Report: PIMS CRG for the Mathematics of Quantum Information

2012

Barry Sanders, Principal Investigator

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Specific events and activities that took place during your CRG in 2012

Laser Physics 2012 (LPHYS'12): PIMS CRG Director Barry Sanders was co-Chair, and CRG Affiliate Alex Lvovsky was co-Deputy Chair. This prestigious international conference was held at the University of Calgary 23-27 July 2012. There were approximately 400 participants including CRG members David Feder, Christoph Simon and Wolfgang Tittel. Further information can be found at http://www.lasphys.com/workshops/lasphys12/

Canadian Association of Physicists Annual Congress 2012: PIMS CRG Director Sanders was co-Chair. This national conference was held at the University of Calgary 11-15 June 2012 with approximately 600 participants. Members of the CRG that were directly involved with the conference included David Feder, Alex Lvovsky, Christoph Simon and Wolfgang Tittel. Further information on this Congress can be found at http://www.cap.ca/en/congress/2012

Joint course on topological methods in quantum error correction for UBC and SFU Jan-Apr 2012: Participants: Vijaykumar Singh (CRG postdoc from Simon Fraser University), Igor Tupitsyn (postdoc in P. Stamp's group), Arman Zaribafiyan & Poya Haghnegahdar (Students in R. Raußendorf's group), Robert Raußendorf. Class was held two hours per week.

List of CRG participants in 2012

PIMS Faculty – Leaders (Principal Investigators)

1) Aram Harrow – University of Washington
2) Petr Lisonek – Simon Fraser University
3) Robert Raußendorf – University of British Columbia
4) Barry Sanders – University of Calgary

Other Faculty Members in the CRG

1) Leslie Ballentine – Simon Fraser University
2) Boris Blinov – University of Washington
3) David Feder – University of Calgary
4) Kai-Me Fu – University of Washington
5) Gilad Gour – University of Calgary
6) Subhadeep Gupta – University of Washington
7) Paul Haljan – Simon Fraser University
8) Peter Høyer – University of Calgary
9) Alex Lvovsky – University of Calgary
10) Mark Oskin – University of Washington
11) Christoph Simon – University of Calgary
12) Philip Stamp – University of British Columbia
13) Wolfgang Tittel – University of Calgary
14) William Unruh – University of British Columbia

Visitors

Visitors to Network

L.C. Kwek (University of Singapore) visited University of British Columbia (18 -20 July 2012) and University of Calgary (23-27 July 2012)

Courtney Brell (University of Sydney) visited University of British Columbia (27 August – 1 September 2012)

Dan Browne (University College London) visited University of British Columbia (27 August – 1 September 2012)

Norbert Schuch (Universität Aachen) visited University of Washington (10-14 September 2012) and University of British Columbia (18-20 September 2012)

Jens Eisert (Freie Universität) visited University of British Columbia (11-12 September 2012)

Dr. Markus Grassl (Centre for Quantum Technologies, National University of Singapore) visited Simon Fraser University (4 October 2012) and University of British Columbia (9 October 2012) and University of Calgary (10 October 2012)

Intra-network exchanges

Mohammad Amin (IQC, DWave Systems) visited University of Calgary (25 January 2012)

Vlad Gheorghiu (University of Calgary) visited Simon Fraser University (6-8 February 2012) and University of British Columbia (8-10 February 2012)

Ran Hee Choi (University of Calgary) visited Simon Fraser University (6-8 February 2012) and University of British Columbia (8-10 February 2012)

Gilad Gour (University of Calgary) visited University of British Columbia (22 February 2012)

Paul Barclay (University of Calgary) visited University of British Columbia (12 September 2012)

Paul Pham (University of Washington) visited University of British Columbia (14-20 September 2012)

Kamil Michnicki (University of Washington) visited University of Calgary (26 September 2012)

Paul Barclay (University of Calgary) visited University of Washington (13 November 2012)

PDFs and graduate students who are part of your CRG

Graduate Students with Principal Investigators

1) Mark Adcock. Supervisor: Barry Sanders (University of Calgary).
2) Khulud Almutairi. Supervisor: Barry Sanders (University of Calgary).
3) Hessa Alotaibi. Supervisor: Barry Sanders (University of Calgary).
4) Nathan Babcock. Supervisor: Barry Sanders (University of Calgary).
5) Isaac Crosson. Supervisor: Aram Harrow (University of Washington).
6) Ish Dhand. Supervisor: Barry Sanders (University of Calgary).
7) Poya Haghnegahdar. Supervisor: Robert Raußendorf (University of British Columbia).
8) Ben Lavoie. Supervisor: Barry Sanders (University of Calgary).
9) Kamil Michnicki. Supervisor: Aram Harrow (University of Washington).
10) Cihan Okay. Supervisor: Robert Raußendorf (University of British Columbia).
11) Paul Pham. Supervisor: Aram Harrow (University of Washington).
12) David Rosenbaum. Supervisor: Aram Harrow (University of Washington).
13) Zahra Shaterzadeh-Yazdi. Supervisor: Barry Sanders (University of Calgary).
14) Lukas Svec. Supervisor: Aram Harrow (University of Washington).
15) Dongsheng Wang. Supervisor: Barry Sanders (University of Calgary).
16) Johnny Yan. Supervisor: Aram Harrow (University of Washington).
17) Ehsan Zahedinejad. Supervisor: Barry Sanders (University of Calgary).
18) Arman Zaribafiyan. Supervisor: Robert Raußendorf (University of British Columbia).
19) Kevin Zatloukal. Supervisor: Aram Harrow (University of Washington).

PDFs

1) Raouf Dridi. Supervisor: Robert Raußendorf (University of British Columbia).
2) Vlad Gheorghiu. Supervisor: Barry Sanders (University of Calgary).[*]
3) Maritza Hernandez. Supervisor: Philip Stamp (University of British Columbia). [*]
4) Neil Lovett. Supervisor: Barry Sanders (University of Calgary).
5) Vijaykumar Singh. Supervisor: Petr Lisonek (Simon Fraser University).[*]
6) Collin Trail. Supervisor: Barry Sanders (University of Calgary).[*]
7) Yunjiang Wang. Supervisor: Barry Sanders (University of Calgary).

