1 - An Analog Lock-In Amplifier for Error Signal Generation and Laser Locking

Brennan LeBlanc[1], Timothy Hunt[1], Brynle Barrett[1]

[1]University of New Brunswick

Laser-cooled atomic gases are used in neutral-atom quantum computers and state-of-the-art sensors such as atomic clocks and quantum gravimeters. Crucial to these instruments is a very stable reference laser tuned to the atomic transition frequency of interest. Lock-in amplification is a common technique used to produce an error signal that is proportional to the first derivative of the atomic spectrum and to which the laser is stabilized. Commercial lock-in amplifiers, however, are typically digital solutions that introduce a time-delay between the zero-crossing of the error signal and the spectral peak of the atom's transition. We have developed an analog solution using modular circuits, called tiles, to both generate our error signal and lock the laser to a transition frequency. By using a chain of these modular tiles, we pass an error signal generated by our analog lock-in amplifier to a proportional-integral-derivative (PID) controller. Combined with a scan signal, the PID controller is used to select a transition frequency of rubidium-87, our atom of interest, and lock our reference laser to this frequency.

Affiliation

University of New Brunswick

2 - Spectral Heuristics for k-Incoherent Decompositions

Luis M. B. Varona[1]

[1]Department of Politics & International Relations, Mount Allison University

Let $\rho \in \mathbf{C}^{n \times n}$ be the density matrix of an n-level quantum system, where each (real) diagonal element $\rho_{i,i}$ represents the probability that the system is in state i and each (complex) off-diagonal element $\rho_{i,j}$ represents the degree of "coherence" (or interference) between states i and j. Quantum information scientists are interested in how coherent ρ is, since quantum bits (or "qubits") in a coherent system can perform parallel information processing that is impossible for classical computers. One relevant measure here is k-incoherence. Given some integer $k > 0$, ρ is said to be "k-incoherent" if there exists some collection of pure state vectors $\mathbf{v}_1, \mathbf{v}_2, \ldots, \mathbf{v}_r \in \mathbf{C}^n$ such that each $\mathbf{v}_i$ has at most k nonzero entries and ρ can be written as the sum $\Sigma_{i=1}^{r} \mathbf{v}_i \mathbf{v}_i^{\dagger}$.

It is easy to determine whether a given density matrix ρ is k-incoherent via semidefinite programming, but it is far more difficult to find the minimum integer $r > 0$ such that ρ can be decomposed into r terms of the form above. (Decompositions with fewer terms require us to prepare fewer pure states in a lab to represent ρ.) While all known methods of exactly minimizing r (and finding a corresponding decomposition) remain highly inefficient, we herein present some spectral heuristics for obtaining near-optimal k-incoherent decompositions. In particular, we compute the eigenvalues of $k \times k$ submatrices formed from the same row and column indices of ρ,

then apply heuristics to these eigenvalues to select submatrices and take their leading eigenvectors as our pure states. Although this approach is not theoretically optimal, it is useful in practice for simplifying the preparation of mixed quantum states.

Affiliation

Department of Politics & International Relations, Mount Allison University

3 - Study of stellar pulsations in δ Scuti star HD68725

Weyme Issoufi Maiga[1], Viktor Khalack[1]

[1]Université de Moncton

δ Scuti stars are variable stars whose rapid variations in brightness provide important information about their internal structure. However, analyzing these variations remains complex due to the presence of instrumental noise and systematic effects in the photometric data provided by TESS. The applied methodology relies on the use of Python-based tools and libraries dedicated to the analysis of astronomical data. The main steps include data preprocessing, and frequency analysis using the Lomb-Scargle periodogram and the Discrete Fourier Transform (DFT). Preliminary results highlight several dominant frequencies associated with the stellar pulsations in HD68725 selected for this study. The obtained results contribute to a better understanding of the variability of δ Scuti stars and pave the way for more in-depth analyses of their internal structure

Affiliation

Université de Moncton

4 - Cross-Linking Kinetics of Collagen Fibers: Core-Shell VS. Homogenous Regimes

Ana Mastnak[1], Andrew Rutenberg[1]

[1]Dalhousie University

Collagen is the most common biological molecule in the body, forming nano-fibers which can be found through the body, including in skin, cornea, and tendon. Despite this, there isn't a general consensus as to its precise structure. Bending studies suggest collagen nano-fibers are radially in-homogenous, acting like hollow tubes, while other studies support the contrary, proposing a uniform consistency. To unite these different findings, we investigate spatially resolved cross-linking kinetics as a proposed mechanism for the formation of a core-shell structure by modelling a concentration of cross-linking agents, first diffusing into and then reacting with the nano-fiber to form irreversible cross-links. This is as various sugars are already known to cross-link with collagen and tune mechanical properties. We consider a coarse-grained 1-dimensional model with our non-dimensional pair of differential equations depend on scaled

reactivity and scaled concentration, while the diffusivity and fibril radius determines the timescale. The reaction diffusion equations are numerically solved in a cylindrical geometry and modelled in python using an Euler update. We find that an inhomogeneous core-shell structure forms for both high reactivity or high concentration at the early stages of cross-linking. Otherwise, cross-linking proceeds approximately uniformly throughout the fibril until eventual saturation. We then characterize different dynamical regimes of the total amount of cross-linking for both core-shell and uniform cross-linking, deriving a power law relation for the total cross-linking at light time which is consistent with experimental results. The presence of a glyco-protein barrier, found naturally occurring around much of the collagen in the human body, is also investigated as to how it impacts the time-scales present in the system. Overall, this approach to creating core-shell nano-fibers may also have applications in understanding the impacts of the formation of AGE (advanced glycation end products) and manufacturing of pharmaceuticals with controlled release.

