The Third Annual PHAS Symposium

SB 142 and SB 144

February 21, 2018

Program

9:15 am - 9:30 am: Sign-in/name-tag pick-up (SB 142)

9:30 am - 9:45 am: Opening Remarks (SB 142)

9:45 am -10:30 am: Keynote Speaker, Dr. Barry Sanders (SB 142)

10:30 am -10:45 am: Coffee Break (SB 142)

10:45 am - 11:45 am: Session 1 (SB 142)

Chair: Mohammad Hassan Yaghoubi

- 10:45 am - 11:00 am: Masoud Habibi
- 11:00 am - 11:15 am: Faezeh Kimiaee Asadi
- 11:15 am - 11:30 am: Alex Cameron
- 11:30 am - 11:45 am: Bipin Chawla

11:45 am-1:00 pm Lunch and Poster Session (SB 144)

- Steven Nich
- Svetlana Kuznetsova
- John Alho
- Stephen Wein
- Sumit Goswami
- Lingyue Sun
- Burke Brockelbank

1:15 pm - 2:00 pm: Keynote Speaker, Dr. Susan Skone (SB 142)

2:00 pm - 2:45 pm: Session 2 (SB 142)

Chair: Anna Ordog

- 2:00 pm - 2:15 pm: Daniel Korchinski
- 2:15 pm - 2:30 pm: Paul Herringer
- 2:30 pm - 2:45 pm: Andres Zambrano

2:45 pm - 3:15 pm: Coffee break (SB 144)

3:15 pm - 4:15 pm: Session 3 (SB 142)

Chair: Taylor Cameron

- 3:15 pm - 3:30 pm: JP Hadden
- 3:30 pm - 3:45 pm: Gustavo Castro do Amaral
- 3:45 pm - 4:00 pm: Ayush Mandwal

4:00 pm - 4:15 pm: Closing remarks (SB 142)

5:00 pm - 7:30 pm: Social event (LDL)

The organizing committee would like to thank the Department of Physics & Astronomy, the PHAS DGA and PASA for their financial support for this symposium.

The organizing committee

- Taylor Cameron
- Pamela Freeman
- Ayush Mandwal
- Anna Ordog
- Kyle Reiter
- Mohammad Hassan Yaghoubi

Keynote Speakers

Dr Barry Sanders

Building a Quantum Computer

Quantum computing has evolved from intriguing concept 35 years ago to buzzing commercial endeavor today. I explain the purpose of a quantum computer, how it would work, different types of quantum computing approaches, and various media from photons to superconducting circuits to ions for realizing afunctioning quantum computer.

Dr. Barry Sander's Bio:

Dr. Barry Sanders is the Director of the Institute for Quantum Science and Technology at the University of Calgary and holds a 1000-Talent Chair at the University of Science and Technology China. He is especially well known for seminal contributions to theories of quantum-limited measurement, highly nonclassical light, practical quantum cryptography and optical implementations of quantum information tasks. His current research interests include quantum resources and algorithms, optical and atomic implementations of quantum information tasks and protocols, quantum processes in biological systems, and machine learning for quantum control. Dr. Sanders is a Fellow of the Institute of Physics (U.K.), the Optical Society of America, the Australian Institute of Physics, the American Physical Society and the Royal Society of Canada, and a Senior Fellow of the Canadian Institute for Advanced Research. In 2016 Sanders was awarded the Imperial College London Doctor of Science (DSc) degree, and he is Editor-in-Chief of New Journal of Physics.