PDF's and graduate students who were part of your CRG. Where are they now?

Past Graduate Students

1) Ran Hee Choi. Supervisor: Barry Sanders (University of Calgary). [Completed 2012]
2) Michael Skotiniotis. Barry Sanders (University of Calgary). Now a postdoctoral associate at the Institute for Quantum Optics and Quantum Information - Austrian Academy of Sciences. [Completed 2012]
3) Borzumehr Toloui Semnani. Barry Sanders (University of Calgary). Now a postdoctoral fellow at Haverford College. [Completed 2012]

[*] Supported by PIMS: CRG MQI

Past PDFs

1) Patrick Ming-yin Leung. Supervisor: Barry Sanders (University of Calgary). Current position to be determined.

Brief summaries of research projects fostered by your CRG

1) *Quantum Codes*: All four nodes are working on quantum codes now and the CRG has enabled valuable dialogue and exchange between the various nodes, as well bringing in quantum coding experts as visitors, to enable high-quality research in this area within the CRG. Quantum codes are valuable to protect quantum information in efficient ways.
   a) Lisonek's group at SFU has made important breakthroughs with quantum codes. Specifically the group has produced algebraic constructions of entanglement-assisted quantum error correction codes based on linear quaternary codes. These families include cyclic codes and constacyclic codes with concise formulæ for the number of entangled bits used as resources. These formulas form the basis of an efficient algorithm to search for such codes with 'good parameters'. The group has also studied quaternary low-density parity-check matrix codes that lead to entanglement-assisted quantum error correction codes with few requisite entangled bits and Tanner graphs with a girth of six, thereby extending previous girth-four results.
   b) Lisonek's group has developed a new application of Construction X (known from the theory of classical error correcting codes) to quantum stabilizer codes. They have found more than twenty new stabilizer qubit codes with parameters that improve on the best known such codes. One key achievement has been the construction by Michnicki of a stabilizer code that is spatially local in three dimensions and has an energy gap scaling like a polynomial in the number of qubits in the code.
   c) Harrow's group at the University of Washington has been working on spatially local quantum error correcting codes.
   d) The Sanders group developed an enhanced feedback iterative decoding scheme for sparse quantum codes by exploiting not just the syndrome from the stabilizer but also the frustrated checks using belief propagation. In more recent work the Sanders group is studying generalized concatenated quantum coding, which is leading to more efficient ways for generating new quantum codes.
   e) PIMS CRG MQI postdoc Vlad Gheorghiu developed generalized semiquantum secret sharing schemes by exploiting ramp quantum secret sharing. Quantum secret sharing is a subset of quantum error correction, which is a form of quantum coding.
   f) The LU-LC conjecture stated that local unitary equivalent stabilizer states are also local Clifford equivalent, but this was proved to be false in 2008. Lisonek's group has produced geometric constructions of 27-qubit and 35-qubit counterexamples to the conjecture. From these constructions, the group is studying synthetic constructions of non-linear quantum gates.
2) *Models of Quantum Computing*: UBC and UC are working on models of quantum computing, i.e., on different ways to realizes universal quantum computation.
   a) The groups of Raußendorf and Lisonek at UBC and SFU , respectively, have been studying the connection between measurement-based quantum computation quantum

contextuality. In particular this project aims to study how measurement-based quantum computing connects with a sheaf-theoretic mathematical underpinning of contextuality and the role of Cech cohomology therein.

b) Sanders and Høyer with PhD student Adcock undertook a careful study of the advantages and limitations of the so-called continuous variable model of quantum computation. Specifically the model was used to study the oracle decision problem to show that the hitherto believed capability of using momentum states as basis states does not in fact lead to any major speed-up over the classical algorithm due to the Fourier time-bandwidth trade-off. A rigorous framework for the continuous-variable model has been established for both finite- and infinite-dimensional Hilbert space cases.

3) In the Sanders group, quantum simulation has been commenced for open quantum systems. The idea of quantum simulation is to employ quantum computers to compute properties of dynamically changing systems. Preliminary results show that open quantum systems are indeed efficiently simulatable on a quantum computer under the assumption that individual particles interact with separate environments.

Main scientific accomplishments derived from your CRG: any noteworthy theorems or breakthroughs?

Noteworthy breakthroughs

- SFU: An efficient algorithm delivers new quantum stabilizer codes that are superior to previously existing codes. More than twenty have been found so far [Lisonek].

- UW: Given a set of quantum states with bounded pairwise fidelities, a bound on how many copies are required for to distinguish between them reliably is found [Harrow in IEEE TIT].

- UBC: The two-dimensional Affleck-Kennedy-Lieb-Tasaki state on the honeycomb lattice is a universal resource for quantum computation [Raußendorf in Phys. Rev. A].

- UC: Developed a theoretical framework for treating photon coincidence probabilities with single photons entering each input port with controllable relative delays in the entry time. The coincidence rates sample the immanants of the special unitary matrix describing the interferometric transformation [Sanders].

Lists of 2012 publications (PIMS leaders are in bold; PIMS faculty is in *italics*; PIMS postdocs are marked with *; graduate students are marked with a §)

1) B. A. Blumer, M. S. Underwood and *D. L. Feder*, Single-qubit unitary gates by graph scattering, Physical Review A **84**(6): 062302 (7 pp.), 5 December 2011, arXiv.org:1111.5032.