Affiliation

Dalhousie University

5 - Resistance Growth in Iron and Manganese Based Positive Electrode Materials for Lithium-Ion Batteries

Rebecca Fenner[1, 2], Kate Leslie[1, 3], Jeff Dahn[1, 2, 3], Michael Metzger[1, 2, 3]

[1]Dalhousie University, [2]Department of Physics and Atmospheric Science, [3]Department of Chemistry

The need for environmentally friendly energy storage and electric vehicles is increasing and so is the need to develop lithium-ion battery materials with low cost and abundant materials. Electric vehicles typically use $LiNi_xMn_yCo_{1-x-y}O_2$ (NMC) batteries, or $LiFePO_4$ (LFP) batteries. NMC batteries use expensive and scarce transition metals while LFP is a lower cost option but with inferior energy density. Improved energy density can be achieved by using the material $LiMn_xFe_{1-x}PO_4$(LMFP) which includes lithium, manganese, and iron.

In this work, we set to identify the causes of resistance growth in LMFP batteries. $LiMn_{0.8}Fe_{0.2}PO_4$/artificial graphite pouch cells were formed and cycled for 0, 100, 200, 300 cycles and to 80% capacity (~500 cycles). Pouch cells were disassembled and constructed into symmetric cells containing two positive or two negative electrodes to isolate the cause of impedance growth to the positive or negative electrode. Electrochemical impedance spectroscopy (EIS) was run on these cells from -10 °C to 10 °C. As cycles increased, we noticed that the charge transfer resistance increases for the positive electrode but does not for the negative electrode. Next, we charged pouch cells to four different states of charge (SOC): 10%, 30%, 50%, and 90%. This gave us a broad range of points to collect data along the voltage vs. capacity curve of LMFP. This allows us to examine how the Jahn Teller distortion of Mn^{3+} may influence polarization growth. The result might suggest that lithium content is affecting the magnitude of charge transfer resistance.

Affiliation

Dalhousie University

6 - THE HYGROSCOPICITY OF WILDFIRE SMOKE BY MATERIAL

Jessica Vinton[1], Rachel Chang[1]

[1]Dalhousie University

The increase in wildfires in Canada has led to an abundance of smoke being released into the atmosphere. Smoke has negative effects on air quality and the climate via aerosol particles that can act as Cloud condensation nuclei (CCNs). CCNs are atmospheric aerosol particles that have the ability to turn into cloud droplets, and can play a significant role in the formation and properties of clouds. The formation of these particles and their full climate effects depend on size and hygroscopicity.

This study examines the hygroscopicity of aerosol particles generated during the combustion of both inorganic and organic materials in a controlled laboratory setting. The data analyzed in this study are total particle concentration from a condensation particle counter (CPC), aerosol size distribution from a scanning mobility particle sizer (SMPS), and CCN concentration from a CCN Counter (CCNC). These were used to derive the hygroscopicity parameter (κ) by the κ-Köhler theory for each burn experiment, which indicates the ability of the smoke particles to turn into cloud droplets.

By comparing κ values across material types, this analysis provides new insight into how differences in combustion influence CCN activity. This project contributes to a broader understanding of the role of wildfire emissions in cloud interactions and supports efforts to better represent the emissions in atmospheric processes and climate models.

Affiliation

Dalhousie University

7 - Charged Pion Polarizability Reconstruction

Sarah Littlejohn[1], David Hornidge[1]

[1]Mount Allison University

The strong force, responsible for holding quarks together within a hadron, is governed by the theory of quantum chromodynamics (QCD), examining how quarks and gluons interact. The theory is well understood at high energies; however, at low energies the theory remains unsolved. The polarizability is a fundamental property that measures the “stretchiness” of a hadron, a bundle of quarks, in electric and magnetic fields. Since polarizability directly measures the quark

interactions, it gives significant information on the strong force and quantum chromodynamics at low energies. The pion polarizability is exceptionally difficult to measure due to the pion's extremely short decay time. There are few measurements for charged pions and those that exist have large uncertainties, which result in contradictory results. In the summer of 2022, an experiment was run with the GlueX detector in Hall D at Jefferson Lab in Virginia, where data was taken on pion runs using a linearly polarized photon beam on a Pb-208 target with additional multiwire proportional chambers for pion-muon sorting. This data analysis requires reconstruction software to sort event types as well as the use of neural nets and machine learning to sift through different data channels and extract pions. These measurements of polarizability will help with understanding the strong force within simple systems, and this can then be extrapolated and integrated into the theory of QCD at low energies which will provide a better understanding of matter and our universe.

Affiliation

Mount Allison University

8 - Precision of Total Electron Content Estimated Using GPS Observables

Matheus Maica[1]

[1]University of New Brunswick

Total Electron Content (TEC) measurements derived from Global Positioning System (GPS) signals have become indispensable for application-driven ionospheric characterization, detection and characterization of "weak ionospheric signals" resulting from seismic and weather activities, underpinning the accuracy of satellite navigation, space weather forecasting, and ionospheric corrections in communication systems. Therefore, scrutiny of the precision of GPS-derived TEC is essential. Suppose all error sources are accurately identified and accounted for, code-based TEC determinations provide an absolute measure of TEC, albeit with modest precision, due to significant measurement noise and multipath errors where as carrier-phase observations are far more precise, but inherit an unknown integer ambiguity. The precision of GPS-derived TEC depends on careful mitigation of several error sources and two significant assumptions. A primary factor is the differential code bias (DCB) whose magnitude can reach several to tens of nanoseconds (equivalent to many TECU), making them a significant error source if uncalibrated. Modern TEC processing thus relies on robust bias calibrations, often using global networks and stable reference models, to remove these inter-frequency biases. Another major concern is multipath and measurement noise, which predominantly affect code measurements. Improved antenna design and receiver technologies have helped minimize the impact of multipath, but residual multipath can still limit precision in degraded signal environments.
Most previous efforts on determining the precision of TEC measurements have focused

on the hardware and DCB, with very little attention given to the assumptions on the ionospheric condition made in estimating the TEC. Two primary considerations were made in the estimation of TEC using GPS observables: a) the ionosphere is purely refractive, and b) higher-order effects. The effect of these two considerations was never scrutinized in the precision of the TEC estimated using GPS observables. In this study, we examine the effect of these two considerations on the relative TEC precision using high-data-rate (100 Hz) phase observables of L1, L2, and L5 frequencies. The ionospheric conditions under which the precision deteriorates will be discussed.

