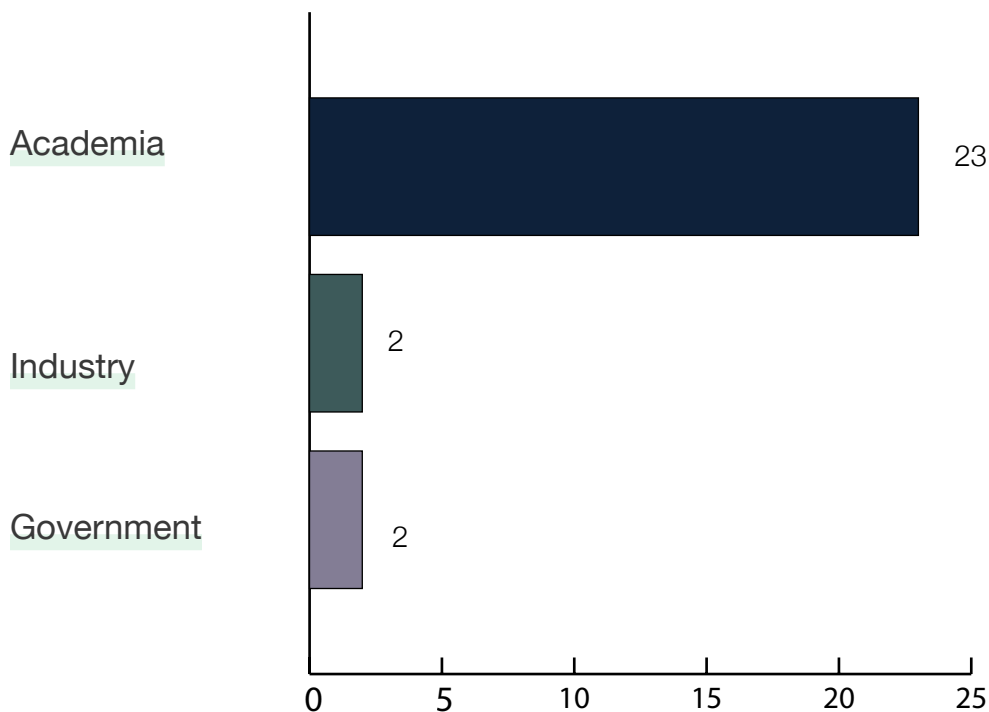
## PUBLICATIONS AND PRESENTATIONS



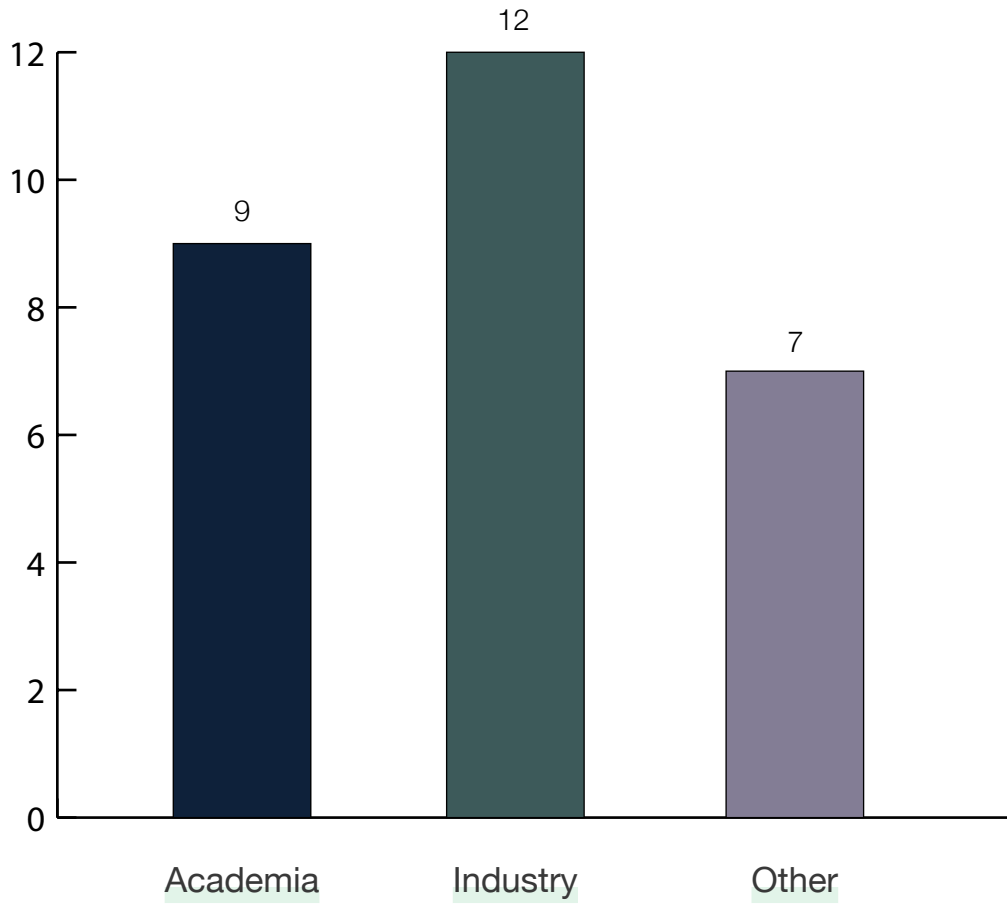
## AWARDS (CHAIRS, FELLOWSHIPS AND SCHOLARSHIPS)



## VISITORS



## TRAINEE DESTINATIONS AFTER IQST



# Research Groups



PAUL BARCLAY

## NANOSCALE OPTICS

Explore interactions between light and nanoscale systems such as single atoms, electron spins and nanomechanical structures. Employ 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 Nanotechnology Research Centre in Edmonton, which has advanced nanofabrication tools plus leading quantum optics and nanotechnology researchers.

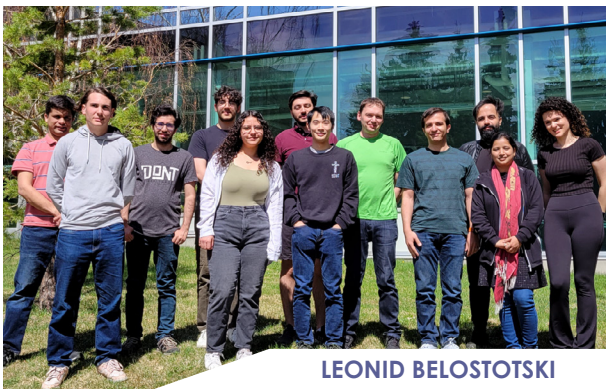


SHABIR BARZANJEH

## INTEGRATED HYBRID QUANTUM CIRCUITS

Focus on the reversible quantum interface between the superconducting circuits and quantum optical systems. Develop quantum communication technology that is integrable with superconducting processors for building large-scale quantum networks.





LEONID BELOSTOTSKI

## RADIO-FREQUENCY AND MIXED-SIGNAL CIRCUITS

Develop integrated circuits and systems for application in wireless systems, radio astronomy, and quantum computing, aiming to realize ultra-low-noise receiver systems in commercial bipolar complementary metal-oxide-semiconductor technologies.



DAVID FEDER

## PRACTICAL QUANTUM COMPUTATION

Explore intrinsic properties of physical systems, such as ultracold atomic gases or spin lattices, which can be employed to construct larger devices able to perform quantum computation. Also explore alternative models for the implementation of quantum logic, such as one-way quantum computation, quantum walks, and topological quantum computation.



TIMOTHY FRIESEN

## TESTING 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. Focus on the development of particle traps, microwave techniques, and annihilation detection for highprecision spectroscopy and gravitational mass measurements on antihydrogen.



GILAD GOUR

## QUANTUM INFORMATION THEORY

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

**PETER HØYER**

## QUANTUM COMPUTING

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

**PIERRE KENNEPOHL**

## MOLECULAR AND MATERIALS ELECTRONIC STRUCTURE

Explore the relationship between electronic structure of molecules and materials and their broader chemical properties and study the use of such interactions in molecular electronics and other applications. X-ray spectroscopies are the major tools for our exploration of electronic structure.





PETER KUSALIK

## MOLECULAR SIMULATIONS OF LIQUIDS & SOLUTIONS, INTERFACES AND CRYSTALLIZATION

Perform molecular simulations to examine collections of molecules representing solid or liquid systems. Probe the molecular behaviour to understand properties of liquids and solids and their transformations including nucleation and crystallization. Explore behaviour of aqueous nanobubbles and the origins of their stability and mobility. Applications range from atmospheric and materials sciences to molecular biology and water treatment.



NASSER MOAZZEN-AHMADI

## SPECTROSCOPY OF HYDROCARBONS AND MOLECULAR CLUSTERS AND COMPLEXES

Measure forces responsible for formation of atomic and molecular clusters. Investigate the intermolecular potential in the region of the potential minimum. Explore non-additive effects on the interaction energy and to determine possible condensation pathways.



### QUANTUM CLOUD LAB

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



### COMPLEX NANO MATERIALS

Computational description and modelling of nanoscale materials for applications to neuromorphic computing, transparent conductors, and sensing. Explore phenomena that emerge when matter is “packed” at the nanoscale at which quantum effects are present.

**DENNIS SALAHUB**

## MULTISCALE MODELLING OF (BIO) CHEMICAL REACTIONS IN COMPLEX ENVIRONMENTS

Investigate mechanisms and rates of chemical reactions occurring in complex environments. Model enzymatic catalysis, electron transfer between proteins and/or heavy oil upgrading. Employ 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.

**BARRY SANDERS**

## QUANTUM INFORMATION SCIENCE

Develop quantum information technologies that have transformative applications and will be feasible 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.





CARLO MARIA SCANDOLO

## QUANTUM INFORMATION AND FOUNDATIONS

Use mathematical tools, such as matrix and convex analysis, to quantify quantum resources and optimize their use in information-theoretic protocols. Apply informational methods to foundational problems in quantum theory, especially using the framework of general probabilistic theories, which combine convex analysis with categorical methods.



YUJUN SHI

## CHEMICAL VAPOUR DEPOSITION CHEMISTRY

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



SAMIRA SIAHROSTAMI

## COMPUTATIONAL CATALYSIS FOR CLEAN ENERGY TRANSFORMATION

Undertake computational catalyst material design for applications to clean-energy technologies such as fuel cells, electrolysers and batteries. Design catalysts from first principles by modelling reactions in silico for a range of electrochemical reaction.



CHRISTOPH SIMON

## THEORETICAL QUANTUM OPTICS

Apply 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

Develop and measure 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. Collaborate with TRIUMF's Ion Trap for Atomic and Nuclear (TITAN) Science, particularly on sympathetic and evaporative cooling.



## ADVANCED MATERIAL DESIGN

Design and characterize novel materials with applications in the energy sector including polymer nanocomposites, nanoparticle stabilized emulsions, bicontinuous interfacially jammed emulsion gels and newly developed bicontinuous intraphase emulsion gels.



**SIMON TRUDEL**

## **NANOSCALE MATERIAL**

Investigate synthesis, characterization, and structure-property relationships in inorganic solid-state nanomaterial, such as metal-oxide thin films and multimetallic nanoparticles. Develop high-performance materials in technologically and commercially relevant focus areas such as clean-energy conversion and spin-based electronics. Characterize materials using state-of-the-art methods, such as electrochemical testing, electron microscopy, X-ray diffraction, and magnetometry based on superconducting quantum interference devices.