2) M. Adcock§, *P. Høyer* and **B. C. Sanders**, Quantum computation with coherent spin states and the close Hadamard problem, arXiv.org:1112.1446, 6 December 2011.
3) R. Ghobadi, A. R. Bahrampour and *C. Simon*, Optomechanical entanglement in the presence of laser phase noise, Physical Review A **84**(6): 063827 (5 pp.), 12 December 2011.
4) S. Raeisi, P. Sekatski and *C. Simon*, Coarse graining makes it hard to see micro-macro entanglement, Physical Review Letters **107**(25): 250401 (5 pp.), 16 December 2011.
5) **A.W. Harrow** and A. J. Winter, How many copies are needed for state discrimination? IEEE Transactions on Information Theory, **58**(1):1–2, 1 January 2012, arXiv: quant-ph/0606131.
6) I. T. Durham and **B. C. Sanders**, Quantum frameness for Charge-Parity-Time (CPT) inversion symmetry, arXiv.org:1201.1594, 8 January 2012.
7) *D. L. Feder*, Maximally entangled gapped ground state of lattice fermions, Physical Review A **85**(1): 012312 (8 pp.), 12 January 2012, arXiv.org: 1112.5133.
8) N. Wiebe and N. S. Babcock§, Improved error-scaling for adiabatic quantum evolutions, New Journal of Physics **14**(1): 013024 (15 pp.), 16 January 2012.
9) A. Ambainis, A. W. Harrow, and M. Hastings, Random tensor theory: extending random matrix theory to random product states, Communications in Mathematical Physics 310(1):25–74, 1 February 2012, arXiv:0910.0472.
10) P. Xue and **B. C. Sanders**, Two quantum walkers sharing coins, Physical Review A **85**(2): 022307 (8 pp.), 6 February 2012.
11) Y. J. Wang, **B. C. Sanders**, B.-M. Bai and X.-M. Wang, Enhanced feedback iterative decoding of sparse quantum codes, IEEE Transactions on Information Theory *58*(2): 1231 - 1241, 6 February 2012.
12) E. Saglamyurek, N. Sinclair, J. Jin, J. A. Slater, D. Oblak, F. Bussières, M. George, R. Ricken, W. Sohler and *W. Tittel*, Conditional detection of pure quantum states of light after storage in a Tm-doped waveguide, Physical Review Letters **108**(8): 083602 (5 pp.), 22 February 2012, arXiv.org:1111.0676.
13) R. Schützhold and *W. G. Unruh*, Cosmological particle creation in the lab? arXiv:1203.1173, 6 March 2012.
14) **A. W. Harrow**, Why now is the right time to study quantum computing, XRDS: Crossroads, The ACM Magazine for Students **18**(3):32–37, 1 March 2012.
15) A. de la Lande, N. S. Babcock§, J. Řezáč, B. Lévy, **B. C. Sanders** and D. R. Salahub, Quantum effects in biological electron transfer, Physical Chemistry Chemical Physics **14**(17): 5902 - 5918, 20 March 2012.
16) S. Raeisi, *W. Tittel* and *C. Simon*, Proposal for inverting the quantum cloning of photons, Physical Review Letters **108**(12): 120404 (5 pp.), 22 March 2012.
17) A. Rubenok, J. A. Slater, P. Chan, I. Lucio Martinez and *W. Tittel*, Proof-of-principle field test of quantum key distribution immune to detector attacks, arXiv.org:1204.0738, 3 April 2012.
18) A. Kleczewski, M. R. Hoffman, J. A. Sherman, E. Magnuson, *B. B. Blinov*, and E. N. Fortson, Coherent excitation of the 6S1/2 to 5D3/2 electric-quadrupole transition in 138Ba+, Physical Review A **85**(4) (5pp.), 20 April 2012.

19) V. Gheorghiu*, Generalized Semiquantum Secret-Sharing Schemes, Physical Review A **85**(5): 052309 (10 pp.), 15 May 2012, arXiv.org:1204.1072 [quant-ph].
20) M. Siomau, A. A. Kamli, S. A. Moiseev and **B. C. Sanders**, Entanglement creation with negative index metamaterials, Physical Review A **85**(5): 050303(R) (4 pp.), 15 May 2012.
21) B. Barak, F. G. Brandão, **A. W. Harrow**, J. Kelner, D. Steurer, and Y. Zhou, Hypercontractivity, sum-of-squares proofs, and their applications, In Proceedings of the 44th symposium on Theory of Computing, STOC '12 19 May 2012. Invited to special issue of SIAM J of Computing. arXiv:1205.4484
22) M. S. Underwood and *D. L. Feder*, Bose-Hubbard model for universal quantum-walk-based computation, Physical Review A **85**(5): 052314 (9 pp.), 22 May 2012, arXiv.org:1204.6021.
23) **B. C. Sanders**, Review of entangled coherent states, Journal of Physics A: Mathematical and Theoretical **45**(24): 244002 (22 pp.), 30 May 2012, arXiv.org:1112.1778.
24) *W. G. Unruh*, Irrotational, two-dimensional surface waves in fluids, arXiv:1205.6751, 30 May 2012.
25) P. Palittapongarnpim, A. MacRae and *A. I. Lvovsky*, A monolithic filter cavity for experiments in quantum optics, Review of Scientific Instruments **83**(6): 066101 (3 pp.), 7 June 2012, arXiv.org:1203.4843.
26) K. Heshami, A. Green, Y. Han, A. Rispe, E. Saglamyurek, N. Sinclair, *W. Tittel* and *C. Simon*, Controllable-dipole quantum memory, Physical Review A **86**(1): 013813 (7 pp.), 9 July 2012.
27) T. Stuart, J. A. Slater, R. Colbeck, R. Renner and *W. Tittel*, An experimental test of all theories with predictive power beyond quantum theory, Physical Review Letters **109**(2): 020402 (5 pp.), 9 July 2012, arXiv.org:1105.0133.
28) M. Skotiniotis§ and *G. Gour*, Alignment of reference frames and an operational interpretation for the G-asymmetry, New Journal of Physics **14**(7): 073022 (21 pp.), 11 July 2012, arXiv.org:1202.3163.
29) B. Pepper, R. Ghobadi, E. Jeffrey, *C. Simon* and D. Bouwmeester, Optomechanical Superpositions via Nested Interferometry, Physical Review Letters **109**(2): 023601 (5 pp.), 12 July 2012.
30) A. MacRae, T. Brannan, R. Achal and *A. I. Lvovsky*, Tomography of a high-purity narrowband photon from a transient atomic collective excitation, Physical Review Letters **109**(3): 033601, 20 July 2012, arXiv.org:1112.4855.
31) J. Clark, K. Heshami and *C. Simon*, Photonic quantum memory in two-level ensembles based on modulating the refractive index in time: Equivalence to gradient echo memory, Physical Review A **86**(1): 013833 (5 pp.), 23 July 2012.
32) S.-H. Tan, Y. Y. Gao, H. de Guise and **B. C. Sanders**, SU(3) Quantum Interferometry with single-photon input pulses, arXiv.org:1208.5677, 28 August 2012.
33) R. Kumar, E. Barrios, A. MacRae, E. Cairns, E. H. Huntington and *A. I. Lvovsky*, Versatile Wideband Balanced Detector for Quantum Optical Homodyne Tomography, Optics Communications **285**: 5259 - 5267, 29 August 2012, arXiv.org:1111.4012.