Affiliation

University of New Brunswick

9 - Orbital Modelling of Fast-Moving Stars in Omega Centauri: New Constraints on the Central Intermediate-Mass Black Hole

Mackenzie Hayduk[1], Vincent Hénault-Brunet[1]

[1]Saint Mary's University

Intermediate-mass black holes (IMBHs), with masses between 10^2 and 10^5 $M_\odot$, represent a missing link between stellar and supermassive black holes. Characterizing their population is key to understanding the evolution of galactic centres and interpreting future gravitational wave signals detectable with the upcoming Laser Interferometer Space Antenna (LISA). Omega Centauri (ω Cen) is a Milky Way globular cluster and a prime candidate for hosting an intermediate-mass black hole. Recently, Haberle et al. (2024) identified several stars near the cluster center that exceeded the central escape velocity, constraining the IMBH mass to be >8,200 $M_\odot$. In this work, we analyse the central mass by fitting the full orbits of the fast-moving stars using the Octofitter package and all available astrometric data. We find a more stringent lower IMBH mass limit of $\sim 5\times10^4$ $M_\odot$. We further predict orbital parameters and line-of-sight velocities for the fast-moving stars that will refine this analysis when compared with upcoming James Webb Space Telescope data.

Affiliation

Saint Mary's University

10 - Asteroseismic Models of the Doubly Magnetic Binary HD 156424

Serena Davis[1]

[1]Mount Allison University

HD 156424 is a hot doubly magnetic binary system in the Sco OB4 association—an unbound group of young OB stars. The primary (HD 156424A) is a B2 main sequence star. OB stars do not have the convective envelopes that are responsible for generating magnetic fields in lower mass stars, but magnetic fields have been detected in about 10% of OB stars. These magnetic fields are thought to be fossil fields—magnetic fields left over from a previous stage of stellar evolution—but many are quite strong, which is the case for both components of HD 156424. We perform asteroseismic modelling of this system using additional magnetic subroutines with MESA (Modules for Experiments in Stellar Astrophysics) and the GYRE stellar pulsation code. There have been few magnetic pulsating hot stars detected, and magnetoasteroseismic studies have been performed on only a handful of these stars. There is little known about the internal magnetic properties of stars with fossil fields, leading to uncertainty in stellar evolution of models of these stars. As asteroseismology is the best known probe of interior stellar structure, magnetoasteroseismic analysis of stars like HD 156424 can provide a better understanding of the effects of fossil magnetic fields on hot stars. We find that HD 156424A is well fit by a model with a mass of 8.2 $M_\odot$ and an equatorial magnetic field strength 1500 G. The best fitting models are also all quite young, which matches HD 156424's location in the Sco OB4 association.

Affiliation

Mount Allison University

11 - Investigations of Laser Locking Techniques using an Electro-Optic Modulator

Chayse Worden[1], Brynle Barrett[1], Timothy Hunt[1]

[1]University of New Brunswick

In the field of atomic physics, frequency stabilization or "locking" of a laser is critical in quantum technologies including atomic clocks, gravimeters, and quantum computing. Two popular techniques to achieve this are known as Frequency Modulation (FM) and Modulation Transfer Spectroscopy (MTS), which use an Electro-Optic Modulator (EOM). Each technique produces an "error signal" that can be used to lock a laser to an atomic transition, which acts as an absolute frequency reference. In this talk, I will present measurements of these error signals under various experimental conditions, and a numerical analysis to determine optimal operating conditions to stabilize our lasers.

Affiliation

University of New Brunswick

12 - Evaluation of Compton Scattering of C12 using the Two Photon Spectrometer to determine the Compton Slope Parameter

Geneviève Borden[1]

[1]Mount Allison Universtiy

The motivation for this project is to further constrain the nuclear Equation Of State (EOS), which describes the structure of both neutron-rich nuclei and dense astrophysical objects such as neutron stars.

To better constrain the EOS, a measurement of the neutron skin thickness in Pb-208 is required. Before doing this, certain parameters, such as the Compton Slope Parameter (CSP), must be evaluated in a simpler nucleus, such as C-12. This project deals with Compton scattering from a carbon-12 target to obtain a more accurate experimental result for the carbon CSP.

To achieve this goal, experimental data on Compton scattering from a graphite target were taken in May 2025 at the Institute for Nuclear Physics in Mainz, Germany. This presentation will discuss various preliminary results of the data analysis along with Monte Carlo simulations of the experimental setup.