# Management Membership

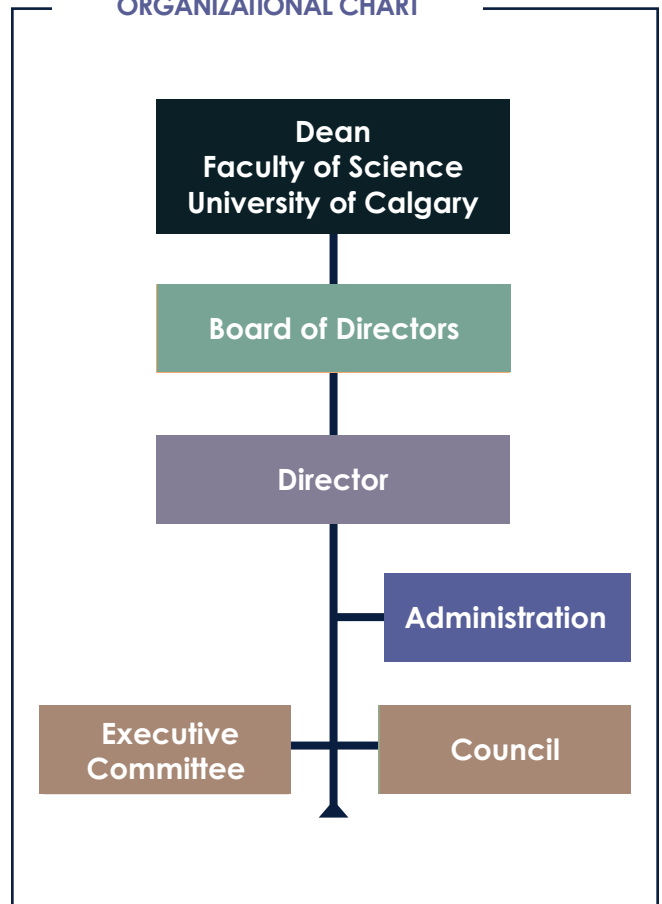
## INSTITUTE STRUCTURE

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 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.

ORGANIZATIONAL CHART





## GOVERNANCE

### BOARD OF DIRECTORS

#### **Kristin Baetz**

Dean, Faculty of Science,  
University of Calgary

#### **Marie D'Iorio**

Chief Operating Officer,  
University of Ottawa

#### **Chip Elliott**

#### **Sir Peter Knight**

Senior Fellow in Residence,  
The Kavli Royal Society  
International Centre

#### **Barry C. Sanders**

Professor, Department of  
Physics and Astronomy,  
University of Calgary

#### **Carl Williams**

President and Chief Executive  
Officer, CJW Quantum  
Consulting

### EXECUTIVE COMMITTEE

#### **Paul E. Barclay**

Professor, Department of  
Physics and Astronomy,  
University of Calgary

#### **Peter Kusalik**

Professor, Department of  
Chemistry, 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

### COUNCIL

#### FACULTY MEMBERS

#### **Paul Barclay**

Professor, Department of  
Physics and Astronomy,  
University of Calgary

#### **Shabir Barzanjeh**

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

#### **Leonid Belostotski**

Professor, Department of  
Electrical and Software  
Engineering, University of  
Calgary

#### **David Feder**

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

#### **Timothy Friesen**

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

#### **Claudia Gomes da Rocha**

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

#### **Gilad Gour**

Professor, Department of  
Mathematics and Statistics,  
University of Calgary

#### **Peter Hoyer**

Associate Professor,  
Department of Computer  
Science, University of Calgary

#### **Pierre Kennepohl**

Associate Professor,  
Department of Chemistry,  
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

#### **Dennis Salahub**

Professor Emeritus,  
Department of Chemistry,  
University of Calgary

#### **Barry C. Sanders**

Professor, Department of  
Physics and Astronomy,  
University of Calgary

#### **Carlo Maria Scandolo**

Assistant Professor,  
Department of Mathematics  
and Statistics, University of  
Calgary

#### **Yujun Shi**

Professor, Department of  
Chemistry, University of Calgary

#### **Samira Siahrostami**

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

**Milana Trifkovic**

Associate Professor,  
Department of Chemistry,  
University of Calgary

**Simon Trudel**

Professor, Department of  
Chemistry, University of Calgary

**AFFILIATE MEMBERS****Robin Cockett**

Professor, Department of  
Computer Science, University  
of Calgary

**Hubert de Guise**

Professor, Department of  
Physics, Lakehead University

**Khabat Heshami**

Research Officier,  
National Research Council  
Canada

**David Hobill**

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

**Reginald Paul**

Professor Emeritus,  
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

Shirin Afzal (completed September 2022)

Ozioma Akakuru

Abhijeet Alase (resigned July 2022 → postdoctoral fellow, University of Sydney)

Aaron Barclay

Natália do Carmo Carvalho

Hanen Chenini

Sigurd Flågan

Arash Hejazi

Sabade Gul

Jiri Hostas

Faezeh Kimiaee Asadi

Youssef Kora

Sourabh Kumar

Renaud Miclette-Lamarche (completed December 2022 → research associate, Concordia University)

Mosayeb Naseri

Trong Huynh Buu Ngo (completed December 2022 → engineer, Norcada)

Mahmood Noweir (completed April 2022, electromagnetic compatibility engineer, MDA)

Nicholas Randell (completed July 2022 → research scientist, Ionic Solutions Ltd.)

Habib Rastegar

Vinaya Kumar Kavatamane Rathnakara

Saubhik Sarkar

Ashutosh Singh

Martin Schon (completed July 2022)

Sunaina Sunaina

Majid Taghavi Dehaghani

Tatek Temesgen Terfasa

Thomas Theurer

Deeksha Verma

Hadi Zadeh Haghighi

Parisa Zarkeshian (completed January 2023)

## Research Associates/Assistant

Morteza Chehel Amirani (research associate, completed September 2022 → computational research scientist, Svante)

Stephanie Bonvicini (research assistant)

Roohollah Ghobadi (research associate, completed October 2022 → researcher, QC Design)

Taras Hrushevskiyi (research associate)

Qasim Khan

Joseph Losby (research associate, completed February 2023 → operations manager, qLab of Quantum City)

Erhan Saglamyurek (senior research associate, completed August 2022 → project scientist, Lawrence Berkeley National Laboratory)

Vahid Salari (research associate)

James Stevenson (research assistant)

## Graduate Students (PhD Program)

David Amaro Alcalá

Shudipto Kazi Amin

Aaron Barclay (graduated June 2022 → postdoc, University of Calgary)

Bishnupada Behera

Stephanie Bonvicini (graduated December 2022 → co-founder, Matter3D)

Oliver Calderon

Archismita Dalal

Katelynn Daly

Danial Davoudi

Sagnik Dutta

Balarama Sridhar Dwadasi

Al-Waleed El-Sayed

Leili Esmaeilifar

Koorosh Esteki

Ujjwal Gautam

Sankha Ghosh

Nasser Gohari Kamel

Pragati Gupta

Lizandra Barrios Herrera (graduated February 2023)

Jiawei Ji

Zahra Kabirkhoo

Mahsa Karimi

Salini Karuvade

Thisara Kulatunga

Prasoon Kumar Shandilya

Linh Ly

Nehad AttaElmanan AbdElrahim Mabrouk

Anindya Mitra  
 Eduardo Páez Barrios  
 Adam Powell  
 Mohammad Radpour  
 Farhad Rasekh  
 Mahdi Rizvandi  
 Rishabh  
 Gaurav Saxena  
 Vishnu Seshan  
 Seyed Shakib Vedaie  
 Hatef Shahmohamadi  
 Alex Sheldon (graduated May 2022 → high-speed analog design engineer, NXP Semiconductors)  
 Rishabh Shukla  
 Shahrzad Taherizadegan  
 Lei Wang  
 Pooja Woosaree  
 Hao Xie  
 Hadi Zadeh Haghighi (graduated June 2022 → postdoc, University of Calgary)  
 Elia Zanoni  
 Elham Zohari  
 Joseph Zsombor-Pindera

### Graduate Students (MSc Program)

Maryam Abarashi (graduated April 2022)  
 Parinaz Abbasi  
 Elijah Adams  
 Snehasis Addy  
 Ishra Afroze  
 Omid Aligholamioskooee (graduated May 2022 → PhD, California Institute of Technology)  
 A. K. D Kavini K. Amarsinghe  
 Jeas Grejoy Andrews  
 Aradhana Anil  
 Ashkan Bayat  
 Parisa Behjat Khatouni  
 Mahdi Bornadel  
 Ziheng Chang  
 Kavini A. K. Don Kaluarachchige  
 Asma Farhat  
 Travis Gartner  
 Sye Ghebretnsae

Mayte Li Gomez  
 Fariba Hosseinynejad Khaledy  
 Thomas Hujon  
 Joe Itoh  
 Santiago Jimenez Villegas (graduated November 2022 → research scientist, Travertine)  
 Pirouz Kiani  
 Mark Lai (graduated September 2022 → RF designer, Kepler Communications)  
 Janet Leahy  
 Zhuohao(Ray) Liu  
 Xinyuan Ma (graduated January 2023)  
 Ismail Majed  
 Zachary Manson  
 Eduardo Miguel Martínez Garcia  
 Abdul Mohamed  
 Robert Riley Nerem (graduated April 2022 → PhD, University of California, San Diego)  
 Joan Ngure (graduated August 2022)  
 Yasser Novo-Fernández  
 Julian Palandri  
 Peyman Parsa  
 Marwa Safa  
 Mahkame Salimi Moghadam  
 Nihari Sathsarani Pathirannehelage (graduated March 2023 → research associate, Katal Energy Inc.)  
 Anuj Sethia  
 Mehreen Shabbir  
 Sara Shafiei Alavijeh (graduated August 2022)  
 Amit Shalev  
 Kenneth Sharman (graduated December 2023 → head of product, Quantized Technologies Inc.)  
 Jordan Smith (graduated January 2023 → chief executive officer, Quantized Technologies Inc.)  
 Amirhossein Sotoodehfar  
 James Stevenson (graduated August 2022 → sessional instructor, University of Calgary)  
 Jay Suh  
 Armin Tabesh  
 Praveen Wakwella  
 Greg Wong  
 Tyler Zegray

## Undergraduate Students

Luis Daniel Abalo-Sangervasi (PHYS 598)  
Amir Ahadi (research assistant)  
Shayaan Ahmad (undergraduate research)  
Lucas Brown (PURE & PHYS 598)  
Lachlan Cuskelly (undergraduate research)  
Joshua Daniel Felce Gonzalez (PHYS 598)  
Shabaz Dhaliwal (PURE)  
Emily Frede (PHYS 598)  
Gabby Galinas (PHYS 598)  
Sye Ghebretnsae (PHYS 598)  
Dareen Hallak (PURE award)  
Mir Humayun (NSERC USRA)  
Simon Hu (PURE award)  
Mobina Jamali (PURE award)  
Emma Johnson (PHYS 598)  
Eugene Kalionau (PHYS 599)  
Marcus Kasdorf (PURE & PHYS 598)  
Anthony Klevsky (PURE award)  
Nick Kuzmin (research assistant)  
Hai Le (NSERC USRA)  
Abdullah Maqsood (Coop internship)  
Quinn Mira Rupert (PHYS 598 & NSERC USRA)  
John Ngo (PHYS 598)  
Lucke Praught (research assistant)  
Raj Rakha (PHYS 599)  
Harris Saleem (CHEM 502)  
Salma Salhi (PHYS 598)  
Peter Shmerko (undergraduate research)  
Reece Stefanyshyn (PHYS 598)  
Abby Swadling (PHYS 598 & NSERC USRA)  
Sean Wilson (PURE award)