34) A. Y. Khramov, A. H. Hansen, A. O. Jamison, W. H. Dowd, and *S. Gupta*, Dynamics of Feshbach molecules in an ultracold three-component mixture, Physical Review A. **86**(3) (4 pp.), 10 September 2012.
35) B. Lavoie§, P. M. Leung and **B. C. Sanders**, Low-loss surface modes and lossy hybrid modes in metamaterial waveguides, Photonics and Nanostructures - Fundamentals and Applications **10**(4): 602 - 614, 14 September 2012.
36) P. Xue and **B. C. Sanders**, Controlling and reversing the quantum-to-classical transition of a quantum walk by driving the coin, arXiv.org:1209.3376, 15 September 2012.
37) R. Thomas, C. Kupchak, G. S. Agarwal and *A. I. Lvovsky*, Observation of electromagnetically induced transparency in evanescent fields , arXiv.org:1209.4318, 19 September 2012.
38) M. Adcock§, *P. Høyer* and **B. C. Sanders**, Gaussian quantum computation with oracle-decision problems, Quantum Information Processing 11, 26 September 2012, arXiv.org:1206.1035. (accepted or in press).
39) *W. G. Unruh*, Temperature of a decoherent oscillator with strong coupling, Philosophical Transactions of the Royal Society A: Physical, Mathematical and Engineering Sciences **370**(1975): 4460-4468, 28 September 2012, arXiv.org:1205.4263.
40) R. Kumar, E. Barrios, C. Kupchak and *A. I. Lvovsky*, Experimental characterization of bosonic photon creation and annihilation operators, arXiv.org:1210.1150, 3 October 2012.
41) R. Ghobadi, *A. I. Lvovsky* and *C. Simon*, Creating and detecting micro-macro photon-number entanglement by amplifying and de-amplifying a single-photon entangled state, arXiv.org:1210.1514, 4 October 2012.
42) S. Raeisi, N. Wiebe and **B. C. Sanders**, Quantum-circuit design for efficient simulations of many-body quantum dynamics, New Journal of Physics **14**(10): 103017 (26 pp.), 9 October 2012.
43) P. J. Coles, V. Gheorghiu* and R. B. Griffiths, Collisional decoherence of tunneling molecules: a consistent histories treatment, Physical Review A **86**(4): 042111 (15 pp.), 11 October 2012, arXiv.org:1205.6188 [quant-ph].
44) P. Xue, Z. Ficek and **B. C. Sanders**, Probing multipartite entanglement in a coupled Jaynes-Cummings system, Physical Review A **86**(4): 043826 (10 pp.), 16 October 2012.
45) J. S. Kim, *G. Gour* and **B. C. Sanders**, Limitations to sharing entanglement, Contemporary Physics **53**(5): 417 - 432, 17 October 2012.
46) D. Rideout, T. Jennewein, G. Amelino-Camelia, T.F. Demarie, B.L. Higgins, A. Kempf, A. Kent, R. Laflamme, X. Ma, R.B. Mann, E. Martin-Martinez, N.C. Menicucci, J. Moffat, *C. Simon*, R. Sorkin, L. Smolin and D. R. Terno, Fundamental quantum optics experiments conceivable with satellites - reaching relativistic distances and velocities, Classical and Quantum Gravity **29**(22): 224011 (44 pp.), 18 October 2012.
47) A. Anis and *A. I. Lvovsky*, Maximum-likelihood coherent-state quantum process tomography, New Journal of Physics **14**(10): 105021, 19 October 2012, arXiv.org:1204.5936.
48) L. Norris, C. Trail*, P. S. Jessen and I. H. Deutsch, Enhanced squeezing of a collective spin via control of its qudit subsystems, Physical Review Letters **109**(17): 173603-1 - 173603-5, 23 October 2012, arXiv.org:1205.4263.

49) V. Gheorghiu* and *G. Gour*, Multipartite Entanglement Evolution Under Separable Operations, Physical Review A **86**(5): 050302 (Rapid Communications) (5 pp.), 7 November 2012, arXiv.org:1205.2667 [quant-ph].
50) A. H. Hansen, A. Y. Khramov, W. H. Dowd, A. O. Jamison, B. Plotkin-Swing, R. J. Roy, *S. Gupta*, Production of quantum degenerate mixtures of ytterbium and lithium with controllable inter-species overlap, arXiv:1211.2267, 9 November 2012.
51) B. Pepper, E. Jeffrey, R. Ghobadi, *C. Simon* and D. Bouwmeester, Macroscopic superpositions via nested interferometry: finite temperature and decoherence considerations, New Journal of Physics **14**(11): 115025 (12 pp.), 27 November 2012.
52) S. Haloui and V. Singh*, The characteristic polynomials of abelian varieties of dimension 4 over finite field, section in book, Volume 574 Contemporary Mathematics: Arithmetic, Geometry, Cryptography and Coding Theory, Y. Aubry, C. Ritzenthaler, A. Zykin eds.: Chapter 5: 59-68, Published by The American Mathematical Society, United States of America, 2012.

