Physics 4999

Honours Theses Presentation Day

April 21st, 2022 (9.45 am – 5 pm)

Room PAB 100

PROGRAM

STUDENT	APR-21-2022	PRESENTATION TITLE	SUPERVISOR
	9.15-9.45	**Talk upload on the classroom computer (all students)**	
Jacob Adams	9.45-10.15	Developing Numerical Methods in Python for Computing Angular Momentum Recoupling in the Framework of Loop Quantum Gravity	*F. Vidotto*
Nadia Aiaseh	10.15-10.45	Examining Ozone Depletion via a Custom Optimal Estimation Method (OEM) for Eureka	*O. Trichtchenko*
Jillian Psotka	10.45-11.15	Optimal Estimation Method-based Retrieval to Calibrate PurpleAir $PM_{2.5}$ Sensors	*R. Sica*
Gabriel Cattrysse	11.15-11.45	Astronaut Underwear: Wearable Materials for Attenuation of High-Energy Radiation	*L. Goncharova*
Steven Chedore	11.45-12.15	Asteroid Apophis and the Possibility of Deflection by Collision	*P. Wiegert*
	12.15-1.15	**Lunch Break**	
Mohamed Elsayed	1.15-1.45	Studying Phase Transitions in Superconducting Rings Using Computational Solutions to the Ginzburg-Landau Mean-Field Equations	*M. Karttunen*
Samantha Lambier	1.45-2.15	Confirming the Candidacy of Very-low-mass Stars for Microsatellite-based Telescopic Observations	*S. Metchev*
Xiyuan Li	2.15-2.45	A Joint-Chirp-rate-Time-Frequency Transform for Non-templated Binary Black Hole (BBH) Merger Gravitational Wave Signal Detection	*M. Houde*
Erin McCurry	2.45-3.15	Generating and Measuring Oscillatory Flow in Microfluidic Devices	*T. Poepping*
	3.15-3.30	**Break**	
Ridwan Bari	3.30-4.00	The Effect Circadian Rhythm Plays in the Amount of Integrated Information Produced for Various Large Scale Brain Networks	*A. Soddu*
Gabriela Robles	4.00-4.30	Developing Stacking Techniques for Detecting Polycyclic Aromatic Hydrocarbons	*J. Cami*
Jenna Veugen	4.30-5.00	Magnetic Resonance Radiofrequency Heating of Implanted Medical Devices	*B. Chronik*

Abstracts

Developing Numerical Methods in Python for Computing Angular Momentum Recoupling in the Framework of Loop Quantum Gravity

Jacob Adams
(Supervisor: Dr. Francesca Vidotto; Collaborator: Mr. Pietropaolo Frisoni)

Quantum gravity aims to understand the quantum properties of the gravitational field. One of the ways we can understand this is by looking at transition amplitudes of quantum states, as after General Relativity the gravitational field should be understood in terms of space-time geometries. The quantum gravitational field will have quantum state of the geometries. These quantum states can be described through Penrose's spin networks, which can be understood as graphs encoding the interactions between spacetime quanta. Transition amplitudes between different spin networks can be computed in the spinfoam formalism. This gives the probability of a state of the geometry to evolve into another. This formalism allows us to study space-time geometries in those regimes where quantum effects cannot be disregarded, such as in the black-hole interior or in the primordial universe, hence the significance of developing these kinds of computations. While the formal expression for the spinfoam amplitudes is well-defined, their evaluation requires the development of new numerical methods. The methods employed are those of recoupling theory, in a formalism that allow for the summing of many angular momenta (Wigner nj-symbols). This project aims to develop code parts to contribute to the amplitude computations. One goal of the project is to write the amplitude using coherent states, constructed from superpositions of spin networks. Another is to be able to implement a method to determine combination of spins which allow for a non-zero summing of 15 angular momenta (Wigner 15j-symbol). The main working language is Python using *pywigxjpf*. Our project mainly focuses on the numerical implementation of calculations that are fundamental in quantum mechanics, such as the summing of angular momenta in a gauge invariant manner, and the use of coherent 24 state to describe the semi-classical regime of the studied system.