## Administration

Jing (Nancy) Lu (Administrator)  
Sonali Keshava Murthy Naik (Part-time  
Webmaster)

# Publications

## REFEREED JOURNAL PUBLICATIONS

- N. Akhtar, B. C. Sanders and X.-L. Gao, "Sub-Planck phase-space structure and sensitivity for SU(1,1) compass states", *Physical Review A* **106**(4): 043704 (14 pp.), October 2022.
- S. Ahmadi, E. Saglamyurek, S. Barzanjeh and V. Salari, "High-contrast interaction-free quantum imaging method", *Physical Review A* **107**(3): 032611 (11 pp.), March 2023.
- A. Alase, S. Karuvade and C. M. Scandolo, "The operational foundations of PT-symmetric and quasi-Hermitian quantum theory", *Journal of Physics A: Mathematical and Theoretical* **55**(24): 244003, May 2022.
- A. Alase, R. R. Nerem, M. Bagherimehrab, P. Høyer and B. C. Sanders, "Tight bound for estimating expectation values from a system of linear equations", *Physical Review Research* **4**(2): 023237 (17 pp.), June 2022.
- S. Back, A. H. Bagherzadeh Mostaghimi and S. Siahrostami, "Enhancing oxygen reduction reaction activity using single atom catalyst supported on tantalum pentoxide", *ChemCatChem* **14**(11): e202101763 (6 pp.), June 2022.
- J. Baek, Q. Jin, N. S. Johnson, Y. Jiang, R. Ning, A. Mehta, S. Siahrostami and X.-L. Zheng, "Discovery of LaAlO<sub>3</sub> as an efficient catalyst for two-electron water electrolysis towards hydrogen peroxide", *Nature Communications* **13**: 7256, November 2022.
- A. J. Barclay, A. R. W. McKellar and N. Moazzen-Ahmadi, "Doped rare gas clusters up to completion of first solvation shell, CO<sub>2</sub>-(Rg)<sub>n</sub>, n=3-17, Rg=Ar, Kr, Xe", *Journal of Chemical Physics* **158**(11), 114302 (14 pp.), March 2023.
- M. Bagherimehrab, Y. R. Sanders, D. W. Berry, G. K. Brennen and B. C. Sanders, "Nearly optimal quantum algorithm for generating the ground state of a free quantum field theory", *PRX Quantum* **3**(2): 020364 (66 pp.), June 2022.
- A. J. Barclay, A. R. W. McKellar and N. Moazzen-Ahmadi, "Observing the completion of the first solvation shell of carbon dioxide in argon from rotationally resolved spectra", *Journal of Physical Chemistry Letters* **13**(27): 6311-6315, July 2022.
- A. J. Barclay, A. R. W. McKellar and N. Moazzen-Ahmadi, "Spectra of CO<sub>2</sub>-Rg<sub>2</sub> and CO<sub>2</sub>-Rg-He trimers (Rg=Ne, Ar, Kr, and Xe): Intermolecular CO<sub>2</sub> rock, vibrational shifts and three-body effects", *Journal of Chemical Physics* **157**(20): 204303 (10 pp.), November 2022.
- A. J. Barclay, A. R. W. McKellar and N. Moazzen-Ahmadi, "Infrared spectra of (CO<sub>2</sub>)<sub>2</sub>-Rg trimers, Rg=Ne, Ar, Kr, and Xe", *Journal of Molecular Spectroscopy* **387**: 111673 (5 pp.), July 2022.
- L. Belostotski, A. T. Sutinjo, R. Subrahmanyam, S. Mandal and A. Madanayake, "General framework for array noise analysis and

- noise performance of a two-element interferometer with a mutual-coupling canceler”, *IEEE Transactions on Antennas and Propagation* **70**(9): 8059–8068, April 2022.
- G. Bobrov, S. A. Kedzior, S. A. Pervez, A. Govedarica, G. Kloker, M. Fichtner, V. K. Michaelis, G. M. Bernard, P. M. Veelken, F. Hausen and M. Trifkovic, “Coupling particle ordering and spherulitic growth for long-term performance of nano cellulose/poly(ethylene oxide) electrolutes”, *ACS Applied Materials and Interfaces* **15**(1): 1996–2008, January 2023.
- S. N. Bonvicini and Y.-J. Shi, “Formation and removal of alloyed bimetallic Au-Ag nanoparticles from silicon substrates for tunable surface plasmon resonance”, *ACS Applied Nano Materials* **5**(10): 14850–14861, September 2022.
- C. Chen, X. Ding, J. Qin, J. Z. Wu, Y. He, C.-Y. Lu, L. Li, X.-J. Liu, B. C. Sanders and J.-W. Pan, “Topological spin texture of chiral edge states in photonic two-dimensional quantum walks”, *Physical Review Letters* **129**(4): 046401 (6 pp.), July 2022.
- A. Dalal and B. C. Sanders, “Two-qubit gate in neutral atoms using transitionless quantum driving”, *Physical Review A* **107**(1): 012605 (20 pp.), January 2023.
- K. Daly, S. Jimenez Villegas, B. Godwin, M. A. W. Schoen, O. Calderon, N. Chen and S. Trudel, “A comparison of photodeposited RuOx for alkaline water electrolysis”, *ACS Applied Energy Materials* **6**(3): 1449–1458, January 2023.
- A. Das and B. C. Sanders, “Blind quantum factorization of 21”, *Physical Review A* **106**(1): 012421 (7 pp.), July 2022.
- M. B. Elamien, B. J. Maundy, A. S. Elwakil and L. Belostotski, “Second-order cascode-based filters”, *Integration* **84**: 111–121, May 2022.
- T. Esmailpour, A. Lotfealian, M. Anvari, M. Namavar, N. Karbalaei, A. Shahedi, I. Bokkon, V. Salari and D. Oblak, “Effect of methamphetamine on ultraweak photon emission and level of reactive oxygen species in male rat brain”, *Neuroscience Letters* **81**(1): 137136 (15 pp.), February 2023.
- X.-X. Fang, K. An, B.-T. Zhang, B. C. Sanders and H. Lu, “Maximal coin-position entanglement generation in a quantum walk for the third step and beyond regardless of the initial state”, *Physical Review A* **107**(1): 012433 (12 pp.), January 2023.
- T. A. Gartner, S. Ghebretnsae, A. R. W. McKellar and N. Moazzen-Ahmadi, “Spectra of CO<sub>2</sub>-Kr in the 4.3 μm region: Intermolecular bend and Symmetry breaking of the intramolecular CO<sub>2</sub> bend”, *Chemistry Select* **7**(36): e202202601 (7 pp.), September 2022.
- D. J. George, Y. R. Sanders, M. Bagherimehrab, B. C. Sanders and G. K. Brennen, “Entanglement in quantum field theory via wavelet representations”, *Physical Review D* **106**(3): 036025 (19 pp.), August 2022.
- O. Golami, K. Sharman, R. Ghobadi, S. C. Wein, H. Zadeh Haghghi, C. Gomes da Rocha, D. R. Salahub and C. Simon, “*Ab initio* and group theoretical study of properties of a carbon trimer defect in hexagonal boron nitride”, *Physical Review B* **105**(18): 184101 (17 pp.), May 2022.
- T. Gonzalez-Raya, M. Casariego, F. Fesquet, M. Renger, V. Salari, M. Möttönen, Y. Omar, F. Deppe, K. G. Fedorov and M. Sanz, “Open-air microwave entanglement distribution for quantum teleportation”, *Physical Review Applied* **18**(4): 044002 (30 pp.), October 2022.
- G. Gour, “Role of quantum coherence in thermodynamics”, *PRX Quantum* **3**(4): 040323 (23 pp.), November 2022.
- F.-K. Gui, Q. Jin, D.-D. Xiao, Z.-H. Jin, Y.-C. Zhang, Y.-J. Cao, M. Yang, Q.-G. Tan, C.-M. Zhang, S. Siahrostami and Q.-F. Xiao, “High-performance zinc-air batteries enabled by hybridizing atomically dispersed FeN<sub>2</sub> with Co<sub>3</sub>O<sub>4</sub> nanoparticles”, *Journal of Materials Chemistry A* **11**(3): 1312–1323, December 2022.
- P. Høyer and J. Leahy, “Spatial search via an interpolated memoryless walk”, *Physical Review A* **106**(2): 022418 (17 pp.), August 2022.
- A. Jacobs, C. Andreoiu, J. Bergmann, T. Brunner, T. Dickel, I. Dillmann, E. Dunling, J. A. D. Flowerdew, L. Graham, G. Gwinner, Z.



- Hockenbery, B. Kootte, Y. Lan, K.G. Leach, E. Leistenschneider, E. M. Lykiardopoulou, V. Monier, I. Mukul, S. F. Paul, W. R. Plaß, M. P. Reiter, C. Scheidenberger, R. I. Thompson, J. L. Tracy, C. Will, M. E. Wieser, M. Yavor, J. Dilling and A. A. Kwiatkowski, "Collision-induced dissociation at TRIUMF's ion trap for atomic and nuclear science", *International Journal of Mass Spectrometry* **482**: 116931 (7 pp.), September 2022.
- A. Jacobs, C. Andreoiu, J. Bergmann, T. Brunner, T. Dickel, I. Dillmann, E. Dunling, J. A. D. Flowerdew, L. Graham, G. Gwinner, Z. Hockenbery, W. J. Huang, B. Kootte, Y. Lan, K.G. Leach, E. Leistenschneider, D. Lunney, E. M. Lykiardopoulou, V. Monier, I. Mukul, S. F. Paul, W. R. Plaß, M. P. Reiter, C. Scheidenberger, R. I. Thompson, J. L. Tracy, C. Will, M. E. Wieser, J. Dilling and A. A. Kwiatkowski, "Improved high-precision mass measurements of mid-shell neon isotopes", *Nuclear Physics A* **1033**(2023): 122636 (13 pp.), March 2023.
- H. Jahandideh, P. Ganjeh-Anzabi, S. A. Kedzior, S. Bryant and M. Trifkovic, "3D graphene-based scaffold as a platform for highly conductive polymer nanocomposites", *Materials Chemistry and Physics* **290**: 126528 (7 pp.), October 2022.
- H. Kaviani, B. Behera, G. Hajisalem, G. de Oliveira Luiz, D. P. Lake and P. E. Barclay, "High-frequency torsional motion transduction using optomechanical coupled oscillators", *Optica* **10**(1): 35–41, January 2023.
- F. Kimiaee Asadi, J.-W. Ji and C. Simon, "Proposal for transduction between microwave and optical photons using  $^{167}\text{Er}$ -doped yttrium orthosilicate", *Physical Review A* **105**(6): 062608, June 2022.
- K. H. Koh, A. H. Bagherzadeh Mostaghimi, Q.-W. Chang, Y. J. Kim, S. Siahrostami, T.-H. Han and Z. Chen, "Elucidation and modulation of active sites in holey graphene electrocatalysts for  $\text{H}_2\text{O}_2$  production", *EcoMat* **5**(1): e12266 (14 pp.), January 2023.
- J.-X. Lian and S. Siahrostami, "A molecular insight into the dehydration of a metal-organic framework and its impact on the  $\text{CO}_2$  capture", *Chemistry – A European Journal* **29**(18): e202203620 (7 pp.), January 2023.
- P.-C. Liao, B. C. Sanders and D. L. Feder, "Topological graph states and quantum error correction codes", *Physical Review A* **105**(4): 042418 (18 pp.), April 2022.
- M. P. Lourenço, J. Hostaš, L. Barrios Herrera, P. Calaminici, A. M. Köster, A. Tchagang and D. R. Salahub, "GAMaterial—A genetic-algorithm software for material design and discovery", *Journal of Computational Chemistry* **44**(7): 801–868, March 2023.
- M. P. Lourenço, L. Barrios Herrera, J. Hostaš, P. Calaminici, A. M. Köster, A. Tchagang and D. R. Salahub, "Automatic structural elucidation of vacancies in materials by active learning", *Physical Chemistry Chemical Physics* **24**: 25227–25239, October 2022.
- M. P. Lourenço, L. Barrios Herrera, J. Hostaš, P. Calaminici, A. M. Köster, A. Tchagang and D. R. Salahub, "A new active learning approach for adsorbate-substrate structural elucidation in silico", *Journal of Molecular Modeling* **28**: 178 (11 pp.), June 2022.
- B. McLaughlin, D. P. Lake, M. J. Mitchell and P. E. Barclay, "Nonlinear optics in gallium phosphide cavities: simultaneous second and third harmonic generation", *Journal of the Optical Society of America B* **39**(7): 1853–1860, June 2022.
- L. Memarzadeh and B. C. Sanders, "Group-covariant extreme and quasi-extreme channels", *Physical Review Research* **4**(3): 033206 (24 pp.), September 2022.
- R. Miclette Lamarche, A. Gasonoo, A. Hoff, R. Chernikov, G. C. Welch and S. Trudel, "Room-temperature photodeposited amorphous  $\text{VO}_x$  hole-transport layers for organic devices", *Chemistry of Materials* **35**(6): 2353–2362, March 2023.
- M. Naseri, D. R. Salahub, S. Amirian and M. A. Rashid, "Computational investigation of  $\text{Ba}_2\text{ZrTiO}_6$  double perovskite for optoelectronic and thermoelectric applications", *Journal of*