Affiliation

Mount Allison University

13 - Analysis of zinc, selenium, arsenic, and lead in human toenails using X-ray fluorescence

Ethan Briand[1], David Fleming[1]

[1]Mount Allison University

X-ray fluorescence (XRF) is a non-destructive analytical technique that exposes samples to high-energy X-rays, causing atoms in the sample to emit secondary characteristic X-rays (fluoresce). This technique allows for a quick identification of the elemental composition of solids, liquids, and powdered substances. This technique is used historically in determining the elemental composition of geological and archeological samples and is now being investigated for potential benefits in biomarker analysis. XRF is used in this study to analyze the concentration of arsenic (As), selenium (Se), zinc (Zn), iron (Fe), lead (Pb), manganese (Mn), mercury (Hg), and vanadium (V) in 383 human toenail samples of individuals who reside in Nova Scotia, Canada. This project was introduced in conjunction with the Atlantic Partnership for Tomorrow's Health (PATH) Study to explore the geological concerns of arsenic-rich well water and other heavy metal

exposure in Nova Scotia. These findings of this project will be used as part of a larger study being conducted at Dalhousie University to provide information on how environmental exposure in Nova Scotia impacts mental health status and to develop feasible intervention solutions. Some challenges that arise with XRF analysis are the sample geometry and surface condition, the precision of the measurements, the limits of detection, and the calibration of the XRF system. When measuring the elemental concentrations of nails, common sources of error in XRF methods, such as the thickness, width, and length of the nail, need to be taken into account. The impact of these conditions is explored numerically in this study.

This presentation will present the physics behind X-ray fluorescence and how the analysis method can be applied to the medical field. The presentation will also present the use of human nails as biomarkers of long-term exposure to heavy metals as opposed to the more common and invasive methods of using whole blood or plasma. Toenails also have the advantage that they are easy to collect and store, and they are less exposed to external contaminants than hair or fingernails. The analysis of toenails using the XRF technique is a relatively new technique, and the effect of the thickness of the nail, the curvature, and which toe the nail came from will be determined. Further, time permitting, I will present the results of the elemental concentration found in the nails of groups of people based on their health condition classification.

Affiliation

Mount Allison University

14 - Robustness and Selection of Radiomics Features for Classification in Clinical Glioma

Aaron Carey[1], James Rioux[1]

[1]Dalhousie university

Magnetic Resonance Imaging (MRI) is a diagnostic technique well suited for the diagnosis and non-invasive analysis of clinical subjects. MRI is particularly well suited for brain imaging especially in an oncological context, where glioblastoma — a highly aggressive brain tumour with a poor long term prognosis, and high recurrence rate — is of particular interest. It is well documented that glioblastoma differs in treatment and prognosis between men and women; Understanding this difference may help to personalize treatment further, improving potential prognosis.

To aid in the analysis of glioblastoma MRI, radiomics is employed — a powerful tool that extracts quantitative statistical features from image gray levels for use in downstream analysis. Despite radiomics' strengths, clinical applications remain limited due to the heterogeneous nature of clinical data.

This study analyzes the robustness of radiomics features computed on whole-brain regions of interest (ROIs) of glioblastoma patients, and compares two different feature reduction methods

feeding into a logistic regression model to predict patient sex, a proxy for exploring the sexually dimorphic patterns prevalent in glioblastoma. On a dataset of 43 patients, shape, first order, and texture features were computed, then their reproducibility under a range of gaussian noise was assessed using the intraclass correlation coefficient (ICC). First order features were found to be most robust, achieving mostly ICC values greater than 0.8, whereas texture features showed greater variability.

Additionally, this study compares a more traditional pearson correlation feature reduction; where features are removed if their correlation to another feature is greater than some threshold, to a novel Multi-Dimensional Scaling (MDS) clustering feature reduction technique, that — using Pearson correlation values — maps the correlation values into a correlation space where correlation can be more easily quantified using a set of coordinates in high dimensional space. Points are then clustered, and the medoids of each cluster are chosen as the representative of the cluster as a whole. The selected features from each algorithm is then fed into a Random Forest Feature Importance (RFFI) and LOGO (Leave One Group Out) logistic regression to determine patient sex, it was found that both models performed comparably, reaching PR AUC values of up to 0.91 using only 5-10 features. These results identify robust feature sets that may be more attractive in the application of clinical radiomics, and that these features do hold important sex-linked data that may help further understand the sex dependence of glioblastoma.

Affiliation

Dalhousie University

15 - Calibration & Application of an NaI(Tl)Detector for Environmental Radiation Measurement

Kennedy Lawrence[1]

[1]St Francis Xavier University

Environmental gamma radiation originates from naturally occurring and anthropogenic radionuclides. These radioactive substances are hidden within the soil which surrounds us everyday, contributing to long-term radiation exposure. Gamma-ray spectroscopy has been widely used to monitor environmental radioactivity in many regions across the globe. Many studies focus primarily on regions with industrial or nuclear activity, leaving gaps in the understanding of radiation levels in rural areas and farmlands. This research aims to address this lack of regional data by measuring gamma emitting radionuclides in soil samples using a sodium iodide (NaI (Tl)) scintillation detector. The gamma spectrum was acquired from collected soil samples and analysis was done using GammaVision Software. Results show that Uranium-238 series dominates in both provinces, reflecting regional geology. Detected activities are used to calculate annual effective doses following the methodology laid out in ICRP Publication 103. Results are consistent with expected natural background levels. and the calculated radiation doses (0.12 to 0.38 μSv/y) pose no health concern.

Affiliation

St Francis Xavier University

16 - MRI Through the Lens of Quantum Physics

Matthew Whitehead[1]

[1]St. Francis Xavier University

Magnetic Resonance Imaging (MRI) can be described as a two-level quantum system. Mathematica was used to model the time evolution which is best visualized by the Bloch vector. Detailed models of spin echo were created in a close system. Similarly spontaneous emission was modeled in an open system.

Affiliation

St. Francis Xavier University

17 - Acoustic phonon dynamics of polycrystalline SnSe by Brillouin light scattering spectroscopy.