Dr. Susan Skone

Space Weather and Future Global Navigation Satellite Systems

The U.S. Global Positioning System (GPS) has generated a multi-billion dollar industry with hundreds of millions of users worldwide. New Global Navigation Satellite System (GNSS) constellations and capabilities are emerging from Europe, Russia and China. By the end of this decade there will be more than 150 navigation satellites transmitting more than 400 multifrequency signals. Positioning accuracies are approaching the threshold of sub-centimetre worldwide, with new services supporting everything from precision timing to self-driving cars and drones. Such rapid development of new GNSS capabilities requires ongoing investigation of space weather phenomena, and associated ionospheric propagation conditions, that may adversely affect GNSS signals. In this presentation work is presented from multiple studies conducted in partnership with national agencies to ensure reliability and continuity of GNSS during severe space weather events. The impacts of space weather on GNSS are demonstrated and mitigation methods described for evolving user applications. Real-world examples are provided from projects conducted with the Canadian Coast Guard, NAV CANADA, NASA JPL and the European Space Agency.

Dr Susan Skone's Bio:

Dr. Susan Skone is a Professor in the Department of Geomatics Engineering and Associate VicePresident (Research) at the University of Calgary. Dr. Skone conducts research in Global Navigation Satellite Systems, leading projects in GPS technology for commercial aviation, maritime navigation and spaceborne applications. She led the development and deployment of the CanX-2 satellite mission GPS payload and has developed licensed software products sold worldwide. She has led more than 25 sponsored research projects with industry and government partners including the Canadian and European Space Agencies, the Canadian Coast Guard and NAV CANADA. Recognitions include over a dozen Institute of Navigation best paper/presentation awards.

Presentation Abstracts

Continuous-variable quantum ramp secret sharing schemes

M. Habibi and B. Sanders

Secret sharing is an information theoretically secure cryptographic protocol which enables a dealer to distribute a message, which can be a bit string or a qubit string, between multiple players. In a secret sharing scheme, specific subset of players form access structure to retrieve the message whereas the other subsets ; i.e., the adversarial structure, are denied any information about the secret whatsoever. Continuous-variable quantum secret sharing still faces the challenge that information about the quantum secret can be leaked into the adversarial structure. The mutual information between dealer and player structures for the continuous-variable quantum secret sharing schemes is required to assess the security of aforementioned protocols. Our aim is to solve quantum mutual information between dealer and any player structure correspond to Tyc-Row-Sanders continuous-variable quantum secret sharing scheme. Quantum state sharing facilitates a broad range of multi-node quantum communication networks and our result can be empolyed to analyze the leakage of quantum information to unreliable components in such networks.

Quantum repeaters with individual rare-earth ions at telecommunication wavelengths

F. Kimiaee Asadi, N. Lauk, S. Wein, N. Sinclair, C. O'Brien and C. Simon

Long-distance entanglement distribution is an essential ability for future applications such as quantum networks, quantum key distribution (QKD) or secure communication, quantum teleportation and global clock networks. However, due to the unavoidable transmission losses present in every quantum communication channel, the distances for an efficient entanglement distribution via direct state transfer are limited to a few hundred kilometers. To overcome this limitation, the use of a quantum repeater has been suggested. Here, I present a scheme for generating heralded entanglement between spatially-separated single erbium and europium ions that are doped into crystals. Gate operations between nearby ions are performed using the electric-dipole coupling to map the quantum states of the ions onto each other and establish long-lasting entanglement between distant ions. I describe preparation strategies that allow the design of a quantum repeater. I also propose an approach that utilizes multiplexing to enhance the entanglement distribution rate.

Irregular Lattice Chains and Fermionic Entanglement Scaling

A. Cameron

Quantum thermodynamics aims to elucidate the principles governing the strange behaviours of many systems at the edge of our current understanding. A key quantity in this field is the resource of quantum entanglement, which naturally embeds itself into the study of strongly correlated matter and quantum information processing. In particular, the scaling of bipartite entanglement with the size of the bipartition is a tool we may use to identify curious quantum phase transitions, such as that for a superconductor. This scaling is known for non-interacting fermions on a regular lattice of arbitrary dimension, as well as for one-dimensional systems whose correlations decay exponentially in distance. This work considers an irregular lattice configuration to study the effect of band structure on the scaling of bipartite entanglement for a chain of non-interacting fermions. The location of the Fermi surface with respect to the lattice band gap is varied, and results compared to the current literature.