- Solid State Chemistry* **314**: 123385 (10 pp.), July 2022.
- M. Naseri, D. R. Salahub, T. V. Vu and H. Zakaryae, "XSnS<sub>3</sub> (X = Ga, In) monolayer semiconductors as photo-catalysts for water splitting: a first principles study", *Journal of Materials Chemistry C* **10**: 11412–11423, July 2022.
- M. R. Niazi, H. Zhao, R. Miclette Lamarche, R. Munir, S. Trudel, J.-G. Hu and G. C. Welch, "Cellulose nanocrystals–tin-oxide hybrid electron transport layers for solar energy conversion", *Advanced Materials* **9**(30): 2201363 (7 pp.), September 2022.
- S. A. Pervez, E. P. L. Roberts and M. Trifkovic, "Pressure- and temperature-dependent interface kinetics in Na<sub>3</sub>Zr<sub>2</sub>Si<sub>2</sub>PO<sub>12</sub>-based all-solid-state Na metal battery", *Energy Technology* **10**(11): 2200658 (6 pp.), September 2022.
- H. Rauch, E. Saglamyurek, T. Hrushevskiy and L. J. LeBlanc, "Superradiance-mediated photon storage for broadband quantum memory", *Physical Review Letters* **129**(12): 120502 (6 pp.), September 2022.
- R. Rishabh, H. Zadeh Haghghi, D. R. Salahub and C. Simon, "Radical pairs may explain reactive oxygen species-mediated effects of hypomagnetic field on neurogenesis", *PLoS Computational Biology* **18**(6): e1010198 (18 pp.), June 2022.
- D. R. Salahub, "Multiscale molecular modelling: from electronic structure to dynamics of nanosystems and beyond", *Physical Chemistry Chemical Physics* **24**: 9051–9081, April 2022.
- V. Salari, D. Paneru, E. Saglamyurek, M. Ghadimi, M. Abdar, M. Rezaee, M. Aslani, S. Barzanjeh and E. Karimi, "Quantum face recognition protocol with ghost imaging", *Scientific Reports* **13**(1): 2401 (9 pp.), February 2023.
- T. Salehi, M. Zomorodi, P. Plawiak, M. Abbaszade and V. Salari, "An optimizing method for performance and resource utilization in quantum machine learning circuits", *Scientific Reports* **12**: 16949 (16 pp.), October 2022.
- S. Sarkar, C. Mukhopadhyay, A. Alase and A. Bayat, "Free-fermionic topological quantum sensors", *Physical Review Letters* **129**(9): 090503 (6 pp.), August 2022.
- G. Saxena and G. Gour, "Quantifying multiqubit magic channels with completely stabilizer-preserving operations", *Physical Review A* **106**(4): 042422 (16 pp.), October 2022.
- C. M. Scandolo, G. Gour and B. C. Sanders, "Covariant influences for finite discrete dynamical systems", *Physical Review E* **107**(1): 014203 (23 pp.), January 2023.
- P. K. Shandilya, S. Flågan, N. C. Carvalho, E. Zohari, V. K. Kavatamane Rathnakara, J. E. Losby and P. E. Barclay, "Diamond integrated quantum nanophotonics: Spins, photons and phonons", *Journal of Lightwave Technology* **40**(23): 7538–7571, December 2022.
- K. Sharma, B. C. Sanders and M. M. Wilde, "Optimal tests for continuous-variable quantum teleportation and photodetectors", *Physical Review Research* **4**(2): 023066 (15 pp.), April 2022.
- A. Sheldon and L. Belostotski, "A cryo-CMOS low-noise amplifier with 2.3-to-8.5-K noise temperature at 20 K for highly integrated radio-astronomy receivers", *IEEE Microwaves and Wireless Components Letters* **32**(11): 1319–1322, June 2022.
- S. Siahrostami, "H<sub>2</sub>O<sub>2</sub> electrosynthesis and emerging applications, challenges, and opportunities: A computational perspective", *Chem Catalysis* **3**(3): 100568, March 2023.
- S. Siahrostami, "Rechargeable metal-hydrogen peroxide battery, a solution to improve the metal-air battery performance", *ACS Energy Letters* **7**(8): 2717–2724, July 2022.
- D. Spivak, M. Y. Niu, B. C. Sanders and H. de Guise, "Generalized interference of fermions and bosons", *Physical Review Research* **4**(2): 023013 (19 pp.), April 2022.
- W.-J. Su, G.-Z. Ye, Y.-D. Wu, Z.-B. Yang and B. C. Sanders, "Quantum information processing with nuclear spins mediated by

- a weak-mechanically controlled electron spin”, *Communications in Theoretical Physics* **74**(5): 055102 (9 pp.), May 2022.
- M. Taheri, S. Maaref, A. Kantzas, S. Bryant and S. Trudel, Improving the colloidal stability of PEGylated BaTiO<sub>3</sub> nanoparticles with surfactants, *Chemical Physics* **564**(11): 111701 (7 pp.), September 2022.
- J. Taylor, S. Goswami, V. Walther, M. Spanner, C. Simon and K. Heshami, “Simulation of many-body dynamics using Rydberg excitons”, *Quantum Science and Technology* **7**(3): 035016 (14 pp.), June 2022.
- A. M. Teale, T. Helgaker, A. Savin, C. Adamo, B. Aradi, A. V. Arbuznikov, P. W. Ayers, E. J. Baerends, V. Barone, P. Calaminici, E. Cancès, E. A. Carter, P. Kumar Chattaraj, H. Chermette, I. Ciofini, T. D. Crawford, F. De Proft, J. F. Dobson, C. Draxl, T. Frauenheim, E. Fromager, P. Fuentealba, L. Gagliardi, G. Galli, J.-L. Cao, P. Geerlings, N. Gidopoulos, P. M. W. Gill, P. Gori-Giorgi, A. Görling, T. Gould, S. Grimme, O. Gritsenko, H. J. A. Jensen, E. R. Johnson, R. O. Jones, M. Kaupp, A. M. Köster, L. Kronik, A. I. Krylov, S. Kvaal, A. Laestadius, M. Levy, M. Lewin, S.-B. Liu, P.-F. Loos, N. T. Maitra, F. Neese, J. P. Perdew, K. Pernal, P. Pernot, P. Piecuch, E. Rebolini, L. Reining, P. Romaniello, A. Ruzsinszky, D. R. Salahub, M. Scheffler, P. Schwerdtfeger, V. N. Staroverov, J.-W. Sun, E. Tellgren, D. J. Tozer, S. B. Trickey, C. A. Ullrich, A. Vela, G. Vignale, T. A. Wesolowski, X. Xu and W.-T. Yang, “DFT exchange: sharing perspectives on the workhorse of quantum chemistry and materials science”, *Physical Chemistry Chemical Physics* **24**: 28700–28781, August 2022.
- R. Valivarthi, L. Narváez, S. I. Davis, N. Lauk, C. Peña, S. Xie, J. P. Allmaras, A. D. Beyer, B. Korzh, A. Mueller, M. Kiburg, M. D. Shaw, E. E. Wollman, P. Spentzouris, D. Oblak, N. Sinclair and M. Spiropulu, “Picosecond synchronization system for quantum networks”, *Journal of Lightwave Technology* **40**(23): 7668–7675, August 2022.
- L. Vallez, S. Jimenez Villegas, A. T. Garcia-Esparza, Y. Jiang, S. W. Park, Q.-Y. Wu, T. M. Gill, D. Sokaras, S. Siahrostami and X.-L. Zheng, “Effect of doping ToO<sub>2</sub> with Mn for electrocatalytic oxidation in acid and alkaline electrolytes”, *Energy Advances* **1**: 357–366, April 2022.
- Y.-Z. Wang, T. Sun, A. H. Bagherzadeh Mostaghimi, T. J. Goncalves, Z.-Z. Liang, Y.-Y. Zhou, W. Zhang, Z.-H. Huang, Y.-H. Ma, R. Cao, S. Siahrostami and H.-Q. Zheng, “Two-dimensional metal-organic frameworks with unique oriented layers for oxygen reduction reaction: trailing the activity through exposed crystal facets”, *CCS Chemistry* **4**(5): 1633–1642, May 2022.
- L. Wang, K. Wm. Hall, Z.-C. Zhang and P. G. Kusalik, “Mixed hydrate nucleation: molecular mechanisms and cage structures”, *Journal of Physical Chemistry B* **126**(36): 7015–7026, September 2022.
- L. Wang, Z.-C. Zhang and P. G. Kusalik, “Hydrate nucleation in water nanodroplets: key factors and molecular mechanisms”, *Energy & Fuels* **37**: 1044–1056, January 2023.
- S. C. Wein, J. C. Loredó, M. Maffei, P. Hilaire, A. Harouri, N. Somaschi, A. Lemaître, I. Sagnes, L. Lanco, O. Krebs, A. Auffèves-Garnier, C. Simon, P. Senellart and C. Antón-Solanas, “Photon-number entanglement generated by sequential excitation of a two-level atom”, *Nature Photonics* **16**: 374–379, April 2022.
- J. Z. Wu and B. C. Sanders, “Sparse interferometry for measuring multiphoton collective phase”, *Physical Review Research* **4**(2): 023134 (14 pp.), May 2022.
- S. Xu, J. Schmiedmayer and B. C. Sanders, “Nonlinear quantum gates for a Bose-Einstein condensate”, *Physical Review Research* **4**(2): 023071 (17 pp.), April 2022.
- A. Yadav, B. Fu, S. N. Bonvicini, L.-Q. Ly, Z.-T. Jia and Y.-J. Shi, “β-Ga<sub>2</sub>O<sub>3</sub> nanostructures: Chemical vapor deposition growth using thermally dewetted Au nanoparticles as catalyst and characterization”, *Nanomaterials* **12**(15): 2589 (15 pp.), July 2022.