Jenna Penney[1]

[1]Memorial University of Newfoundland and Labrador

Tin selenide (SnSe) is a layered semiconducting material that has recently gained popularity due to its potential in the field of thermoelectricity. Single crystal SnSe has been found to have the highest reported value for thermoelectric efficiency, due to an extremely low value for thermal conductivity. Since heat travels in solids through lattice vibrations known as phonons, a measurement of the phonon dynamics, such as velocities or attenuation, will give further insight to the thermal properties of the material. There has been little study done to investigate the thermal conductivity in single crystal samples of SnSe, and even less for polycrystalline SnSe, which is expected to be more favourable in terms of thermoelectric applications. Furthermore, the few results that have been reported for phonon velocities show wide variation. To fill this void, Brillouin light scattering spectroscopy was used to probe acoustic surface phonons in polycrystalline SnSe to determine acoustic phonon velocities and attenuation. The Brillouin spectra contained peaks due to a Rayleigh mode and a longitudinal resonance mode. The Rayleigh surface mode velocity was found to be independent of direction of propagation in the sample surface plane, and the associated spectral peak was sharp and narrow, indicating low attenuation. In contrast, the longitudinal resonance peak was over an order of magnitude more broad, indicating high attenuation and by extension a short lifetime and lower thermal conductivity. It was found that both the Rayleigh velocity and longitudinal resonance velocities were higher for polycrystalline SnSe

than reported for single crystal SnSe, indicating a higher thermal conductivity in polycrystalline samples.

Affiliation

Memorial University of Newfoundland and Labrador

18 - Shock-Driven Mixing and Structure Formation in High Resolution Simulations of Merging Galaxy Subclusters

Emily Fisher[1], Robert Thacker[1], Fraser Smith[1], Jorge Meza[1]

[1]Saint Mary's University

Cosmological structure formation has previously been shown to proceed in a hierarchical manner. Dark matter density perturbations in the early Universe expand over time due to cosmic inflation, giving rise to structures such as galaxies and clusters embedded within dark matter halos. An emerging area of interest is in studying substructure formation and gas mixing in clusters, which are driven in part by merging events. Merging subclusters produce strong, turbulent shocks in the intracluster medium (ICM) that can be studied both observationally and through numerical simulations. Using the simulation code GIZMO, which incorporates both hydrodynamical and gravitational solvers through a meshless finite-mass method, we simulate the collision and mixing of two initially separate subclusters. Each subcluster has a mass of 10^{14} solar masses, and we employ simulations with resolutions of up to 60 million individual elements. A variance-based mixing statistic μ reveals progressively greater interleaving along the surface between the merged subclusters. To determine whether this mixing surface is influenced by shocks propagating through it, as is possible in the Richtmyer-Meshkov instability, we implement a shock-tracking algorithm based on the velocity divergence field combined with the gradient of the logarithmic pressure. High resolution simulations reveal a weak shock-like feature passing along the mixing surface, although initial analysis suggests that it does not have a significant impact on the mixing. In addition to presenting these results, we discuss the resolution dependence of the mixing and shock properties in these simulations as well as the emergence of post-collision substructures in the merged system.

Affiliation

Saint Mary's University

19 - A Numerical Framework for Quantifying the Illusion of Mixing in Galaxy Cluster Mergers

Robert Thacker[1], Jorge Meza[1], Fraser Smith[1], Emily Fisher[1]

[1]Saint Mary's University

Numerical simulations are indispensable for studying the complex gas dynamics of galaxy cluster mergers, but interpreting their results is challenging. Averaging physical quantities over a measurement cell, a process known as coarse-graining, can create an artificial illusion of mixing while smaller-scale structures go unresolved, a concept called sub-grid heterogeneity. A similar overestimation occurs when simulations lack the spatial resolution required to fully capture the underlying fluid dynamics. This discrepancy can be statistically analyzed throughout a collision of galaxy subclusters as the flow progresses through the shearing, folding, and eventual diffusion stages across the mixing surfaces. To systematically quantify the gap between perceived and actual mixing, we have implemented a numerical framework to compare two fine-scale mixing indices, mu and M_m, which capture different mixing behaviours, alongside their corresponding evaluation diagnostics, D_mu and D_M_m.

Affiliation

Saint Mary's University

20 - Magnetic Resonance Relaxation Correlation Measurements for Analysis of Solution Composition

Nicholas Littlefield[1], Andres Aguilera[1], Bruce Balcom[1]

[1]University of New Brunswick

Bulk magnetic resonance (MR) measurements acquire signal from the presession of ^{1}H magnet dipole moments in the presence of an external magnetic field. The signal’s recovery is sensitive to molecular motion, diffusion and other material properties such as viscosity. Current trends in magnetic resonance favour superconducting, high magnetic field strength, instruments. Despite the many advantages of working at high field, there are notable disadvantages: cost, the average super conducting instrument costs hundreds of thousands, size, and as a consequence portability. We are exploring sample composition measurements with low cost, low field, portable magnets.

The work presented will detail the development of a new MR measurement for the compositional analysis of water-based solutions. Due to the high molarity of water, and as a consequence, the high abundance of hydrogen associated with water, it can be difficult to accurately measure the signal behaviour of species dissolved in water as the signal from water will dominate in the bulk signal acquired. Consequently, specific measures must be taken to handle the excess of water signal. This modifies the experimental procedure, and the data processing procedure as well.

Success in the development of this technique, a relaxation correlation method, will expand the ability of MR to characterize, in situ, the presence of macromolecules, or other solutes present in minority concentrations.