Examining Ozone Depletion via a Custom Optimal Estimation Method (OEM) for Eureka

Nadia Aiaseh
(Supervisor: Dr. Olga Trichtchenko; Collaborators: Drs. Ghazal Farhani and Robert Sica)

In this work, we customize previously existing methods to obtain ozone density profiles using data from the Eureka Stratospheric Ozone lidar (SOLID). In order to use the previously devised optimal estimation method (OEM) to retrieve ozone densities from photon counts, we modify the input data, namely the station parameters and the a priori. This modified input is then used in the forward model and in the OEM to retrieve ozone densities from photon counts. Focusing on the ozone depletion event of 2020, we examine how the ozone densities change based on di↵erent a priori and uncertainty estimates and compare to existing measurements.

Optimal Estimation Method-based Retrieval to Calibrate PurpleAir $PM_{2.5}$ sensors

Jillian Psotka
(Supervisor: Dr. Robert Sica)

Exposure to pollutant particles of diameter ≤ 2.5 µm (i.e., fine particulate matter or PM2.5) can lead to numerous adverse health effects including cardiopulmonary disease, heart attacks, and premature death. Low-cost home air quality sensors have the ability to provide near-instantaneous local particulate matter concentrations both indoors and outdoors, and have the potential to contribute to air quality monitoring and prediction. While ideal for home monitoring, these sensors are susceptible to large uncertainties in absolute calibration and therefore must be properly calibrated before scientific use of the measurements. In this thesis, we investigated the calibration of the PurpleAir PA-II sensor. Different groups have proposed calibrations for PurpleAir sensors using standard regression methods. In my previous summer work, we proposed an empirical correction based on the Optimal Estimation Method (OEM), an inverse modelling technique. One significant advantage of using an OEM-based retrieval for the calibration is the ability to estimate the uncertainty in the retrieved calibration constants due to the uncertainty in each model parameter. In this thesis, we used OEM to apply a calibration model that is based on the physical properties of PM2.5 and its hygroscopic growth in the presence of humidity. We analyzed and simplified the existing physical model, making it accessible to more PurpleAir sites. The physical calibration reduced average daily Mean Absolute Error (MAE) of PM2.5 measurements from 5.58 $\mu g/m^3$ to 1.64 $\mu g/m^3$ and average daily bias from 4.75 $\mu g/m^3$ to -1.52 $\mu g/m^3$. It reduced average hourly MAE 6.79 $\mu g/m^3$ to 2.78 $\mu g/m^3$ and average hourly bias from 5.29 $\mu g/m^3$ to -1.12 $\mu g/m^3$.

Astronaut Underwear: Wearable Materials for Attenuation of High-Energy Radiation

Gabriel Cattrysse
(Supervisor: Dr. Lyudmila Goncharova; Collaborators: Drs. J.J. Noel, P. Rogan, and E. Walker)

Ionizing radiation, in the form of high-energy particles ejected from the sun and cosmic rays, can be a serious threat to astronauts in space. It can cause irreversible damage to human cells and can cause cancers. These incoming high-energy particles (primary radiation) can also generate potentially harmful secondary radiation when they collide with other matter in space like a space station or an astronaut's space suit. This secondary radiation is predominantly in the form of x-rays, gamma rays, and fast neutrons. The aim of this research is to test some lightweight shielding materials that can both be easily worn by astronauts in space and also effectively attenuate ionizing radiation. Stopping photons and charged particles can be achieved by taking advantage of interaction processes (such as electromagnetic forces) between high-velocity ions and target atoms. Secondary radiation that is not charged such as neutrons can be attenuated using materials that contain a large number of nuclei that interact strongly with neutrons. Stopping and Range of Ions in Matter (SRIM) software simulations were used to make predictions of projected ion ranges prior to ion attenuation experiments. Experiments for simulating collisions between either protons or alpha particles and the proposed shielding materials were conducted at the UWO Tandetron Accelerator Laboratory. The McMaster Nuclear Reactor (MNR) is currently being used to similarly test the shielding material's ability to attenuate neutrons. A firefighter suit with four layers of Nomex® in different chemical configurations was tested during both the neutron and ion attenuation experiments. Stacking all four layers of the firefighter suit resulted in zero transmitted 5.1 - 5.9 MeV He^+ ions, and transmission coefficients of the four layers were quantified and compared. SRIM calculations for Kapton®, Nomex® and aluminum foils provided predictions for thicknesses of these materials required to completely stop flux of He^+ and H^+ ions in the 10 keV – 150 MeV range. This research study provided a better understanding of material thicknesses and compositions for radiation shielding and also yielded observations on how a material's porosity affects its ability to attenuate particles. This research also contributed to knowledge related to developing materials that are more practical for astronauts to wear that attenuate radiation to safe levels (ideally less than the CSA and NASA's safe administrative dose equivalent of 500 millisievert/year for blood forming organs).