Measuring Turbulence in Disks of CHANG-ES Spiral Galaxies by Depolarization of Radio Waves

B. Chawla, J. M. Stil, P. Schmidt, M. Krause, J. A. Irwin

Polarization of radio waves is the only way we can measure magnetic fields in distant galaxies. Faraday rotation of linearly polarized radio waves is one of the most effective ways to measure these distant magnetic fields.

The turbulent plasma and depth of galaxies causes different amounts of Faraday rotation for each line of sight. These effects are referred to as differential Faraday rotation. In the case of a turbulent plasma, differential Faraday rotation leads to depolarization of the radio waves at longer wavelengths.

Measuring depolarization is a new technique that exploits a special capability of new receiver technologies. Using observations from the CHANG-ES Survey I have detected depolarization of the radio waves for the nearby edge-on galaxy NGC 891. CHANG-ES is a survey of 35 edge-on spiral galaxies made with the Janskey Very Large Array. The strength of the depolarization depends on the amount of turbulence in the magnetized plasma inside galaxies, measuring small-scale structure. The magnetic fields are a fundamental component of the structure and dynamics of galaxies, affecting the dynamics of all of the matter inside galaxies. These results are related to the star formation rate, large scale magnetic fields traced by polarization, cosmic ray transport from the galactic disk to the halo, scale heights of interstellar gas and various other aspects of the galaxy. Understanding the present galactic magnetic fields is essential for dynamo theory which explains the origin of magnetic fields in galaxies.

Signatures of Griffiths Phases in Noisy Neuronal Systems

D. Korchinski and J. Davidsen

In computational neuroscience the so called “criticality hypothesis” posits that the activity of healthy neural systems is precisely poised at the infinitesimal phase transition dividing super- and sub-critical states. In a sub-critical state activity will ineluctably dwindle, while in a super-critical state it will grow exponentially. Both states reduce the dynamic range and information processing capabilities of neural systems, making criticality optimal for computation. Recent theoretical advances have suggested that the hierarchical structure of brain networks might broaden this phase transition into what is called a “Griffiths Phase”. This may serve to obviate the need for precise tuning. However, most theoretical models of brain criticality fail to include spontaneous activity that is intrinsic to neurons. Using extensive simulations modelling brain regions, I will show that Griffiths phases appear even in the presence of spontaneous activity. Finally, I will present preliminary results using a more biologically detailed model which models individual neurons.

Inferring the Connectome of Neural Networks

P. Herringer

If we wish to gain a greater understanding of the brain, an important step will be reliably reconstructing the structural connectivity between neurons. One way to do this is to infer the causal relationships between neurons based on observed time series of their firing activity. Several techniques from the field of information theory have been developed in response to this problem, and more recently machine learning has also emerged as a promising tool. I developed a connection inference method that combines these two paradigms by augmenting a deep convolutional network model with the predictions of generalized transfer entropy. The model meets or exceeds the predictive capability of current state of the art methods on simulated data, and is robust to large numbers of confounding variables. It also has the important advantage over previous methods of being able to distinguish between excitatory and inhibitory connections.

Magnitude correlations and their statistical properties in a self-similar model of seismicity

A. Zambrano and J. Davidsen

Forecasting of earthquakes is an active research area where one of the open questions is whether magnitude correlations exist within seismic data. A recent model of seismicity that incorporates a self-similar rate equation; one which describes the temporal evolution of earthquake triggering, has been shown to provide a more accurate description of seismicity in Southern California when compared to other more established models. Prior to this

work, the statistical analysis of magnitude correlations of the self-similar model had not been addressed. Here we present statistical properties of the magnitude correlations for the self-similar model and explore what the model can tell us when it comes to magnitude correlations in real world catalogs.