Affiliation

University of New Brunswick

21 - A computational method for improving signal quality in a magnetic resonance flow measurement

Taylor Belczewski[1], Sebastian Richard[1], Ben Newling[1], Bruce Balcom[1]

[1]University of New Brunswick

Magnetic resonance (MR) is well known to be sensitive to molecular movement, including diffusion and flow. MR techniques have the advantage of being non-invasive, however they often involve complicated instruments and measurements. We are developing a simple MR instrument using a portable low field magnet and an equally simple rheology measurement to characterize fluid flow through a tube. Our measurement uses the phase of the MR signal of the fluid to determine the average velocity of the fluid as well as its velocity profile. It is possible, and desirable, to acquire multiple data points in a single measurement. This method significantly reduces the measurement time, relative to acquiring each data point individually, but also leads to an accumulation of unwanted signal that interferes with the flow signal we are interested in. We can reduce this unwanted signal using a method called phase cycling, which involves choice of measurement parameters that, if chosen carefully, leads to a cancellation of some of unwanted signal while leaving the flow signal intact.

Phase cycling is a simple method in principle, but in our measurement there are so many parameters to choose from that finding a suitable combination proves challenging. By simulating our measurement in Matlab we can systematically explore a reasonable subset of phase cycling parameters and then use a Python script to determine which of the simulations, each associated with a unique set of parameters, is least corrupted by the presence of indirect echoes. Once a good set of parameters is identified through simulation the corresponding phase cycle can be employed experimentally, allowing us to acquire multiple data points in a single measurement without significant accumulation of unwanted signal.

Affiliation

University of New Brunswick

22 - Strained Transition Metal Dichalcogenide Monolayers

Annika Kienast[1], Jasleen Jagde[1], Grant Wilbur[1], Laurent Kreplak[1], Kimberley Hall[1]

[1]Dalhousie University

Transition-metal dichalcogenide (TMDC) monolayers have been recognized as suitable materials for quantum technologies due to their unique optical and electronic properties. TMDC monolayers are two-dimensional semiconductor materials consisting of a transition metal atom covalently bonded with two chalcogen atoms. While bulk samples of TMDCs are indirect bandgap semiconductors, their monolayers possess a direct bandgap. Direct bandgaps allow for efficient absorption and emission of light, which is necessary for optoelectronic devices. Strain fields can be applied to TMDC monolayers to create quantum emitters, which are nanoscale devices that confine excitons, enabling the controlled emission of single photons. TMDC monolayers can either be indented by the sharp tip of an atomic force microscope (AFM) or deposited onto pillared substrates to induce the localized strain necessary to decrease the bandgap of the monolayers and form quantum emitters. We have fabricated tungsten diselenide (WSe_2) monolayers by mechanical exfoliation, employing a similar method as that which is used to create graphene. One potential WSe_2 monolayer has been indented using an AFM to create strain-localized single-photon emission centers, while others WSe_2 monolayers have been strained by pillars. Photoluminescence spectroscopy will be used to identify single photon emitters in the strained WSe_2 monolayers. TMDC monolayers are one of the solid-state quantum emitter systems which are studied at Dalhousie's lab in an effort to optimize quantum light sources. Optical pulse shaping of ultrafast lasers can be used to engineer the precise trigger pulses necessary for the quantum emitters formed by straining the TMDC monolayers to become ideal single photon sources. These devices lay the foundation for many areas of quantum information such as distributed quantum networks and quantum key distribution.

Affiliation

Dalhousie University

23 - Using Monte Carlo Simulations to Determine the Effect of Polymer Architecture on Entropic Repulsion in Polymers

Matthew O'Connell[1]

[1]University of Prince Edward Island

This research involved using Monte-Carlo simulations to investigate a system of two ring polymers confined to a cylindrical cavity. This system mimics the conditions in a bacterial cell such as *E. coli* after DNA replication has finished, with the ring polymers representing the chromosomes of the bacterium. The objective of the research was to characterize the effects of entropic repulsion between the two polymers, with a particular focus on the effects of internal cross-linking between different sites on the ring. Simulations were carried out with various

distances separating the centres of mass of two polymers in order to calculate the free energy of the system as a function of separation distance. In addition, other quantities of the polymers were measured, such as total extension length and extension length of the internal loops. One notable result was an anomaly for certain polymer architectures in which the extension length of the polymers, rather than decreasing continuously with separation distance to a minimum value (as expected from previous research), decreased in short spurs separated by plateaus. The reason for this result was found to be a nesting effect between internal loops of the two polymers, itself caused by a break in symmetry between the two rings. The research provides insight into the processes behind bacterial chromosome segregation and opens up new avenues for investigating the system of two ring polymers in a cavity, such as the effect of symmetry on the behaviour of the polymers.

Affiliation

University of Prince Edward Island

24 - Compton Scattering from Helium-4 at the Mainz Microtron: Experimental Setup and Tagging Efficiency Calculations

Zoey Henrich[1]

[1]Mount Allison University

The A2 Collaboration, based at the Mainz Microtron (MAMI) in Mainz, Germany, investigates quantum chromodynamics, the theory of the strong force. Using Compton scattering off a Helium-4 target, the collaboration probes the structure of nucleons in the form of the nucleon polarizabilities. One of the important ingredients that goes into the calculation of the reaction probability is the tagging efficiency, and it is critical for measuring the absolute cross section. However, following the 2025 beamtime, calculations for this quantity resulted in values approximately twice the expected value. Correction to the tagging efficiency is the intended outcome of this work. Preliminary results will be presented, with a focus on the experimental setup in the A2 Hall at MAMI.