Asteroid Apophis and the Possibility of Deflection by Collision

Steven Chedore
(Supervisor: Dr. Paul Wiegert)

99942 Apophis is an asteroid in the Solar System with a diameter of about 400 m. This is large enough to cause widespread damage in the event of a collision with the Earth. On April 13th, 2029, it will make a very near pass by the Earth but is not expected to be an impact threat. Similar passes have been projected to occur in the years 2036 and 2068. Recent measurements of Apophis have indicated these passes are not significantly likely. Nevertheless, there exist narrow regions that if crossed in the 2029 pass, indicate a substantial increase in this likelihood. Unexpected changes in the trajectory of Apophis may result in these future passes becoming hazardous. In this report, the likelihood of other asteroids altering the trajectory of Apophis is examined. Using a large database obtained from the NASA Jet Propulsion Laboratory, the minimum distance between Apophis and each asteroid's orbits were evaluated via Python. This was performed with two levels of precision. Of the asteroids with the least minimum distance to Apophis' orbit, a full simulation of the asteroids' positions over the next 60 years were simulated to find the true minimum separation within a period that will influence these impact risks.

Studying Phase Transitions in Superconducting Rings Using Computational Solutions to the Ginzburg-Landau Mean-Field Equations

Mohamed Elsayed
(Supervisor: Dr. Mikko Karttunen)

Quantum computing is plagued by the difficulties in maintaining extreme conditions necessary for qubits, and some current methods such as using free electrons between semiconducting layers are difficult to extend to more ambient conditions. While there are existing quantum computers today, they are relatively inaccessible and require large costs for maintenance. However, there have been studies regarding the use of superconducting quantum phase slips as qubits in type-II superconducting rings of 1D and some extensions to quasi-2D. These have promising capabilities to expand to ambient conditions as more high-temperature type-II superconductors are discovered, given that improvements are continuously being made in reaching room temperature superconductivity. The phase slips are a result of imperfections in the superconducting ring approaching the critical current from an applied emf, which can be modelled using a non-superconducting nanowire. These phase slips produce Josephson junctions across the nanowires, which in parallel can be used as a series of qubits. We will investigate these instabilities using the Ginzburg-Landau mean-field equations for type-II superconductors computationally, extending the work on 1D and quasi-2D superconducting rings. Furthermore, we aim to improve upon existing methods in leveraging control over the production of phase slip qubits as well as to discover new approaches in tuning the parameters of the system for a similar effect.

Confirming the Candidacy of Very-low-mass Stars for Microsatellite-based Telescopic Observations

Samantha Lambier
(Supervisor: Dr. Stanimir Metchev)

In recent years, Earth-like exoplanets have become a major topic of interest in the search for life in our universe. These are planets in other star systems that are in habitable zone of their star and are around the same size as the Earth. Very low mass stars and brown dwarfs (known together as ultracool dwarfs, UCDs) are the best candidates for the detection of these exoplanets. Most stars in the universe are very low mass stars, and they have the highest fraction of Earth-sized planets compared to larger stars. Due to their lower luminosity and lower stellar masses, the habitable zones are closer to the star and thus Earth-like exoplanets will have shorter orbital periods. This is important because we will be using the transit method for detection, where we detect the exoplanet when it passes in front of a star, blocking some of its light. Shorter orbital periods allow for faster overall characterization, because multiple transits will occur over a shorter period. The Photometric Observations of Exoplanet Transits (POET) microsatellite is a proposed space telescope currently in development and will be able to detect Earth-like planets around UCDs. In this work, we began the process of building a catalogue of UCDs for observation by POET. We identified 3726 potential candidates from the Early Data Release 3 of the European space mission Gaia and constructed spectral energy distributions for 3046 of the objects. Radii of 0.1-0.3 $R_\odot$, effective temperatures of 2200-2900 K, and surface gravities (logg) of 4.5-5.5 cm/s^2 were determined for these objects and it was observed that a number of the UCDs appeared to be too young. Future work is to determine the properties of the missing objects, improve modelling fits, and ultimately generate optimal sample of approximately 100 targets for POET.