Creation of high density nitrogen vacancy ensembles within femtosecond laser written waveguides for fully integrated sensing devices

J. P. Hadden, V. Bharadwaj, B. Sotillo, S. Rampini, R. Osellame, T. T. Fernandez, A. Chiappini, C. Armellini, M. Ferrari, R. Ramponi, P. E. Barclay, S. M. Eaton

Diamond's nitrogen vacancy (NV) centre is a natural spin-based quantum sensor in a biologically non-toxic material. The development of fully integrated optical waveguides incorporating dense ensembles of NV centers for will open the way for high sensitivity lab on chip diamond quantum sensing compatible with biological applications. Here we demonstrate the creation of high density NV ensembles with concentrations of at least 5×10^{14} cm^{-3} integrated in femtosecond laser written waveguides in diamond samples with nitrogen content ranging from 0.1 to 3000 ppm. This suggests a the possibility of fully integrated broadband sensing devices with shot noise limited sensitivities within one order of magnitude of the record sensitivity for state of the art bulk broadband magnetic and electric field sensing. However with improvement in the NV density we can expect to improve upon this. The laser induced strain which confines light within the waveguides simultaneously additionally is expected increase the sensitivity of NV centers to extremely weak electric fields, with projected sensitivities above the state of the art for such diamond sensing devices.

Non-Classical Correlations between Photons Retrieved from Two Independent Quantum Memories

G. C. do Amaral, M. Grimau Puigibert, M. Falamarzi, J. Davidson, T. Lutz, N. Sinclair, D. Oblak, and W. Tittel

Entanglement is a fundamental resource for quantum information processing. Indeed, one of the most promising ways to realize the quantum connection between quantum nodes is entanglement swapping between independent multipartite entangled states. In this context, the quantum nodes are equipped with quantum memories, which store the successfuly transmitted quantum states until a Bell State Projection measurement can be performed. Using the Atomic Frequency Comb (AFC) quantum memory protocol in two different rare-earth doped materials, we store and retrieve each member of a wavelength non-degenerate entangled photon pair and show that the original non-classical correlations are preserved.

On-going experiments aim to show that entangled qubit states can be stored thus paving the way for the future development of versatile quantum nodes.

Temporal learning mechanism in the Purkinje cell

A. Mandwal, J. Orlandi, J. Davidsen

The traditional interpretation of learning and storing memory in the brain involved chemical connections called synapses between its constituent units called neurons. The relative strengths of these synapses changes depending upon activities or timings of different stimuli a neuron receive, allowing the brain to store information regarding an event or an experience. Recently, in a conditioned response eye-blink experiment, Purkinje cells within the cerebellum were observed to memorize and encode time intervals between two different stimuli it received during the experiment. Purkinje cells encode time intervals by reducing their tonic firing rate during the time interval between the two different stimuli, and this phenomenon is termed as the conditional response of the Purkinje cell. Recently, a specific G-protein coupled receptor (mGluR7) on Purkinje cells is found to be responsible for the conditional response. However, the underlying mechanism remains unknown so far.

From these observations, two critical questions arise: (i) What is the underlying mechanism behind such behavior? (ii) Can we explain it with the conventional learning paradigms which involve only synapses between neurons or do we need to invoke cellular reactions involving various ion channels and proteins along with synaptic modifications? A possible mechanism is proposed that explains memorizing and the process of time-interval encoding by Purkinje cells and suggests ways to verify it experimentally.

This result opens up a new direction towards understanding roles of the Cerebellum Cortex and Nuclei in motor learning. As Purkinje cells are learning the time interval duration, one can assume that two different Purkinje cells can memorize two different time interval durations. Signals from the Mossy fibers select specific Purkinje cells which allow us to make movements at different rates and timings. Postulating mechanism behind this selection process shall be our focus of research in future.