Affiliation

Mount Allison University

25 - Transient Amplification of Gravitational Waves

Benjamin Vatcher[1], Ivan Booth[1], Joseph G. Fitzgerald[1]

[1]Memorial University of Newfoundland

Transient amplification is a well-established phenomenon in dynamical systems and fluid mechanics, particularly in meteorology, where non-normal mode interactions can produce substantial temporary growth in perturbations despite overall linear stability. Although the qualitative behavior of such transient growth has been extensively studied in atmospheric and hydrodynamical contexts, it has been largely unexplored in the context of gravitational wave (GW) physics. We begin by identifying the mathematical structure underlying non-normal evolution in fluid systems and reformulate it in a manner suitable for gravitational perturbation theory. In non-normal systems, the evolution operator governing linear perturbation is non-self-adjoint, allowing for significant short-time amplification even when all eigenmodes are stable. This amplification arises not from instabilities, but from the non-orthogonality of modes and their resulting interference during time evolution. The central aim of this work is to determine whether analogous non-normal structures arise in gravitational settings and to identify spacetimes that may support such behavior. In curved backgrounds, the propagation equations for GWs acquire geometric contributions that can modify the properties of the associated evolution operator. Spacetimes characterized by strong curvature gradients provide natural candidates for this analysis. In particular, Schwarzschild and Kerr geometries offer physically well-motivated settings in which non-normal behavior may emerge. Framing GW propagation within the generalized theory of non-normal dynamical systems, allows us to identify spacetimes that permit transient amplification of GWs, and we can determine the limits of GW growth in strong curvature regimes.

Affiliation

Memorial University of Newfoundland

26 - Elastic Properties of Semiflexible Polycatenane Chains: A Simulation Study

Carlos Emilio Padilla Robles[1]

[1]University of Prince Edward Island

Catenanes are assemblies of two or more molecular rings held together by mechanical interlocking rather than conventional covalent bonding. One fascinating catenane found in nature is the kinetoplast, a chain-mail-like structure composed of circular DNA rings, present in the mitochondria of certain trypanosome parasites. Another example is a polycatenane, an extended linear catenane structure analogous to a polymer in which interlocking molecular rings constitute monomeric units. Recently, advances in chemical synthesis techniques have enabled the design and construction of polycatenanes, whose unique physical properties are imparted by topological bonds and can be characterized experimentally using methods such as optical trapping. In this

study, Monte Carlo simulations were used to investigate the effects of variable flexibility of the constituent rings of a polycatenane model, under conditions simulating angular optical trap experiments. In particular, a polycatenane chain is both stretched and twisted when a force and a torque are applied to the end rings. A key observation is that a maximum extension was observed for chains with intermediate flexibility, suggesting an optimal rigidity range for mechanical response. Another notable observation is that the angle characterizing the degree of chain twist initially increases linearly with the applied torque, but then undergoes an abrupt, rapid increase over a short range of torque, qualitatively comparable to a phase transition. Long equilibrium times and a pronounced peak in the variance of the twist angle are observed throughout this sudden increase. A useful quantity to help characterize the conformational properties of the chain is the gyration tensor. Here, we use the eigenvalues of this second-rank tensor to calculate scalar shape descriptors such as asphericity and prolateness to monitor the changes in the size and shape of the rings in response to the applied force and torque. Similar to the twist angle, sharp transitions in these quantities are observed, accompanied by pronounced peaks in their variance. In future work, we hope to develop a theoretical model to account for this fascinating phase-transition-like behaviour. We hope that experiments using single-molecule force spectroscopy methods will eventually be applied to study polycatenane to test the predictions of our simulations.

Affiliation

University of Prince Edward Island

27 - Cross-site validation of an open-source phantom for a novel magnetic brain imaging system

Clara Knox[1], Carson Leslie[1], William Gaetz[2]

[1]Dalhousie University, [2]University of Pennsylvania

Magnetoencephalography (MEG) non-invasively measures magnetic flux due to brain activity, which can be modelled as temporally varying current segments. Localization error is a key performance metric in MEG, indicating how well the system can localize brain activity. Conventional MEG sensors are superconducting quantum interference devices (SQUIDs). Recently, novel quantum MEG sensors called optically pumped magnetometers (OPMs) have eliminated the need for cryogenic cooling, resulting in new systems with novel sensor configurations. Standardized methods to quantify and compare localization error across these systems are needed. We have developed an open-source device (called a “phantom”) with current segments at known positions and orientations. The phantom was validated for assessing localization error on three MEG systems: an OPM system at the design site at the Biosignal Lab (Halifax, NS), plus a SQUID and a second OPM systems at the test site at the Children’s Hospital of Philadelphia (USA). We expected localization error to be within 3-5 mm. At both sites, magnetic fields were recorded while each source was driven 100 times at magnitudes similar to human brain activity (50nAm). Field data were averaged at peak activation after noise-reduction

processing to isolate the phantom signal. Source localization was completed using recursive least squares fitting to appropriate dipole models for each current configuration. Localization error and systematic bias was determined by comparing measured and known locations across all current segments and repeated measures. For the Biosignal OPM system, localization error was 2.2±1.1mm. No bias exceeded the variability. At the test site, we measured 4.5±1.7mm for the OPM system and 8.1±2.7mm for the SQUID system, with evidence of a 3-to-5-mm bias in one direction. The open-source phantom is approaching performance achieved in recent publications, but some systematic error was noted at the test site. A likely cause is some fabrication and installation error, as the phantom was disassembled and reassembled after travelling to the test site. A new revision is underway to improve the reproducibility of the build. In the long run, an open-source phantom will allow operators worldwide to assess MEG performance on a common platform.