A Joint-Chirp-rate-Time-Frequency Transform for Non-templated Binary Black Hole (BBH) Merger Gravitational Wave Signal Detection

Xiyuan Li
(Supervisor: Dr. Martin Houde; Collaborator: Dr. Sree Ram Valluri)

With the development of machine learning (ML) algorithms, attempts to use ML techniques like artificial neural networks (ANNs) in the binary black hole (BBH) and binary neutron star (BNS) merger gravitational wave (GW) detection have been made by W. Wei et al. and many others. Despite the surge of interest in all types of ANN architectures, time-frequency spectrograms remain one of the preferred input data structures due to their relevance to some highly efficient and robust image ANN architectures. Traditional Fourier transforms (FT) based time-frequency decomposition methods have difficulties identifying continuous frequency changes since FTs only fit the input signal to waveforms with constant frequency. BBH and BNS merger GW signal frequencies vary continuously and are chirp signals. A transform method that incorporates the rate of frequency change (chirp-rate) may be crucial to improving the performance of existing BBH and BNS merger GW signal detection image ANNs by providing chirp-rate enhanced spectrograms. Building upon the foundation of the linear chirp transform (LCT) by O, A, Alkaishriwo and L.F. Chaparro, in this thesis, we develop a version of the short-time linear chirp transform (STLCT) and introduce the joint-chirp-rate-time-frequency transform (JCTFT) methods for spectrogram generation. These methods are achieved by replacing the constant frequency waveform model with a linear chirp model. We validate the JCTFTs using BBH merger GW waveforms with noise generated using the numerical relativity corrected effective-one-body (EOBNR) formalism and advanced Laser Interferometer Gravitational-wave Observatory (aLIGO) zero-detuned noise models. We plan to further demonstrate the positive effects of JCTFTs on merger signal detection image ANNs in follow-up studies.

Generating and Measuring Oscillatory Flow in Microfluidic Devices

Erin McCurry
(Supervisor: Dr. Tamie Poepping)

Cells react to forces and mechanical conditions within structures, including wall shear stress, a frictional force exerted on the surface of a tube by a moving fluid. Wall shear stress can trigger cellular responses important for biological function. Understanding how flow results in shear stress helps illuminate cellular environments within systems. Microfluidic channels, in combination with vibrational actuators, can be used to simulate flow environments within the body, such as pulsatile blood flow through vessels. Simulating biological flow means fluid velocities and shear stress can be found with high accuracy, then applied to the relevant biological system to determine the conditions that cells are subject to within these systems. In this project, a small plunger attached to a speaker was used to facilitate oscillatory flow in microfluidic channels. The speaker can be used with a signal generator to create a wide range of flow conditions, as dictated by the signal generator. Using particle-seeded fluid in the channel, the flow was imaged using a microscope and high-speed camera. With these images, particle image velocimetry (PIV) was used to find particle velocities and map the resulting flow field. From these velocity fields, the aim was to calculate wall shear stress within the microfluidic channel. The objective of this project was to determine the wall shear stress that arises in the microfluidic channel under various frequency and flow settings. This knowledge can then be applied to biological systems to understand the shear stress acting on cells and the associated effects. Various oscillatory flow conditions were produced in the microfluidic channel, imaged, and analyzed in two dimensions. Laminar flow of 50 μL/min was also observed in three dimensions, where the wall shear stress in the channel was found to be 1.535×10^{-7} N.

The Effect Circadian Rhythm Plays in the Amount of Integrated Information Produced for Various Large Scale Brain Networks

Ridwan Bari
(Supervisor: Dr. Andrea Soddu)

The lack of quantitative metrics for diagnosing comatose patients after they have experienced a significant brain injury has led to the increase in misdiagnosis of these patients using qualitative comatose scales. Integrated information (Φ) is a neural correlate that has been proposed to have the potential to quantify the level of consciousness a patient experiences and could prove useful in reducing the misdiagnosis rate of comatose patients. A common method of diagnosing a patient's cognitive ability is through the Glasgow Coma Scale (GCS)—which involves asking a series of questions designed to gauge the verbal and motor skills of a patient after they have experienced a traumatic brain injury. While this technique has proven successful all throughout the healthcare system, it is still largely rooted in qualitative methods which can have difficulty distinguishing patients with slightly altered stages of consciousness. Φ can potentially aid in establishing quantitative benchmarks but is a relatively novel metric; therefore, characterizing the Φ for many brain networks for different types of patients (healthy, impaired, comatose, etc.) under various types of stimuli might provide deeper insight into Φ's ability to characterize the neuronal integration at the individual brain network level. The goal of this study is to model the effects of circadian rhythm (cyclic wake and sleep patterns) on the amount of integration information (Φ) produced in various brain networks (DMN, auditory, etc.). We will use the Generalized Ising Model (GIM) to develop a model for the brain networks by introducing an oscillating external magnetic field, B(t), into the GIM to emulate the wake/sleep stimulation cycles. Afterwards, we will calculate the Φ value for various brain networks and see how they change throughout the stimulation timeline. If time permits, the nature of the external magnetic field (i.e., the shape, frequency, amplitude, etc.) will be adjusted to see when integrated information breaks down depending on the type of external magnetic field applied. The objective of this study is to have plots to compare the variation of the integrated information of various brain networks throughout the simulated circadian rhythm time interval.