Networking that can be directly attributed to your CRG. Exchanges that took place between the institutes are listed below. This list also relates to the “Seminar/Lecture Series Award Conditions”

List of talks given

Date: 25 January 2012
Speaker: Mohammad Amin [DWave Systems]
Location: University of Calgary
Title: Robustness of adiabatic quantum computation against decoherence

Abstract: Decoherence is widely regarded as the most significant obstacle in the development of quantum computers. Without complex and costly error correction schemes, most forms of quantum computation must be completed within a short decoherence time, significantly limiting their applicability. Adiabatic quantum computation (AQC), however, is a quantum computation scheme that is believed to be more robust against decoherence. In this talk, I will start by introducing AQC as a scheme for quantum computation, with an emphasis on its inherent tolerance towards environmental noise. I then demonstrate a hardware implementation of AQC using superconducting flux qubits, and present experimental results from the operation of a 16-qubit block of a 128-qubit superconducting quantum processor. The results show not only tolerance against environmental noise, but also significant enhancement of performance from weakly coupling to a thermal environment. All results are shown to be in close agreement with quantum mechanical predictions.

Date: 7 February 2012
Speaker: Vlad Gheorghiu [University of Calgary]
Title: Optimal semi-quantum secret sharing schemes
Location: University of British Columbia

Abstract: I will introduce the notion of stabilizer quantum error correcting codes and perfect quantum secret sharing schemes. Then I will illustrate how, using any given stabilizer code, one can always construct a perfect quantum secret sharing scheme out of it by allowing the sharing of extra classical bits between the dealer and the players. Next I will describe a general scheme of reducing the amount of classical communication, then prove that the scheme is optimal for the stabilizer code being used. The optimality proof is based on the fact that the correlations between the dealer and the players can be fully described by an "information" group, a subgroup of the symplectic Weil-Heisenberg group. The symplectic structure of the information group effectively gives the minimum number of classical bits required. Finally I will provide an explicit protocol that achieves the bound by employing the notion of "twirling" (or scrambling) the information group. The talk will be self-contained and no prior exposure to quantum information is assumed. Most ideas will be illustrated by simple examples.

Date: 8 February 2012
Speaker: Vlad Georghiu [University of Calgary]
Title: Optimal perfect quantum secret sharing schemes via stabilizer quantum error correcting codes and "twirling" of symplectic structures
Location: University of British Columbia

Abstract: I will introduce the notion of stabilizer quantum error correcting codes and perfect quantum secret sharing schemes, then I will illustrate how, using any given stabilizer code, one can always construct a perfect quantum secret sharing scheme out of it by allowing the sharing of extra classical bits between the dealer and the players. Next I will describe a general scheme of reducing the amount of classical communication, then prove that the scheme is optimal for the stabilizer code being used. The optimality proof is based on the fact that the correlations between the dealer and the players can be fully described by an ``information" group, a subgroup of the symplectic Weil-Heisenberg group; the symplectic structure of the information group effectively gives the minimum number of classical bits required. Finally I will provide an explicit protocol that achieves the bound by employing the notion of ``twirling" (or scrambling) the information group. The talk will be self-contained and no prior exposure to quantum error correcting theory is assumed. Most ideas will be illustrated by simple examples.

Date: 9 February 2102
Speaker: Ran Hee Choi [University of Calgary]
Title: Entanglement Sharing Schemes
Location: University of British Columbia

Abstract: Entanglement is a necessary resource for quantum information tasks such as teleportation, dense coding, and Ekert QKD scheme. In entanglement sharing scheme, one share of a bipartite entangled pair is encoded and distributed to untrusted players in a way that they must collaborate in groups to unlock the entanglement. I show how to use quantum error correcting codes to share maximally entangled states between a dealer and collaborating groups of players by exploiting quantum secret sharing concepts and techniques.

Date: 22 February 2012

Speaker: Gilad Gour [University of Calgary]
Title: Local additivity of the minimum entropy output of a quantum channel
Location: University of British Columbia

Abstract: An important open problem in quantum information concerns with the question whether entanglement between signal states can help to send classical information on quantum channels. Recently, Hasting proved that entanglement does help by finding a counter-example for the long standing additivity conjecture that the minimum von-Neumann entropy output of a quantum channel is additive under taking tensor products. In this talk I will show that the minimum von-Neumann entropy output of a quantum channel is locally additive. Hasting's counterexample for the global additivity conjecture, makes this result somewhat surprising. In particular, it indicates that the non-additivity of the minimum entropy output is related to a global effect of quantum channels. I will end with few related open problems.

Date: 29 March 2012
Speaker: Vijaykumar Singh [Simon Fraser University]
Title: Classification of isogeny classes of supersingular abelian varieties over finite fields
Location: University of British Columbia

Abstract: I will give a complete classification of the isogeny classes of supersingular abelian varieties for all dimensions by explicitly finding all possible characteristic polynomial of Frobenius endomorphism up to dimension 7 and giving an algorithm to find for all dimensions using Honda-Tate Theory. This is joint work with Gary McGuire and Alexey Zaytsev.

Date: 20 July 2012
Speaker: L. C. Kwek [University of Singapore]
Title: Quantum simulator using atoms and photons in a hollow core fiber
Location: University of British Columbia

Abstract: To circumvent the limitations of conventional computers in tackling complex physical processes, Richard Feynman proposed nearly thirty years ago a means of using well-understood quantum systems called quantum simulators (or quantum emulators) to emulate similar, but otherwise poorly understood, quantum systems. Among the various physical systems that could be used to build a quantum simulator, one possibility is the use of regular arrays of atoms or ions that are held in place by laser fields. In this talk, we describe how a quantum simulator is also possible through photons propagating through a nonlinear optical waveguide and interacting with cold atomic ensemble placed inside the fiber.