Poster Abstracts

Validation of egs_brachy Monte Carlo dose calculation algorithms for Pd-103 brachytherapy source

S. Nich[1,2], C. Kirkby[1,3,4], and E. Villarreal-Barajas[5]

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The TG-43 dose calculation formalism is the current standard for radiation dosimetry calculations in low-energy brachytherapy treatments for breast and prostate cancers, but this formalism can lead to errors when the calculations occur in heterogeneous media and these errors have the potential to impact clinical decisions and outcomes. Monte Carlo simulations offer a means to address these shortcomings. egs_brachy is a recently released user code for the EGSnrc Monte Carlo package that is specifically designed to handle brachytherapy dose calculations. In this research, we benchmark egs_brachy by comparing calculated radial dose functions and dose rate distributions using a Pd-103 source against those established in the literature for both water and acrylic (PMMA) media. We demonstrate agreement (within 3% over a range of 0.2 - 5 cm) using the point source model in the literature and small deviations in simulated dose distributions (average difference less than 5% up to 5 cm and less than 5.5% from 5 - 10cm) using a more detailed line source model. These results allow us to move forward with confidence in more detailed simulations.

Finding the Best Approach for Registration of the Liver in Multimodality Imaging

S. Kuznetsova, P. Grendarova, K. Thind, N. Ploquin

Radiation therapy commonly utilises information obtained from multiple imaging modalities (such as MRI and CT), as a result rigid and deformable image registration (DIR) is required to align image volumes. When a specific organ is of interest (e.g. liver), the proper fusion of this region can be influenced by the registration of entire image volume. To curtail these effects, Structure-guided DIR is a registration method in Velocity AI (Velocity Medical Systems, Atlanta, GA) which employs structure outlines on both image sets to better register the volume encompassed. The purpose of our study is to determine the performance of structure-guided DIR for the fusion of CT and post radiation therapy MRI, and evaluate whether it is preferred to use entire liver outlines, or separate segments of the liver in DIR.

Nine patient's CTs and MRI scans were obtained. The liver outlines along with interior segments were delineated and checked by radiation oncologist which were then used in

structure-guided DIR. The Dice coefficient of similarity (DSC) was used to quantify the conformality between regions on the scans post registration. Registration using liver outlines alone consistently demonstrated larger DSC, suggesting that it is the preferred method of structure-guided DIR for the liver.

Bat Fatalities Around Wind Turbines

J. Alho

Wind power is an important part of the energy transition away from fossil fuels. Unfortunately, many bats are killed each year due to collisions with wind turbines. It is unclear as to why bats collide with wind turbines, although there is some evidence that bats may be attracted to wind turbines. This project explores one possible contribution to why bats are colliding with wind turbines: magnetic fields created by wind turbines. Some species of bats such as the big brown bat (Eptesicus fuscus) and the Chinese noctule (Nyctalus plancyi) have been shown to respond to changes in the magnetic field. Bats may navigate using a magnetic compass or through use of magnetic signposts in which subtle changes in the field are used to trigger changes in direction. This project explores whether the magnetic field of a wind turbine would be strong enough to interfere with bat navigation.

Towards room temperature indistinguishable single-photon sources using ultra-small mode volume cavities and solid-state emitters

S. Wein, N. Lauk, R. Ghobadi, and C. Simon

Highly efficient sources of indistinguishable single photons that can operate at room temperature would be very beneficial for many applications in quantum technology. We show that the implementation of such sources is a realistic goal using solid-state emitters and ultra-small mode volume cavities. We derive and analyze an expression for photon indistinguishability that accounts for relevant detrimental effects, such as plasmon-induced quenching and pure-dephasing. We then discuss the general cavity and emitter conditions required to achieve efficient indistinguishable photon emission. Using these conditions, we propose that a nanodiamond negatively-charged silicon-vacancy center combined with a plasmonic-Fabry-Perot hybrid cavity is an excellent candidate system.