- A. Yadav, J. Stevenson, E. Ampong and Y.-J. Shi, “Theoretical study on the decomposition kinetics and thermochemistry of tetramethyldisilazane and hexamethyldisilazane—formation of silanimine and silene species”, *Journal of Physical Chemistry A* **126**(44): 8156–8172, October 2022.
- N. Yazdi, V. Salari and R. Ghobadi, “Spin-induced multipartite steady-state entanglement of motional modes in hexagonal boron nitride membranes”, *Physical Review A* **107**(1): 012610 (8 pp.), January 2023.
- H. Zadeh Haghighi and C. Simon, “Magnetic field effects in biology from the perspective of the radical pair mechanism”, *Journal of the Royal Society Interface* **19**(193): 20220325 (39 pp.), August 2022.
- H. Zadeh Haghighi, R. Rishabh and C. Simon, “Hypomagnetic field effects as a potential avenue for testing the radical pair mechanism in biology”, *Frontiers in Physics* **11**: 1026460 (9 pp.), January 2023.
- H. Zadeh Haghighi and C. Simon, “Radical pairs may play a role in microtubule reorganization”, *Scientific Reports* **12**: 6109 (11 pp.), April 2022.
- P. Zarkeshian, T. Kergan, R. Ghobadi, W. Nicola and C. Simon, “Photons guided by axons may enable backpropagationbased learning in the brain”, *Scientific Reports* **12**: 20720 (11 pp.), December 2022.
- Z.-C. Zhang, P. G. Kusalik, N.-Y. Wu, C.-L. Liu and F.-L. Ning, “Molecular insights into the impacts of calcite nanoparticles on methane hydrate formation”, *ACS Sustainable Chemistry & Engineering* **10**(35): 11597–11605, August 2022.
- Z.-C. Zhang, P. G. Kusalik, N.-Y. Wu, C.-L. Liu and Y.-C. Zhang, “Molecular simulation study on the stability of methane hydrate confined in slit-shaped pores”, *Energy* **257**: 124738 (10 pp.), July 2022.
- H. Zhao, Q. Jin, M. A. Khan, S. Larter, S. Siahrostami, M. G. Kibria and J.-G. Hu, “Rational design of carbon nitride for remarkable photocatalytic H<sub>2</sub>O<sub>2</sub> production”, *Chem Catalysis* **2**(7): 1720–1733, July 2022.

## REFEREED CONFERENCE PROCEEDINGS

- P. Behjat Khatouni, P. K. Shandilya, B. Behera, N. C. Carvalho and P. E. Barclay, “Multimode diamond cavity optomechanics”, TuC1, Proceedings of 2022 IEEE Photonics Conference: 1–2, Vancouver, British Columbia, Canada, 13–17 November 2022.
- L. Cuskelly, D. Bhaskar and L. Belostotski, “A high-linearity 10-GHz-ERBW 3-to-7-GS/s voltage-to-time converter with built-in S/H”, Proceedings of The 23rd IEEE Topical Meeting on Silicon Monolithic Integrated Circuits in RF System: 62–65, Las Vegas, United States of America, 22–25 January 2023.
- A. Das, M. Falamarzi Askarani, J. Davidson, G. Amaral, N. Sinclair, J. A. Slater, S. Marzban, D. Oblak, C. W. Thiel, R. L. Cone and W. Tittel, “A long-lived spectrally multiplexed solid-state optical quantum memory for high-rate quantum repeaters”, Proceedings of SPIE Photonics Europe 2022, volume 12133 (6 pp.), Quantum Technologies, Strasbourg, France, 3–7 April 2022.
- A. Das, M. Falamarzi Askarani, J. Davidson, G. Amaral, N. Sinclair, J. A. Slater, S. Marzban, D. Oblak, C. W. Thiel, R. L. Cone and W. Tittel, “A solid-state multimode long-lived optical quantum memory for quantum repeaters”, STU5F.6, Proceedings of 2022 Conference on Lasers and Electro-Optics (CLEO 2022): 1–3, San Jose, California, United States of America, 15–20 May 2022.
- S. Kumar, E. Saglamyurek and D. Oblak, “Superradiance from spectrally tailored absorption lines in a cavity”, Proceedings of Photonics North 2022, Niagara Falls, Ontario, Canada, 24–26 May 2022.



M. Masum, M. Nazim, M. J. H. Faruk, H. Shahriar, M. Valero, M. A. H. Khan, G. Uddin, S. Barzanjeh, E. Saglamyurek, A. Rahman and S. I. Ahamed, “Quantum machine learning for software supply chain attacks: How far can we go?”, Proceedings of 2022 IEEE 46th Annual Computers, Software, and Applications Conference (COMPSAC): 530–538, Los Alamitos, United States of America, 27 June–1 July 2022.

M. Radpour and L. Belostotski, “An LNA exploiting intrinsic gate-drain feedback for wideband input match from 7.7 to 33.3 GHz and the noise-figure minimum of 1.83 dB”, Proceedings of 2022 IEEE 65th International Midwest Symposium on Circuits and Systems (virtual) (MWSCAS 2022): 1–4, 7–10 August 2022.

M. Radpour and L. Belostotski, “An LNA with input power match from 6.1 to 38.6 GHz, the noise-figure minimum of 1.9 dB, and employing back gate for matching”, Proceedings of 2022 IEEE Radio Frequency Integrated Circuits Symposium (RFIC 2022): 235–238, Denver, Colorado, United States of America, 19–21 June 2022.

S. Taherizadegan, J. Davidson, S. Kumar, R. Ghobadi, D. Oblak and C. Simon, “Demonstration of a model for cavity-enhanced atomic frequency comb quantum memory”, QM4B.6, Proceedings of Quantum 2.0 2022, Boston, Massachusetts, United States of America, 13–16 June 2022.

P. B. Upama, M. J. H. Faruk, M. Nazim, M. Masum, H. Shahriar, G. Uddin, S. Barzanjeh, S. I. Ahamed and A. Rahman, “Evolution of quantum computing: A systematic survey on the use of quantum computing tools”, Proceedings of 2022 IEEE 46th Annual Computers, Software, and Applications Conference (COMPSAC): 520–529, Los Alamitos, United States of America, 27 June–1 July 2022

P. Woosaree and the ALPHA collaboration. “Precision antihydrogen annihilation reconstructions using the ALPHA-g detector”, Proceedings of 12th International Conference on Position Sensitive Detectors, Journal of Instrumentation **17**, C08026, Birmingham, United Kingdom, 12–17 September 2021 (published August 2022).

E. Zohari, J. E. Losby, H. El-Sayed, P. Behjat Khatouni, G. de Oliveira Luiz, J. P. Davis and P. E. Barclay, “Optomechanical crystal nano beam cavities in single crystal diamond”, ThF1, Proceedings of 2022 IEEE Photonics Conference: 1–2, Vancouver, British Columbia, Canada, 13–17 November 2022.

## BOOKS AND CHAPTERS

S. Siahrostami, S. R. Stoyanov, S. Gusarov, I. D. Gates and M. Karamad, “Artificial intelligence for catalysis”, Phil de Luna, eds., Accelerated Materials Discovery: How to Use Artificial Intelligence to Speed Up Development, published by Walter de Gruyter GmbH & Co KG in 2022.

## STUDENT THESES

M. Abarashi, “Electronic properties of tailored 2D materials for chemical sensor applications” (MSc Thesis), April 2022.

O. Aligholamioskooee, “Applying group theory to the study of a carbon trimer defect in hexagonal boron nitride” (MSc Thesis), June 2022.

A. J. Barclay, “Mid Infrared investigations of van der Waals complexes of atmospheric molecules (water, CO, CO<sub>2</sub>, N<sub>2</sub>)” (PhD Thesis), June 2022.

L. Barrios Herrera, “Investigation of Ni-Ceria nanocatalysts: Improved computational methods towards hydrogen production in aquaprocessing of heavy oil” (PhD Thesis), February 2023.

S. N. Bonvicini, “Formation and characterization of monometallic and bimetallic nanoparticles via thermal and pulsed laser dewetting” (PhD Thesis), December 2022.

S. Jimenez Villegas, “Metal oxide-mediated transformations of small molecules for chemical synthesis and energy storage” (MSc Thesis), November 2022.

M. Lai, “300-1500 MHz broadband LNA for the Canadian hydrogen observatory and radio-transient detector” (MSc Thesis), September 2022.

X.-Y. Ma, “Non-suspended optomechanical cavities” (MSc Thesis), January 2023.

N. S. P. Pathirannehelage, “Molecular dynamics simulations of bulk nanobubbles: Investigation of factors important to their stability” (MSc Thesis), March 2023.

S. Shafiei Alavijeh, “Hole burning spectroscopy of Erbium-doped optical fibre for applications in quantum networks” (MSc Thesis), September 2022.

K. Sharman, “Density functional theory studies of optically active defects in two-dimensional hexagonal boron nitride” (MSc Thesis), December 2022.

A. Sheldon, “Cryogenic noise-parameter measurement and the design of cryo-CMOS circuits” (PhD Thesis), May 2022.

J. Smith, “Toward realizing commercially viable MDI-QKD” (MSc Thesis), January 2023.

J. M. Stevenson, “Theoretical and experimental studies of the gas-phase decomposition chemistry of organosilicon compounds containing silicon-nitrogen bonds via hot-wire chemical vapor deposition” (MSc Thesis), August 2022.

X. Tong, “Defining the role of partially-covalent weak interactions in chemical reactions” (PhD Thesis), August 2022.

H. Zhou, “Improving water oxidation with iridium catalysts” (PhD Thesis), September 2022.

## INTELLECTUAL PROPERTY

M. Trifkovic, “Methods of forming a bicontinuous intraphase jammed emulsion gel and uses thereof”, US patent #11,458,444 B2, granted October 2022.

## INVITED PRESENTATIONS AT WORKSHOPS/ CONFERENCES

1 April 2022, C. Simon, “Could quantum entanglement play a role in the brain?”, US Army Research Office Workshop on Quantum Biology (virtual), 1 April 2022.

14 April 2022, B. C. Sanders, “Observing a changing Hilbert-space inner product”, World Quantum Day, National Institute for Theoretical and Computational Sciences, South Africa (virtual), 14 April 2022.

24 April 2022, C. G. Rocha, “Intelligent network materials for sensors and brain-inspired computing applications”, 2022 Korea-Canada Symposium and the workshop on Multiplex Brain Networks (virtual), Calgary, Canada, 21–24 April 2022.

12 May 2022, S. Trudel, “Magnetic nanomaterials: From unexpected luminescence to unexpected magnetism”, EQ07: Emerging Opto-Magnetic Materials—Advances, Trends and Challenges at the Interface Between Optics and Magnetism Symposium, Materials Research Society 2 Spring Meeting 2022, Honolulu, Hawaii, United States of America, 8–13 May 2022.