Affiliation

Dalhousie University

28 - Bifurcations In Black Hole Mergers

dave Van Moyo[1]

[1]Memorial university of Newfoundand

This thesis investigates the mathematical structures underlying black hole horizons. To fully capture the dynamics of these objects, precise mathematical tools capable of tracking a black hole's boundary, or horizon, throughout its evolution are required. This project centers on the concept of a Marginally Outer Trapped Surface (MOTS), which provides a precise, instantaneous definition of a black hole's surface. During a dynamic merger, these surfaces evolve, split, and merge in a manner that describes the collision. I examine how bifurcation theory, which describes sudden qualitative changes in a system, offers a framework for understanding black hole structure and modeling mergers. Specifically, a pitchfork bifurcation directly models the moment two distinct MOTS fuse into a single common surface. Subsequently, a transcritical bifurcation models the ringdown phase, during which the newly formed black hole vibrates and settles into a final, stable state. To investigate this, I employ numerical simulations using a simplified model of a charged, non-spinning black hole described by the Reissner-Nordström metric, where the charge serves as the parameter distorting the horizon. I implement this model using Painlevé-Gullstrand coordinates, which are particularly well-suited for tracking dynamical horizons across the black hole interior. Utilizing equations known as MOTSodesics, I developed a computational model within the SageMath environment. By solving these equations, I map how the MOTS locations change as the charge varies, generating a bifurcation tree. The central outcome of this work is the construction and analysis of this diagram, which visually captures the stability and merger-like dynamics of the horizons. By identifying the precise points of pitchfork and transcritical bifurcations, this project provides insight into black hole dynamics, potentially advancing our understanding of black holes from their formation to their eventual evolution.

Affiliation Memorial University of Newfoundland

29 - Monte Carlo Study of Confinement-Induced Polymer Organization in an Elliptical Cavity

Behzad Seyyedi Viand[1], James Polson[1]

[1]University of Prince Edward Island

Plasmids are small circular DNA molecules that replicate independently of chromosomal DNA in bacterial cells. Understanding the organizational behaviour of plasmids within confined cellular environments has posed a significant challenge for a long time. However, recent advancements in nanofluidic technology have enabled experiments to be conducted to better understand the physical properties of such systems. Of special note is the experimental research conducted by the Reisner group at McGill University. In one project, their work focused on observing the equilibrium arrangement and dynamics of a solitary DNA strand confined within an elliptical nanofluidic chamber alongside smaller plasmid DNA molecules as a minimal model for a bacterial cell. Their experiments revealed preferential polar localization of the plasmids, an effect that was strengthened by the presence of T4 DNA and by increasing the plasmid population. In this research, we use Monte Carlo simulations of semiflexible coarse-grained polymers to model this experimental system. The polymers are confined to an elliptically capped rectangular cavity bounded above and below by planar walls. A semiflexible polymer and one or more ring polymers are used to represent the linear DNA and plasmids, respectively. The polymers are modeled as hard-sphere chains, and all relevant length-scale ratios in the model, including cavity dimensions, polymer contour lengths, and persistence lengths, are chosen to accurately reproduce the experimental system. We examine the effects of confinement geometry and ring polymer number on the spatial organization of ring polymers. We find that the linear polymer cannot easily occupy the elliptical caps, generating an entropic depletion effect that drives the ring polymers to fill the vacant regions at the poles of the cavity. Our findings are mostly congruent with the experimental results, including the preferential localization of plasmids near the cavity poles. The primary discrepancy is the invariance of the spatial probability distribution of ring polymers as their number is increased. The discrepancy suggests that the hard-sphere model may not fully capture all relevant physical interactions of the DNA molecules under confinement.

Affiliation

University of Prince Edward Island

30 - X-ray fluorescence analysis of infant formula to determine Fe, Zn, and K concentrations,

Brycen Thibodeau[1]

[1]Mount Allison University Physics Department

Iron (Fe), zinc (Zn), and potassium (K) are essential micronutrients for infant growth and development, and their concentrations in infant formula must be carefully regulated to ensure nutritional adequacy and safety. In this study, X-ray fluorescence (XRF) spectroscopy was utilized as a rapid, non-destructive method for determining elemental concentrations in commercially available infant formula. Twenty-three powdered infant formula samples were analyzed using XRF, with primary focus on Fe, Zn, and K. Additional elements were examined to provide broader spectral insight. The XRF results were compared to reference concentrations obtained using inductively coupled plasma mass spectrometry (ICP-MS). The ICP-MS results were obtained from a partner lab in Nevada, and were conducted on the same brand of infant formula; however, the original samples were destroyed in the measurement process. The software PyMca was used to generate spectral images of elemental concentrations and to fit analytical curves to the XRF data to obtain numerical data on the concentration peaks of selected elements. Coefficients of determination (R^2) were calculated to assess agreement between the two techniques. Stronger correlations were observed for iron ($R^2 = 0.72$), while the data obtained for zinc and potassium provided coefficients of determination of $R^2 = 0.47$ and $R^2 = 0.25$, respectively. Use of total area ratios (TAR) improved agreement for iron ($R^2 = 0.78$) and zinc ($R^2 = 0.39$), though potassium correlation decreased ($R^2 = 0.19$). A Bland-Altman plot was utilized to assess the agreement between the measured XRF results and the ICP-MS results by plotting their differences against their averages. Results indicated a concentration-dependent bias, with XRF overestimating higher elemental concentrations and underestimating lower concentrations. These results suggest that XRF shows promise as a screening tool for elemental analysis of infant formula, particularly for iron, but further calibration is required for accurate quantification of potassium and zinc.

Affiliation

Mount Allison University

31 - Low cost Homodyne Frequency noise Measurement of a single mode laser

Mathias DeGrace[1]

[1]Université de Moncton

The coherence of a single mode laser is directly related to random phase noise and frequency fluctuations arising from mechanical instabilities, temperature variations,, and quantum processes. These random fluctuations manifest as spectral width broadening, and therefore the suitability of these lasers for certains applications like interferometry, spectroscopy and LiDAR. In this project we characterize the frequency noise of one of our single mode lasers using a homodyne method. The frequency noise is extracted using Welch's method to obtain a statistical estimate of the laser noise. An innovative experimental setup based on the homodyne method is developed. This method is a simple, low cost, and efficient approach for estimating a single mode laser's line width and coherence.

Affiliation Université de Moncton

Author Index