Date: 27 August 2012
Speaker: Dan Browne [University College London]
Title: Computation from Correlation: Putting Bell inequality violation to work
Location: University of British Columbia

Abstract: The violation of Bell inequalities is perhaps the most striking example of the incompatibility of quantum physics and the classical world. Measurements on separated entangled quantum particles can be correlated in ways provably impossible if the measurements are described by any local hidden variable model. Quantum information aims to exploit the non-classical features of quantum mechanics for new technologies. The non-classicality of quantum correlations has been exploited for both quantum cryptography and quantum computation - most prominently in measurement-based quantum computation - an architecture for a quantum computer proposed by Hans Briegel (Univ. Innsbruck) and Robert Raussendorf (UBC) [1]. In measurement-based quantum computation, the computation proceeds as a set of single particle measurements on a lattice of particles prepared in a special entangled state. Remarkably, this model is equivalent in power to standard models of quantum computation such as networks of entangling quantum logic gates, even though, after the initial state preparation, particles do not interact. In my talk, I will give an overview of the Bell inequalities and an introduction to measurement-based quantum computation and describe recent research [2,3,4] which demonstrates a concrete connection between these two. I will show that Bell inequality experiments have a natural interpretation as “measurement-based computations” which clearly and concise captures the limitations on correlations in local hidden variable theories, and describe new insights on Bell inequalities which arise from this. [1] R. Raussendorf and H. J. Briegel (2001). A One-Way Quantum Computer, Phys. Rev. Lett. 86 5188 (2001) [2] J. Anders and D.E. Browne, Computational power of correlations, Phys. Rev. Lett. 102, 050502 (2009). [3] R. Raussendorf, Quantum computation, discreteness, and contextuality, arXiv:0907.5449 [4] M.J. Hoban and D.E. Browne, Stronger Quantum Correlations with Loophole-free Post-selection, Phys. Rev. Lett. 107, 120402 (2011)

Date: 28 August 2012
Speaker: Courtney Brell [University of Sydney]
Title: Quantum Double Cluster States
Location: University of British Columbia

Abstract: The toric code and the cluster state are related in a few ways. Perhaps most straightforwardly, the toric code state can be prepared by single qubit measurements on a cluster state. The cluster state can also be used to implement topologically protected computation by simulating the braiding of topological defects in the toric code. The toric code is the simplest member of a family of models called the Kitaev quantum double models. This is a class of lattice spin models whose excitations are described by anyons. Significantly, in some cases these anyons can be non-abelian and can implement universal quantum computation by braiding. We make use of the relationship between the toric code and cluster state to define generalized cluster states corresponding to each quantum double model, and show that analogous relationships hold between these Quantum Double Cluster States (QDCS) and the Kitaev quantum double models. We explore the use of QDCS for topological cluster state computation, and find that it may be most suited to implementation in an adiabatic architecture, as opposed to the measurement-based scheme that is typically envisaged. In doing so, we describe a protocol for universal topologically protected adiabatic quantum computation.

Date: 30 August 2012
Speaker: Dan Browne [University College London]

Title: Magic state distillation for fault-tolerant quantum computation in all prime dimension
Location: University of British Columbia

Abstract: Joint work with Earl Campbell (FU-Berlin) and Hussain Anwar (UCL) Magic state distillation is a key component of some high-threshold schemes for fault-tolerant quantum computation [1], [2]. Proposed by Bravyi and Kitaev [3] (and implicitly by Knill [4]), and improved by Reichardt [4], Magic State Distillation is a method to broaden the vocabulary of a fault-tolerant computational model, from a limited set of gates (e.g. the Clifford group or a sub-group[2]) to full universality, via the preparation of mixed ancilla qubits which may be prepared without fault tolerant protection. Magic state distillation schemes have a close relation with quantum error correcting codes, since a key step in such protocols [5] is the projection onto a code subspace. Bravyi and Kitaev proposed two protocols; one based upon the 5-qubit code, the second derived from a punctured Reed-Muller code. Reed Muller codes are a very important family of classical linear code. They gained much interest [6] in the early years of quantum error correction theory, since their properties make them well-suited to the formation of quantum codes via the CSS-construction [7]. Punctured Reed-Muller codes (loosely speaking, Reed-Muller codewords with a bit removed) in particular lead to quantum codes with an unusual property, the ability to implement non-Clifford gates transversally [8]. Most work in fault-tolerant quantum computation focuses on qubits, but fault tolerant constructions can be generalised to higher dimensions [9] - particularly readily for prime dimensions. Recently, we presented the first magic state distillation protocols [10] for non-binary systems, providing explicit protocols for the qutrit case (complementing a recent no-go theorem demonstrating bound states for magic state distillation in higher dimensions [11]). In this talk, I will report on more recent work [12], where the properties of punctured Reed-Muller codes are employed to demonstrate Magic State distillation protocols for all prime dimensions. In my talk, I will give a technical account of this result and present numerical investigations of the performance of such a protocol in the qutrit case. Finally, I will discuss the potential for application of these results to fault-tolerant quantum computation. This will be a technical talk, and though some concepts of linear codes and quantum codes will be briefly revised, I will assume that listeners are familiar with quantum error correction theory (e.g. the stabilizer formalism and the CSS construction) for qubits. [1] E. Knill. Fault-tolerant postselected quantum computation: schemes, quant-ph/0402171 [2] R. Raussendorf, J. Harrington and K. Goyal, Topological fault-tolerance in cluster state quantum computation, arXiv:quant-ph/0703143v1 [3] S. Bravyi and A. Kitaev. Universal quantum computation based on a magic states distillation, quant- ph/0403025 [4] B. W. Reichardt, Improved magic states distillation for quantum universality, arXiv:quant-ph/0411036v1 [5] E.T. Campbell and D.E. Browne, On the Structure of Protocols for Magic State Distillation, arXiv:0908.0838 [6] A. Steane, Quantum Reed Muller Codes, arXiv:quant-ph/9608026 [7] Nielsen and Chuang, Quantum Information and Computation, chapter 10 [8] E. Knill, R. Laflamme, and W. Zurek, Threshold accuracy for quantum computation, quant-ph/9610011 [9] D. Gottesman, Fault-Tolerant Quantum Computation with Higher-Dimensional Systems, quant-ph/9802007 [10] H. Anwar, E.T Campbell and D.E. Browne, Qutrit Magic State Distillation, arXiv:1202.2326 [11] V. Veitch, C. Ferrie, J. Emerson, Negative Quasi-Probability Representation is a Necessary Resource for Magic State Distillation, arXiv:1201.1256v3 [12] H. Anwar, E.T Campbell and D.E. Browne, in preparation