18 May 2022, C. M. Scandolo, “Dynamical entanglement”, Entanglement in Action, Benasque, Spain, 15–20 May 2022.

19 May 2022, D. Oblak, “Introduction to quantum communication principles and experiments”, 23rd International Symposium on Physics, Monterrey, United States of America, 19–21 May 2022.

- 20 May 2022, D. Oblak, “Quantum networks: What are they for and how do we build them”, 23rd International Symposium on Physics, Monterrey, United States of America, 19–21 May 2022.
- 24 May 2022, C. Simon, “Quantum light-matter interactions from the quantum internet to the brain (remote talk)”, Photonics North 2022, Niagara Falls, Canada, 24–26 May 2022.
- 25 May 2022, P. E. Barclay, “Optomechanical interface to quantum memory”, Photonics North 2022, Niagara Falls, Canada, 24–26 May 2022.
- 7 June 2022, P. E. Barclay, “Optomechanical interface to quantum memory”, SPIE Photonics for Quantum, Rochester, United States of America, 6–9 June 2022.
- 14 June 2022, C. Simon, “Could quantum entanglement play a role in the brain?”, Canadian Chemistry Conference and Exhibition 2022, Calgary, Canada, 13–17 Jun 2022.
- 14 June 2022, H. Zadeh Haghighi, “The roles of radical pairs in biology”, Canadian Chemistry Conference and Exhibition 2022, Calgary, Canada, 13–17 Jun 2022.
- 23 June 2022, G. Gour, “On the role of quantum coherence in thermodynamics”, Quantum Information and Quantum Technology (QIQT-2022, virtual), 23 June 2022.
- 18 July 2022, M. Trifkovic, “Hierarchically structured porous monoliths enabled by moving away from equilibrium in tricontinuous polymer blend nanocomposites”, the 49th World Polymer Congress (MACRO 2022), 17–21 July 2022, Winnipeg, Canada.
- 19 July 2022, C. G. Rocha, “Random nanowire networks for neuromorphic applications”, 20th International Symposium on the Physics of Semiconductors and Applications (ISPSA 2022, virtual), Jeju, South Korea, 17–21 July 2022.
- 4 August 2022, C. Simon, “Could quantum entanglement play a role in the brain?”, Templeton Foundation Workshop on Quantum Effects in Microtubules, Banff, Canada, 4 August 2022.
- 11 August 2022, D. L. Feder, “A graph approach to the matrix permanent and determinant”, Workshop on Graph Theory, Algebraic Combinatorics and Mathematical Physics, Montreal, Canada, 25 July–19 August 2022.
- 12 September 2022, P. E. Barclay, “Diamond quantum photonic sensors,” IEEE RAPiD 2022, Miramar Beach, United States of America, 12–14 September 2022.
- 12 October 2022, P. E. Barclay, “Interfacing light and diamond quantum memory using nanomechanics”, Alberta Quantum Summit 2022, Calgary, Canada, 11–13 October 2022.
- 12 October 2022, L. Belostotski, “A path to fully integrated QPUs” (plenary), Alberta Quantum Summit 2022, Calgary, Canada, 11–13 October 2022.
- 12 October 2022, D. L. Feder, “Qubit resource states for measurement-based quantum teleportation”, Alberta Quantum Summit 2022, Calgary, Canada, 11–13 October 2022.
- 12 October 2022, Y.-J. Shi, “Fabrication of metal nanoparticles and semiconductor nanowires and their applications”, Alberta Quantum Summit 2022, Calgary, Canada, 11–13 October 2022.
- 12 October 2022, C. Simon, “Entanglement from the quantum internet to quantum neuroscience”, Alberta Quantum Summit 2022, Calgary, Canada, 11–13 October 2022.
- 12 October 2022, S. Trudel, “Amorphous photodeposited semiconductors in optoelectronic devices”, Alberta Quantum Summit 2022, Calgary, Canada, 11–13 October 2022.
- 24 October 2022, M. Trifkovic, “Spatiotemporally resolved dynamical transitions in flow of cellulose nanocrystal stabilized emulsions through porous media”, Canadian Chemical Engineering Conference 2022, 23–26 October 2022, Vancouver, Canada.
- 25 October 2022, M. Trifkovic, “Tricontinuous polymer blend nanocomposites as templates for monoliths with hierarchical porosity”, Canadian Chemical Engineering Conference 2022, 23–26 October 2022, Vancouver, Canada.

3 November 2022, C. Simon, “Could quantum entanglement play a role in the brain? (remote talk)”, Hitchhiker’s Advanced Guide to Quantum Collapse Models Workshop, Frascati, Italy, 31 October–4 November 2022.

13 November 2022, P. E. Barclay, “Spin-optomechanics: using vibrations talk to quantum systems,” 2022 IEEE Photonics Conference (IPC), Vancouver, Canada, 13–17 November 2022.

16 November 2022, D. Oblak, “Light-matter interfaces for quantum networks”, 2022 IEEE Photonics Conference (IPC), Vancouver, Canada, 13–17 November 2022.

4 December 2022, C. M. Scandolo, “The operational foundations of PT-symmetric and quasi-Hermitian quantum theory”, Winter Meeting of the Canadian Mathematical Society, Toronto, Canada, 2–5 December 2022.

5 December 2022, D. L. Feder, “The matrix permanent and determinant as an eigenvalue problem”, Winter Meeting of the Canadian Mathematical Society, Toronto, Canada, 2–5 December 2022.

7 December 2022, G. Gour, “On the role of quantum coherence in thermodynamics”, Quantum resources workshop: from mathematical foundations to operational characterisation, Singapore, 5–8 December 2022.

29 December 2022, G. Gour, “On the role of quantum coherence in thermodynamics”, The Quantum Retreat Day, Ramat HaNadiv, Zichron Yaakov, Israel, 29 December 2022.

9 February 2023, C. M. Scandolo, “The power of quantum resources”, First Workshop on Computational Topology and Quantum Computing (virtual), Kigali, Rwanda, 6–10 February 2023.

16 February 2023, C. Simon, “Could quantum entanglement play a role in the brain? (remote talk)”, BIRS Workshop on Non-Markovianity in Open Quantum Systems, Banff, Canada, 12–17 February 2023.



# Linkage

## ACADEMIC COLLABORATIONS

### International Institutions

Aarhus University, Denmark  
 Beihang University, People's Republic of China  
 Ben-Gurion University of the Negev, Israel  
 California Institute of Technology, United States of America  
 Centro de Investigación y de Estudios Avanzados (CINVESTAV), Mexico  
 Cockcroft Institute, United Kingdom  
 Cornell University, United States of America  
 European Organization for Nuclear Research (CERN), Switzerland  
 Florida International University, United States of America  
 Indian Statistical Institute, India  
 Institute for Quantum Computing, Baidu Research, People's Republic of China  
 Jet Propulsion Laboratory, United States of America  
 Jiangnan University, People's Republic of China  
 National Institute of Standards and Technology, United States of America  
 National Institute for Nuclear Physics – Pisa (INFN), Italy  
 National University of Singapore, Singapore  
 Purdue University, United States of America  
 Qingdao Institute of Marine Geology, People's Republic of China  
 RWTH Aachen University, Germany  
 Soreq Nuclear Research Centre, Israel  
 Stockholm University, Sweden  
 Swansea University, United Kingdom  
 Trinity College Dublin, Ireland  
 Università Ca' Foscari Venezia, Italy

Università degli Studi di Cagliari, Italy  
 Università di Pavia, Italy  
 Universität Ulm, Germany  
 Université catholique de Louvain, Belgium  
 Université Paris-Saclay, France  
 Universidade Federal do Espírito Santo, Brazil  
 Universidade Federal do Rio de Janeiro, Brazil  
 University of Cambridge, United Kingdom  
 University College Dublin, Ireland  
 University of Brescia, Italy  
 University of California at Berkeley, United States of America  
 University of California at Los Angeles, United States of America  
 University of Hong Kong, People's Republic of China  
 University of Liverpool, United Kingdom  
 University of Manchester, United Kingdom  
 University of Oxford, United Kingdom  
 University of Science and Technology of China, People's Republic of China  
 University of Sydney, Australia  
 University of Technology Sydney, Australia  
 University of Tokyo, Japan  
 University of Warsaw, Poland

### National Institutions

British Columbia Institute of Technology  
 Simon Fraser University  
 University of Alberta  
 University of British Columbia  
 University of Manitoba  
 University of Ottawa  
 University of Victoria  
 University of Waterloo  
 York University

## INDUSTRIAL/NON-PROFIT/GOVERNMENT COLLABORATION

Collaborative Entity	Name	Role	Nature			Topic
			Collaboration	Service	Training	
1QBit	Seyed Shakib Vedaie	Collaborator (scientific)	✓		✓	Quantum machine learning MITACS graduate internship
ApexQubit	Barry C. Sanders	Scientific Advisory Board Member		✓		Quantum Computing
Clariant Specialty Chemical	Pierre Kennepohl	Collaborator	✓	✓		Catalyst optimization through AI-enabled spectroscopic analysis
CMC Microsystems	Shabir Barzanjeh		✓			Quantum computing
Defence Research and Development Canada	Paul E. Barclay	Collaborator	✓			Quantum sensor
Katal Energy Inc.	Peter Kusalik	NSERC Alliance Grant		✓		Nanobubbles in nanoemulsion fuels
National Research Council Canada	Leonid Belostotski	Principal Investigator	✓			High-speed digitization
National Research Council Canada	Daniel Oblak	Collaborator	✓			Quantum dots for MDI-QKD, integrated quantum dot circuits for quantum communication, and ultraweak photon detection from biological samples
National Research Council Canada	Christoph Simon	Collaborator	✓			Quantum sensing with biophotons, quantum simulation, quantum networks and quantum neuromorphic computing
National Research Council Canada	Nasser Moazzen-Ahmadi	Collaborator	✓			Molecular clusters & gas sensors
SBQuantum	Barry C. Sanders	Advisor		✓		Quantum sensing
TRIUMF	Robert I. Thompson & Timothy Friesen	Collaborator	✓			ALPHA project
Zapata Computing	Archismita Dalal	Collaborator	✓			Noise tailoring for robust amplitude estimation

## VISITORS

Name	Institution
Dorcas Addo	Kwame Nkrumah University of Science and Technology
Javier Aizpurua	Center for Materials Physics in San Sebastian (CSIC-UPV/EHU)
Ismail Akkouche	University Frères Mentouri Constantine 1
Patrizia Calaminici	Centro de Investigación y de Estudios Avanzados (CINVESTAV), Mexico
Shane Eaton	Politecnico di Milano
Mile Gu	Nanyang Technology University/National University of Singapore
Zheng-Cheng Gu	Chinese University of Hong Kong
Hubert de Guise	Lakehead University
Aurélien de la Lande	Centre national de la recherche scientifique (CNRS), Orsay
Sanjib Dey	Indian Institute of Science Education and Research, Mohali
Ania Jayich	University of California, Santa Barbara
Phil Kaye	National Research Council Canada
Andreas Koster	Centro de Investigación y de Estudios Avanzados (CINVESTAV), Mexico
Asif Iqbal	Natural Resources Canada (NRCan)
Nana Liu	Institute of Natural Sciences, University of Michigan and Shanghai Jiao Tong University Joint Institute
Min Namkung	Kyung Hee University
Mosayeb Naseri	Islamic Azad University, Kermanshah Branch
Russ Renzas	Oxford Instruments
Kora-at Petchrat	Prince of Songkla University
Jeong San Kim	Kyung Hee University
Javad Shabani	New York University
Atharva Shukla	Indian Institute of Technology, Roorkee
Namrata Shukla	Banaras Hindu University
Enrique Solano	Kipu Quantum
Thomas Sowinski	Polish Academy of Sciences
Qiping Su	Hangzhou Normal University
Peter Zoller	Universität Innsbruck