A Solid state detector to detect a single photon without destroying it

S. Goswami, K. Heshami, and C. Simon

Rapid development in quantum computing and quantum communication technologies necessitates building a global quantum network. Such a quantum network is needed to implement quantum communication protocols like quantum cryptography worldwide along with help establishing connections between individual future quantum computers, essentially forming a quantum internet. Here, we are working towards implementing a solid state single photon quantum non-demolition (QND) detector which would be a part of the future global quantum network and, in general, of quantum computing architectures. A QND detector (or a non-destructive photon detector) is needed to detect the presence of a photon without destroying it. Although there is some progress in making a QND detector using ultracold single atoms in sophisticated optical traps, it was quite complex and not scalable. Here we are proposing to implement an efficient, practical and scalable QND detector in solid state system, using rare earth ions (ions of rare earth elements) doped crystals. Recently, a proof of principle many photon QND measurement experiment was performed using AC stark shift in rare earth ion doped crystal. We are now investigating the possibility of using an optical cavity to reach single photon level QND.

A Quantitative Assessment of the Consequences of Allowing Dose Heterogeneity in Prostate Radiation Therapy Planning

L. Sun, W. Smith, A. Ghose, and C. Kirkby

Target dose uniformity has been historically an aim of volumetric modulated arc theray (VMAT) planning. However, this may not be strictly necessary and removing this constraint could theoretically improve organs at risk (OAR) sparing and tumor control probability (TCP). This study systematically and quantitatively investigates the necessity of planning target volume (PTV) dose uniformity that results from the application or removal of an upper dose constraint (UDC) in the planning process for prostate VMAT treatments. OAR sparing, clinical target volume (CTV) and PTV coverage and hotspots as well as plan complexity were compared between plans with and without the PTV UDC optimized using the Progressive Resolution Optimizer (PRO, Varian Medical Systems, Palo Alto, CA). Removing the PTV UDC, the median of the dose received by 1cc of the volume (D1cc) reaches 144.6% for the CTV and 144.6% for the PTV, and an average increase of 3.2% TCP is demonstrated, while CTV and PTV coverage evaluated by the dose received by 99% of the volume (D99) is slightly decreased ($< 0.6\%$, $p < 0.01$). Moreover, systematic improvement in rectum DVHs was shown (5-10% decrease of the volume receiving 50% to 75% prescribed dose), resulting in a decrease of rectal normal tissue complication probability (1.3%, $p < 0.01$). There were 6 patients who did not meet the rectum dose constraints with the PTV UDC on but 5 of them were met and the last one had significant improvement when the PTV UDC was removed. Additional consequences included more MUs and higher degrees of modulation. In conclusion, removing the PTV UDC appears to be a viable option in treatment planning for

most prostate cancer cases and this can be particularly useful for patients who are struggling meeting the rectal dose constraints.

Use of quantum-correlated twin beams for cancellation of power fluctuations in a continuous-wave optical parametric oscillator for highresolution spectroscopy in the rapid scan mode

B. Brockelbank, J. N. Oliaee, and N. Moazzen-Ahmadi

Continuous-wave (cw) optical parametric oscillators (OPOs) are efficient and widely tunable sources of coherent light. In particular, the commercially available singly resonant OPO manufactured by Lockheed Martin Aculight is ideal for high resolution spectroscopy. It is capable of producing hundreds of milliwatts of idler output, has a wide tuning range between 2.2 and 4.6 micron and less than 1 MHz laser linewidth. We have used this OPO with Module D (2180-2580 cm^{-1}) and now with Module C (2650-3100 cm^{-1}) to record high resolution spectra of several molecular clusters. Our data acquisition is based on a rapid-scan signal averaging mode with continuous background subtraction. Wavelength scanning of about 30 GHz is made by strain variation of the fiber length in the seed laser. We use a tuning rate of 100 Hz which is larger than the 30 Hz recommended by Aculight. As a result, the OPO suffers from large amplitude power fluctuations which contribute to the noise in the measured signal and a decrease in the signal to noise. Here, we describe the use of quantum-correlated twin beams (idler and signal) for cancellation of the power fluctuations in the rapid-scan mode and compare the resulting sensitivity to a digital subtraction scheme which we have employed prior to the present work.