Date: 11 September 2012
Speaker: Jens Eisert [Freie Universitaet]
Title: Equilibration and thermalization of quantum many-body systems: A quantum information perspective
Location: University of British Columbia

Abstract: Complex quantum systems out of equilibrium are at the basis of a number of the most intriguing puzzles in physics. This talk will be concerned with recent progress on understanding how quantum many-body systems out of equilibrium eventually come to rest. The first part of the talk will highlight theoretical progress on this question, taking in several ways a quantum information view - employing ideas of Lieb-Robinson bounds, quantum central limit theorems and of concentration of measure. These findings will be complemented by experimental work with ultra-cold atoms in optical lattices, constituting a dynamical "quantum simulator", allowing to probe physical questions that are presently out of reach for state-of-the-art numerical techniques based on matrix-product states, states generalizing the AKLT construction. We will also claim that such a device could solve problems that are presumably difficult to solve classically even with other techniques.

Date: 11 September 2012
Speaker: Norbert Schuch [Universitaet Aachen, Germany]
Title: Characterizing topological spin liquids with Projected Entangled Pair States
Location: University of Washington

Abstract: We apply the framework of Projected Entangled Pair States (PEPS) to characterize the spin liquid nature of resonating valence bond (RVB) states on the kagome lattice. First, we use symmetries in the PEPS description to prove that the RVB state appears as the four-fold topologically degenerate ground state of a local Hamiltonian which is adiabatically connected to both the dimer state and Kitaev's Toric Code. Second, we use exact diagonalization type numerical PEPS techniques to study its spin liquid nature: We demonstrate that any correlation function in the RVB state decays exponentially, and that both the decay of correlations and the overall change of the state behave smoothly for the entire path connecting the RVB with the Toric Code state, suggesting that both systems are in the same topological phase. This is joint work with I. Cirac, D. Perez-Garcia, and D. Poilblanc.

Date: 12 September 2012
Speaker: Paul Barclay [University of Calgary]
Title: Nanoscale optomechanics: sensors and hybrid quantum systems
Location: University of British Columbia

Abstract: Recent advances in optomechanics utilize the co-localization of optical and mechanical modes for coherent energy exchange between photons and phonons within nanoscale structures. These optomechanical devices have demonstrated exceptional promise as sensors of mechanical motion, and as probes of mesoscopic quantum effects. In this talk I will review these advances, and discuss efforts to create optomechanical devices optimized for detecting torsional excitations associated with nanoelectronic and magnetic systems. I will also examine the possibility of studying the interaction between electron spins embedded within optomechanical devices and single phonons.

Date: 14 September 2012
Speaker: Paul Pham [University of Washington]
Title: Quantum Architecture
Location: University of British Columbia

Abstract: Quantum architecture is the study of how efficiently a quantum algorithm can be implemented given realistic constraints on qubit layout and interactions. The usual model is a two dimensional lattice with single- and two-qubit nearest-neighbor gates. I will present recent progress in constructing quantum circuits on a 2D architecture, which can be used to implement Shor's factoring algorithm in depth polylogarithmic in the size of the input, described in http://arxiv.org/abs/1207.6655 I will also discuss the connection between quantum architecture and quantum compiling via the Kitaev-Shen-Vyalyi algorithm, more general results about how quantum architecture affects algorithm efficiency, and implications for future research, both theoretical and experimental.

Date: 18 September 2012
Speaker: Norbert Schuch [Universität Aachen]
Title: Characterizing topological spin liquids with Projected Entangled Pair States
Location: University of British Columbia

Abstract: We apply the framework of Projected Entangled Pair States (PEPS) to characterize the spin liquid nature of resonating valence bond (RVB) states on the kagome lattice. First, we use symmetries in the PEPS description to prove that the RVB state appears as the four-fold topologically degenerate ground state of a local Hamiltonian which is adiabatically connected to both the dimer state and Kitaev's Toric Code. Second, we use exact diagonalization type numerical PEPS techniques to study its spin liquid nature: We demonstrate that any correlation function in the RVB state decays exponentially, and that both the decay of correlations and the overall change of the state behave smoothly for the entire path connecting the RVB with the Toric Code state, suggesting that both systems are in the same topological phase. joint work with I. Cirac, D. Perez-Garcia, and D. Poilblanc

Date: 26 September 2012
Speaker: Kamil Michnicki [University of Washington]
Location: University of Calgary
Title: Self correcting quantum memories with a polynomial energy barrier

Abstract: The ferromagnetic hard disc drive is a paradigmatic example of a self-correcting classical memory. It uses natural thermalization to passively protect against errors by encoding information in the ground state of a Hamiltonian. Local errors must pass through a large energy barrier to perform a global bit flip error. Self-correcting quantum memories have the further restriction that both bit flip and phase errors must simultaneously be protected. The previous highest energy barrier for a 3-d quantum code is O(log N) where N is the number of qubits in the lattice. Whether quantum codes with power law energy barriers exist or not has been an open problem before this result. A primitive called welding is introduced which like concatenation is a method for creating new stabilizer codes from pre-existing stabilizer codes. The procedure of welding is applied to a 3-d toric code, with rough and smooth boundaries, to produce a stabilizer code with a power law minimum energy barrier, an exponential improvement over previous results.