# Graduate Courses

Course Name	Instructor	Description
CHEM689.3 Selected Topics in Physical Chemistry (Advanced Materials Characterization Methods)	S. Trudel	Courses covers metrics characterization methods such as electron microscopy, X-ray absorption spectroscopy, X-ray diffraction, X-ray photo electron spectroscopy, and conductivity measurements.
CHEM619.09 Advanced Mas Spectrometric Techniques	Y. J. Shi	Theoretical and practical aspects of mass spectrometric techniques; instrumentation design, method development, instrument maintenance and troubleshooting aspects; operation of different types of instruments and hands-on experience in mass spectra acquisition; analysis and Interpretation of experimental data; applications in identification of unknown chemical compounds; recent developments in the field of mass spectrometry instrumentation including hyphenated techniques and their applications in multidisciplinary fields.
ENGG 601 Professional Development I	M. Trifkovic	Topics include: health and safety, communication styles, supervisory relationships and respect in the lab, presentation skills including presentation planning and voice projection, reference gathering and management, awareness of plagiarism, and writing abstracts.
ENGG 603 Professional Development II	M. Trifkovic	Topics include: presentation skills, skills for writing scientific manuscripts, peer review process, defence and candidacy, engineering design, intellectual property, and networking basics.
MATH653.2 Topics in Pure Mathematics: Representation Theory	C. M. Scandolo	The course is an introductory graduate course to group representation theory, with some reference to actual quantum research. Topics will be chosen according to the interest of the instructors and students.
PHYS677 Implementation of Quantum Information	B. C. Sanders	Proposals and realizations of quantum information tasks including quantum computation, quantum communication, and quantum cryptography in optical, atomic, molecular, and solid state systems.

# Services and Outreach

## CONFERENCES/WORKSHOPS

Name	Committee	Conference Workshop	Location	Dates
P. E. Barclay	Chair, Quantum and Nonlinear Optics Committee	Advanced Photonics Congress	Maastricht, the Netherlands	24–28 July 2022
P. E. Barclay	Co-Chair	NanoCanada International Conference: From Earth to Space	Edmonton, Canada	8–10 June 2022
D. Salahub	Chair, Organizing Committee	21st deMon Developers Workshop	Kananaskis, Canada	13–17 October 2022
B. C. Sanders	Chair, Program Committee	International Conference on Quantum Communication, Measurement and Computing	Lisbon, Portugal	11–15 July 2022
S. Trudel	Co-organizer	North American Solid State Chemistry Conference	Calgary, Canada	2–4 August 2023

## PROFESSIONAL SERVICES

Name	Role	Journal Society Institution
P. E. Barclay	Member, Selection Committee	Banting Postdoctoral Fellowship Program, Government of Canada
P. E. Barclay	Member, Alliance Quantum Evaluation Committee	National Sciences and Engineering Research Council (NSERC)
P. E. Barclay	Project Leader, Quantum Sensing	National Research Council Canada
P. E. Barclay	Project Leader, NanoInitiative Project	National Research Council Nano
P. E. Barclay	Associate Editor	<i>Optics Express</i>
P. E. Barclay	qLab Scientific Lead	Quantum City, Calgary
S. Barzanjeh	Reviewer	<i>Nature Physics</i>
L. Belostotski	Editor-in-Chief	<i>IEEE Journal of Solid-State Circuits</i>

Name	Role	Journal Society Institution
L. Belostotski	Chair, SCC/CAS Chapter	Institute of Electrical and Electronics Engineer (IEEE)
D. L. Feder	Member, Editorial Board	<i>PLOS ONE</i>
D. Oblak	Member, Expert Group on Quantum Technology	Canadian Photonic Industry Consortium (CPIC)
D. R. Salahub	Member, Editorial Board	<i>Advances in Quantum Chemistry</i>
D. R. Salahub	College of Reviewers	Canadian Institutes of Health Research
D. R. Salahub	Member, Editorial Board	<i>Computation</i>
D. R. Salahub	Vice Chair, Editorial Board	<i>Interdisciplinary Science: Computational Life Sciences</i>
D. R. Salahub	Member, Editorial Board	<i>Journal of Computational Chemistry</i>
D. R. Salahub	Member, Academic Editorial Board	<i>PLOS ONE</i>
B. C. Sanders	Scientist	Creative Destruction Lab—Rockies
B. C. Sanders	Scientist	Creative Destruction Lab—Toronto
B. C. Sanders	Member, Core Task Force, Open Quantum Initiative	GESDA—Geneva Science and Diplomacy Anticipator
B. C. Sanders	Member, Editorial Board	IOP ebooks™
B. C. Sanders	Chair, Board of Directors	Deep Tech Canada
B. C. Sanders	Member, Advisory Committee, Applied Quantum Computing Challenge Program	National Research Council Canada
B. C. Sanders	Member, Evaluation Committee	Photonique Quantique Québec
B. C. Sanders	Scientific Director	Quantum City, Calgary
B. C. Sanders	Chair, Steering Committee	Quantum Africa Conference Series
B. C. Sanders	Member, Quantum Working Group 3, Cercle en recherche et innovation Québec-Europe (CRIQUE)	Québec Ministère des Relations internationales et de la Francophonie
B. C. Sanders	Member, Mirror Committee ISO/TC 229	Standards Council of Canada
B. C. Sanders	Chair, Catalyst Grants Support Committee	University of Calgary
B. C. Sanders	Co-Chair, Quantum Computing Task Force	University of Calgary
Y.-J. Shi	Associate Editor	<i>Canadian Journal of Chemistry</i>
C. Simon	Member, Advisory Board of AEP/NANO/SDT	National Research Council Canada
M. Trifkovic	Associate Editor	<i>Physics of Fluids</i>
M. Trifkovic	Member, Prize Selection Committee	<i>Journal of Process Control</i>
S. Trudel	Member, Scholarship and Fellowship Committee	Natural Sciences and Engineering Research Council (NSERC)



## OUTREACH LECTURES

2 June 2022, H. Zadeh Haghighi, “Quantum physics and its applications: Advancing subject awareness in high school students”, Center for Learning at Home, Okotoks, Canada.

24 January 2023, P. E. Barclay, “Diamond photonics: Connecting quantum systems with light and sound”, Optica Nanophotonics Technical Group webinar.

## 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 Peter Zoller from University of Innsbruck delivered a public lecture titled “A taste of quantum: A quantum leap in quantum information” to about 180 persons on 11 October 2022 in the Telus Spark Science Centre in Calgary, and this event was supported by the Faculty of Science marketing and communication team as a joint outreach effort. This public lecture was part of 2022 Alberta Quantum Summit organized by Quantum City, Government of Alberta’s Major Innovation Fund Quantum Project and *Quantum Alberta*.

## MEDIA COVERAGE

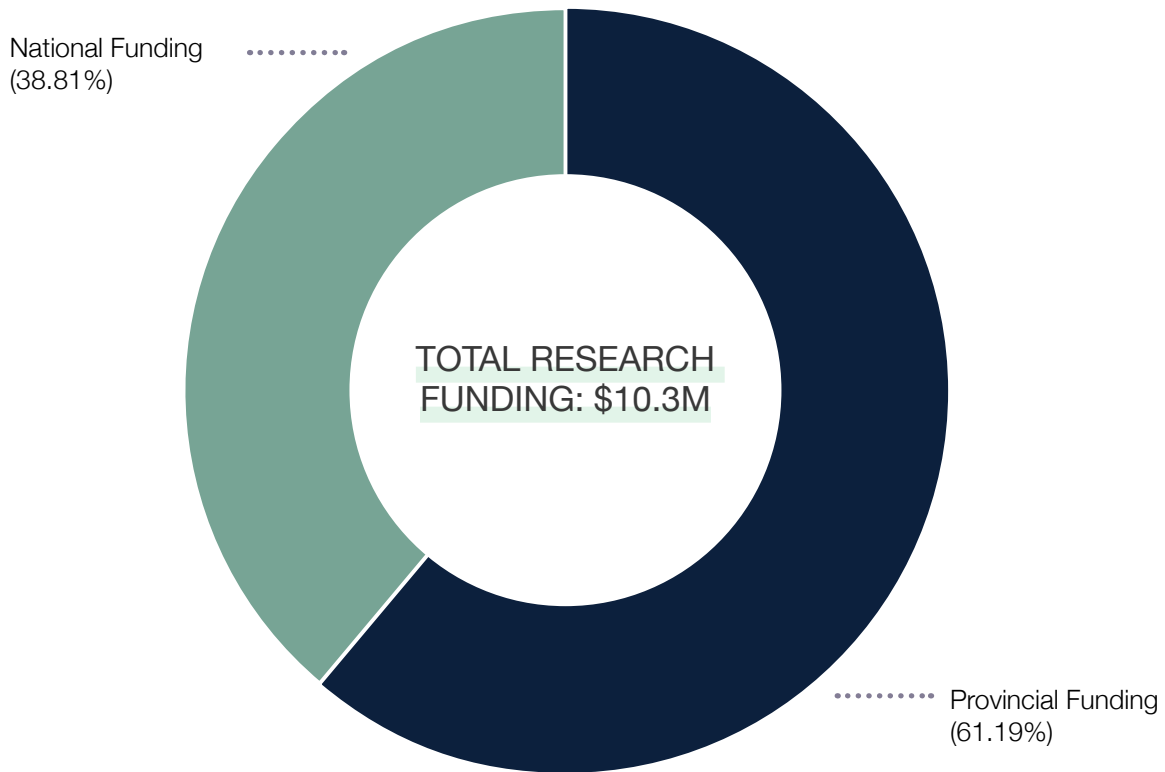
Source	Title of Article	Date
Abu Dhabi TV	10th annual hackathon for social good at NYU Abu Dhabi: Dorcas Addo & Pragati Gupta	1 April 2021
UToday	International team of scientists finds new and simpler way to generate “quantum light”: Christoph Simon	8 April 2021
Betakit.com	Alberta launches new innovation strategy focused on attracting tech talent, capital: Quantum	12 April 2022
CCA-Reports.ca	CCA appoints expert panel on quantum technologies: Barry C. Sanders	26 May 2022
Quantomagazine.org	Physicists rewrite the fundamental law that leads to disorder: Carlo Maria Scandolo	26 May 2022
Globe and Mail	Canadian company Xanadu achieves "big leap forward" in quantum computer race: Barry C. Sanders	1 June 2022
UCalgary News	UCalgary graduate students accelerate online security with quantum physics: Jordan Smith	6 June 2022
Calgary Herald	Global tech firm Mphasis launches in Calgary with potential for hundreds of jobs: Quantum City	7 June 2022
Calgary Herald	Alberta investing \$23 million toward UofC's Quantum City: Barry C. Sanders	9 June 2022
UCalgary News	Quantum City ready to make big moves with universe's tiniest objects: Barry C. Sanders, Paul Barclay, Daniel Oblak and Megan Lee	10 June 2022