Developing Stacking Techniques for Detecting Polycyclic Aromatic Hydrocarbons

Gabriela Robles
(Supervisor: Dr. Jan Cami)

The interstellar medium (ISM) is known as the low-density gas that lies in the space between stars where 99% of the medium is made up of molecular gas clouds. These interstellar clouds contain numerous complex molecules that may be sources to unidentified interstellar features, Diffuse Interstellar Bands (DIBs). It has been over 100 years since DIBs have been observed, yet only two have an identified source. The ESO Diffuse Interstellar Bands Large Exploration Survey (EDIBLES) is a survey created where the goal is to work toward characterising the physical and chemical conditions for a statistically significant sample of interstellar lines-of-sight. By Using EDIBLES, hopefully more sources for DIBs can be identified. Laboratory spectroscopy is useful for identifying molecules within the ISM because DIBs can only be identified by comparing them to lab spectra. In this project I will be using the lab data of pentacene, a polycyclic aromatic hydrocarbon (PAH). The specific spectrum of Pentacene used has a signal-noise-ratio (SNR) of 5000:1 which has 5 strong absorption peaks at different wavelengths. I will be using stacking of the absorption peaks to obtain a 'super-spectrum' of pentacene with an increased SNR. These super-spectra will result in one easily identifiable absorption feature. Using the Python coding language and previous models from the EDIBLES database, a Voigt fitting was necessary to find the best parameters to apply to each peak, which yielded a central wavelength. The central wavelengths were used as offsets to center each peak and each peak was scaled using a scaling factor determined from the fitting. After these steps the peaks were added to make the super-spectra. In the future this method can be applied to DIBs and other PAHs to result with one distinguished absorption feature. This will simplify the comparison process between DIBS and PAHs, hopefully result in more DIB sources being identified.

Magnetic Resonance Radiofrequency Heating of Implanted Medical Devices

Jenna Veugen
(Supervisor: Dr. Blaine Chronik)

Magnetic Resonance Imaging (MRI) is rising in popularity as an optimal imaging modality. During an MRI scan, implanted medical devices can heat up due to radiofrequency (RF) heating. This occurs when the RF pulses interact with conductive materials, typically around 10-20 cm in size. As a result of the field interactions with the material properties, a current is induced within the device, causing it to heat up. This restricts the use of MRI systems, as patients with implants and other medical devices are limited by the severity of the heating. Currently, each type of medical device is tested to ensure the temperature increase is within a safe range to avoid adverse effects. Although RF induced software has been created to model the radiofrequency heating of simpler devices, the mechanisms and parameters of the device heating and cooling are not yet widely understood. In this thesis, we measured RF-induced heating of various electrically conductive devices at 64 MHz and 128 MHz. Devices were submerged in gelled-saline to mimic human tissue with thermal probes inserted to measure the device temperature. To conduct analysis, MATLAB was used to test and evaluate multi-parameter models of both the device heating and cooling. A functional model was found that showed strong correlation with the measured results with a mean RMS error of 0.061°C. Additionally, a finite-difference-time-domain (FDTD) software tool was used to model the temperature change and was critically compared to the computed fit and measured data. The aim was to characterize and isolate the mechanisms and factors of the radiofrequency heating to achieve a broader understanding of RF heating. The difference in heating effects due to device length was found to directly relate to resonance length. The frequency of the RF exposure influenced the heating shape. The overall repeatability of the measurements was strong with a standard deviation $\leq$1.000 °C. This understanding will one day help in alleviating the limitations of MRI systems for patients with medical devices.