Date: 9 October 2012 Speaker: Markus Grassl [Centre for Quantum Technologies, National University of Singapore]
Title: Concatenation Techniques for Quantum Error-Correcting Codes
Location: University of British Columbia

Abstract: Quantum error-correcting codes (QECC) are important to build large-scale quantum computers. The talk will discuss various concatenation techniques that allow to build large codes from smaller component codes. Moreover, it will be shown how concatenation techniques can be used to construct codes for particular channels, e.g. the amplitude-damping channel.

Date: 10 October 2012
Speaker: Markus Grassl [Centre for Quantum Technologies, National University of Singapore]
Title: Polynomial Invariants of Three-Qubit Systems
Location: University of Calgary

Abstract: Polynomial invariants provide a tool to characterise quantum states with respect to local unitary transformations. Unfortunately, the situation becomes very complicated already for mixed states of three qubits due to combinatorial explosion. After an introduction to the mathematical background and general tools, the talk will present preliminary results for mixed quantum states and Hamiltonians for three-qubit systems. The talk is based on joint work in progress with Robert Zeier.

Date: 8 November 2012
Speaker: Vijaykumar Singh [Simon Fraser University]
Title: Algebraic-geometric approach to local unitary-local Clifford equivalence counter examples
Location: University of British Columbia

Abstract: The LU-LC problem is, that given two stabilizer states which are LU-equivalent are they also LC-equivalent? This is not true in general and a brute force computer generated example was given by Ji et al [1] in the case of 27-qubits. I will give a geometric description of the counter example for 27-qubits using certain elliptic quadric, its automorphism group action and its decomposition into Schafli's double-six and smaller quadric [4]. We can also construct LU-LC counter example for 35-qubits geometrically from the hyperbolic quadric and we are currently looking at constructing the resulting AND-gate computer-free which should lead to a better understanding of it. I will begin with description of the stabilizer state in terms of a quadratic form and a linear code[2] and briefly describe the equivalence of LU-LC problem with the quadratic form problem [3]. In parallel, I will discuss this theory in qudits. This is joint work with Petr Lisonek.

Date: 13 November 2012
Speaker: Paul Barclay [University of Calgary]
Title: Nanoscale optomechanics: sensors and hybrid quantum systems
Location: University of British Columbia

Abstract: Recent advances in optomechanics utilize the co-localization of optical and mechanical modes for coherent energy exchange between photons and phonons within nanoscale structures. These optomechanical devices have demonstrated exceptional promise as sensors of mechanical motion, and as probes of mesoscopic quantum effects. In this talk I will review these advances, and discuss efforts to create optomechanical devices optimized for detecting torsional excitations associated with nanoelectronic and magnetic systems. I will also examine the possibility of studying the interaction between electron spins embedded within optomechanical devices and single phonons.

Exchanges and collaborations that took place

UW-UC collaboration: On a visit of Kamil Michnicki to Calgary, he and Vlad Gheorghiu discussed the problem of efficiently decoding stabilizer codes using single-qubit measurements and two-qubit unitary operations. They also considered the generalization of this problem to stabilizer codes defined on qudits. Michnicki also began collaborating with Yun-jiang Wang on attempting to bound the number of encoded qubits in a code in terms of the spatial dimension defining the code's graph (along the lines of the bounds for classical codes obtained in arXiv:1111.3275).

UW-UBC collaboration: On a visit of Paul Pham to UBC, he discussed new approaches to quantum compiling with several members of the group there. The new approaches were principally based on variants of magic state distillation, and on making use of measurement and classical feedback to improve on the scaling of the Solovay-Kitaev theorem.

UBC-SFU collaboration: Dr. Vijaykumar Singh visits the Raußendorf at UBC weekly to collaborate.

UC-UBC collaboration: Ran Hee and Vlad visited UBC for mutual discussions on quantum secret sharing. Also Gilad Gour went to …

UC-SFU collaboration: Ran Hee and Vlad visited UBC for mutual discussions on quantum secret sharing.

Did you obtain other sources of funding for events connected to your CRG? If so, please list them

1) For Laser Physics 2012 (LPHYS'12)::
    a. Department of Physics and Astronomy (University of Calgary) $7,000.00
    b. Perimeter Institute $3,000.00

   c. US Army $15,000.00
   d. Institute for Quantum Information Science (University of Calgary) $1,000.00
2) For Canadian Association of Physicists Annual Congress 2012:
   a. Department of Physics and Astronomy (University of Calgary) $5,000.00
   b. Faculty of Science (University of Calgary) $5,000.00
   c. Alberta Innovates Technology Futures (AITF) $5,000.00
   d. Office of the Vice-President Research (University of Calgary) $2,500.00
   e. Mount Royal University $1,000.00
   f. Institute for Quantum Information Science (University of Calgary) $1,000.00
   g. Von Humbolt Foundation $500.00
3) Robert Raußendorf received $18,000.00 for postdoc salary of Raouf Dridi, from US IARPA.

Did your CRG help attract new faculty to Western Canada in 2011? Can you give some examples?

No, because no faculty positions were open in theoretical fields associated with quantum information.

Projections for 2013

1) Canadian Summer School on Quantum Information (CSSQI) at the UC 17-21 June 2013. Up to one hundred Canadian and international students are expected to participate. Organized by Sanders and Høyer.
2) Canadian Quantum Information Students' Conference (CQISC). At UC 24-28 June 2013. Up to one hundred Canadian and international students are expected to participate. Organized by Edouard Pelchat.
3) Jointly with Dan Browne (University College London) Robert Raußendorf is organizing the 2013 workshop on 'Quantum Information and Foundations of Quantum Mechanics' to be held at the University of British Columbia in July 2013. Workshop organization has begun.
4) The PIMS CRG MQI seminar series, which invites visitors to at least two of the four PIMS CRG MQI institutions, will continue commencing with Nicolas Brunner from the University of Bristol who will be visiting Calgary in December 2012.
5) Student travel support from the PIMS CRG MQI has enabled students to attend conferences to present theoretical work and will continue.