Source	Title of Article	Date
Calgary Herald	Philanthropic lawyer tagged as Calgary's citizen of the year: Barry C. Sanders	15 June 2022
Calgary.ca	2022 Calgary Awards recipients: Barry C. Sanders	15 June 2022
UCalgary News	Quantum scientist Barry Sanders spreads knowledge far and wide: Barry C. Sanders	17 June 2022
UCalgary News	UCalgary community members honoured at prestigious Calgary Awards: Barry C. Sanders	17 June 2022
UCalgary News	Big quantum week ahead for University of Calgary and Quantum City: <i>Quantum Alberta</i> & Quantum City	7 October 2022
Alharak Alsaeyasi	Sudanese scientists and researchers from abroad present scientific lectures: Barry C. Sanders	29 December 2022
The Hill Times	Quantum innovation depends on diversified startups investments, say experts: Daniel Oblak	1 February 2023

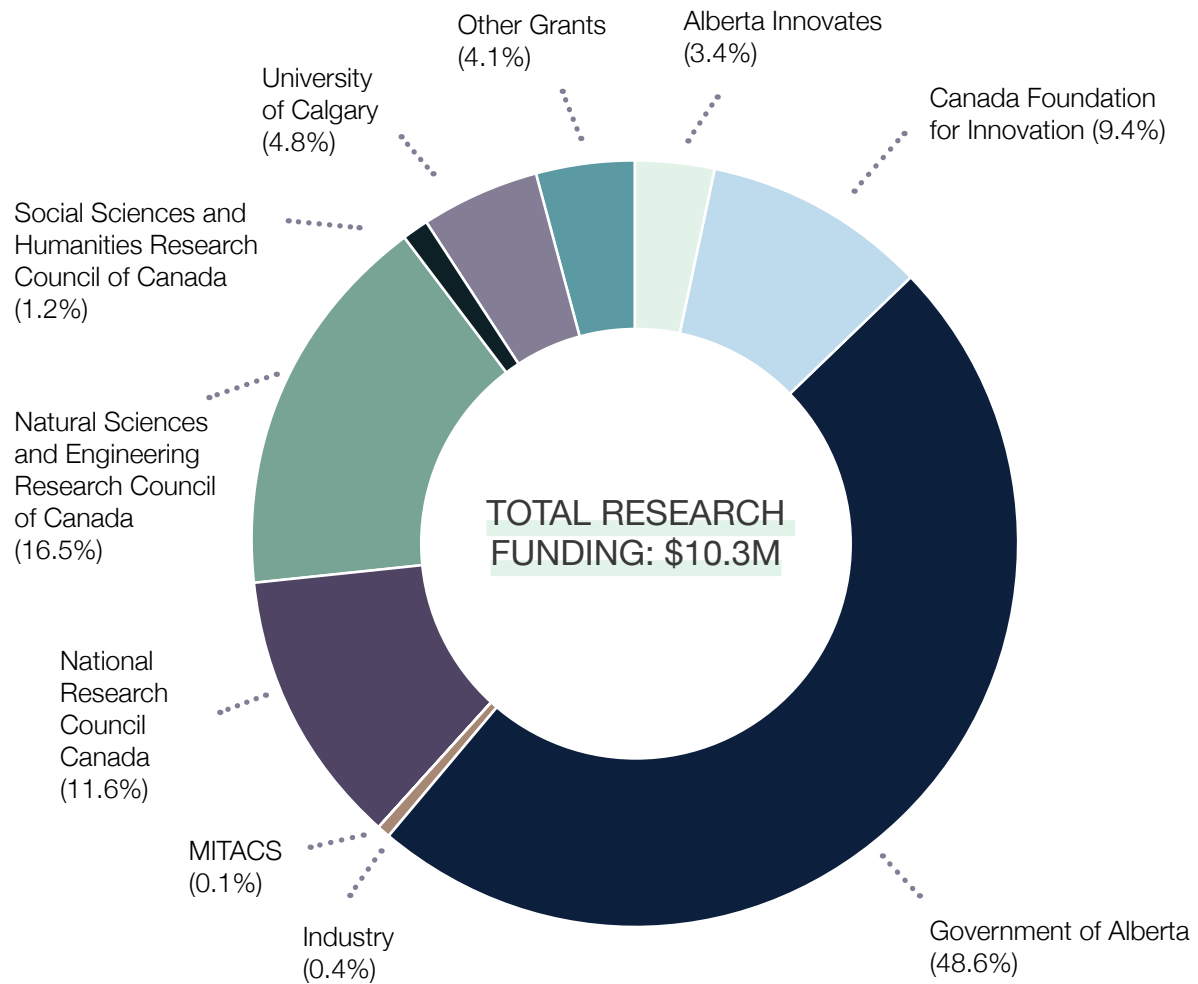
# Research Grants

(unaudited)

## BY ORIGIN



## BY FUNDING AGENCY



# Objectives for Next Year

## PAUL E. BARCLAY

- Measure diamond optomechanical devices in 100 mK environment, with the goal of observing quantum motion
- Demonstrate interactions between high frequency mechanical resonators mediated by a shared coupling to an optical cavity mode
- Demonstrate optomechanical crystal in hBN van der Waals material
- Elucidate the mechanism for unexpected multiphoton emission in diamond nanostructures

## SHABIR BARZANJEH

- Develop integrated topologically insulated entangled sources
- Fabricate quantum-limited amplifiers
- Develop quantum imaging and sensing using single photon sources and single photon sensitive cameras

## LEONID BELOSTOTSKI

- Demonstrate cryo-cooled complementary metal-oxide semiconductor (CMOS) oscillators experimentally for quantum-computer drive and readout
- Develop cryogenic low-noise amplifier and an analog-to-digital converter (ADC) for future use in a quantum-computer integrated drive and control integrated circuits (ICs)
- Develop cryogenic noise-parameter models for FDSOI MOSFETs

## DAVID L. FEDER

- Develop a reinforcement-learning approach to search for good quantum error correction codes in continuous-variable graph states
- Analyze the topological properties of microring resonator arrays
- Extend recently discovered families of one-dimensional resource states for measurement-based quantum teleportation to two dimensions, in order to perform universal measurement-based quantum computation

- Ascertain the influence of interactions on topological states for spin-orbit-coupled Bose-Einstein condensates in optical lattices

### TIM FRIESEN

- Perform improved precision hyperfine spectroscopy of antihydrogen
- Make first direct measurement of the Lamb-shift in antihydrogen
- Develop new microwave resonator and Penning trap electrode to induce antiproton spin flip transitions in antihydrogen
- Improve magnetometry for antihydrogen 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

### PETER HØYER

- Develop quantum algorithms for graph problems

### PIERRE KENNEPOHL

- Explore the role of charge transfer processes in the decoherence lifetime of transition metal-based molecular electron spin qubits
- Define the benefits of charge-neutral molecular electron spin qubits (how important are counterions?)

### PETER G. KUSALIK

- Examine the factors important in the stability and mechanism of formation of aqueous nanobubbles
- Develop and test empirical and coarse grain potential models appropriate for simulations studies of self-assembly processes in zinc-carboxylate metal-organic frameworks
- Use machine learning approaches to characterize formation of order during metal-organic frameworks 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
- Reveal how the aqueous solution structure of potassium dihydrogen phosphate impacts its crystal nucleation and growth

### NASSER MOAZZEN-AHMADI

- Design and test a photonic gas sensor for use at mid-infrared wavelengths
- Develop accurate global potential energy surfaces for molecular complexes
- Spectroscopic studies of microsolvation of carbon dioxide in rare gases



## DANIEL OBLAK

- Detect effect of magnetic fields on photon emission from biological samples using an electron-multiplying charge-coupled device camera and multimode-fibre-coupled superconducting nanowire single-photon detectors
- Extend storage time and efficiency of photons in ytterbium-doped material
- Demonstrate interaction between microwave field and ytterbium-yttrium oxyorthosilicate at sub-Kelvin temperatures
- Demonstrate hole-burning and measure coherence time of molecular lanthanide crystals
- Demonstrate generation of multipartite entangled states
- Develop proof-of-concept of measurement-device-independent quantum key distribution system with post-processing included
- Implement polar code-based error-reconciliation for quantum key distribution

## CLAUDIA GOMES DA ROCHA

- Develop a computational description of electronic quantum transport in metal-oxide-based and carbon-based nanomaterials that can be applied in next-generation neuromorphic systems
- Characterize the optical transmission, thermal properties, and electrical resistance of metallic nanowire thin films to improve transparent conductor technologies
- Develop architectures for quantum neuromorphic networks and quantum sensor devices

## DENNIS R. SALAHUB

- Develop new quantum chemistry/machine-learning algorithms for global structure optimization
- Develop new quantum chemistry/machine-learning algorithms for transition states and molecular dynamics
- Explore the potential of quantum computers for quantum chemistry and for machine learning
- Advance the design of new nanocatalysts by machine learning for quantum chemistry
- Advance the design of new multi-elemental perovskite materials for thermal, optical and electrochemical production of hydrogen using advanced machine learning for quantum chemistry methods
- Coordinate an international collaboration on artificial intelligence for design of new materials producing improved methods and software

## BARRY C. SANDERS

- Devise pulse engineering to enhance performance of ion-trap quantum computing
- Develop a simple yet complete model for clock networks to analyse if and how quantum enhancements could apply
- Complete a conceptual framework for interconnecting machine learning and control in both classical and quantum domains
- Construct, employ and characterize quantum-enhanced computer programs for solving problems in energy and health sectors
- Develop a best-practice verification & validation framework for the quantum supply chain

## CARIO MARIA SCANDOLO

- Establish quantum causality in the framework of operational probabilistic theories
- Explore how classical probabilities emerge from entanglement
- Generalize thermodynamic fluctuation relations to resource theories
- Generalize the objectivity mechanism in general probabilistic theories
- Formulate physical theories on Boolean lattices

## YUJUN SHI

- Explore the technique of solid-state thermal dewetting for the fabrication of bimetallic and high-entropy alloy nanoparticles
- Develop a protocol to use the pulsed laser-induced dewetting method for large-area production of metal nanoparticles
- Develop the growth method for low-dimensional semiconductor nanostructures

## CHRISTOPH SIMON

- Identify promising tasks—time series prediction, classification and quantification of potential quantum advantage for quantum neuromorphic computing with nonlinear oscillators and spin networks
- Collaborate on experiments and model magnetic-field on biophoton emission, pigmentation, anesthesia, and stem cell growth. Model flavin adenine dinucleotide as a potential biological quantum sensor for quantum biology
- Implement quantum memories, quantum repeaters and distributed quantum computing with Rydberg atoms, T centres in silicon, nitrogen-vacancy centres in diamond, rare-earth ion doped crystals and fibers, and hybrid alkali-noble gas vapours for quantum networks
- Quantum sensing with nitrogen-vacancy centres (for magnetoencephalography) and biophotons

## ROB I. THOMPSON

- Resolve atomic structures of antihydrogen
- Upgrade the ALPHA-g apparatus for precision gravitational free-fall experiments on antihydrogen in the ALPHA-g apparatus
- Develop laser-based ion-source options for TITAN

## MILANA TRIFKOVIC

- Expand the use of quantum dots in development of quantum optical circuits through far-from-equilibrium templating techniques

## SIMON TRUDEL

- Develop amorphous materials for use in optoelectronic devices
- Develop materials for use in transistors
- Develop reverse monte Carlo simulations of X-ray absorption spectra

# **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**

**IQST.UCALGARY.CA**

 **@iqstucalgary**

Phone: (403) 220-4403

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

**Institute for Quantum  
Science & Technology**

University of Calgary  
2500 University Drive NW  
Calgary, AB T2N 1N4  
Canada