NSERC UNDERGRADUATE STUDENT RESEARCH AWARDS
at
MCMASTER UNIVERSITY
SUMMER 2019

These prestigious awards enable undergraduate students to spend the summer months (16 weeks) working with a research group. If you are interested in spending "Summer 2019" at McMaster University in Hamilton, Ontario, and you have first-class or high second-class standing, we invite you to apply through our Department of Physics and Astronomy. We offer exciting research opportunities in astronomy, astrophysics, chemical physics, condensed matter physics, biophysics, medical physics, and subatomic physics. Further information about the department and its researchers is available at the URL http://www.physics.mcmaster.ca/. A list of projects currently available for summer students follows. **Students should contact supervisors whose projects interest them in addition to submitting an application to the department**. Information about the award can be found at the NSERC website (www.nserc.ca). **The application deadline is Friday, February 1, 2019.**

The awards result in the following total monthly stipends:
Students completing Year II: $2000 (Year I in Quebec)
Students completing Year III: $2100
Students completing Year IV: $2200

Residence accommodation may be available on campus for out-of-town students. Return airfare is payable by NSERC, where applicable.

Applications are invited from all qualified students who will graduate in 2019, 2020, 2021 and 2022. All applications should include:

1. An official and up-to-date transcript. If this is not available before the application deadline, please submit an unofficial one with your application and follow-up with an official one as soon as possible.
2. NSERC Form 202, Part I. This should be filled out online first (through www.nserc.gc.ca, "On-line services") and then printed out and signed.
3. A short statement on a separate sheet about your interests in physics and a list of any lab and computer programming skills. From the project list below, indicate two projects that interest you in order of preference. Please do not list two projects from the same supervisor. **Reference letters are not required.**

Completed applications should be sent to the address below. Applications must be received by **Friday, February 1, 2019**.

Dr. Graeme Luke, Chair
Department of Physics & Astronomy
ABB 241, McMaster University
1280 Main St. W.
Hamilton, ON L8S 4M1
Attention: NSERC USRA Application

Experiments in soft and living matter at surfaces and interfaces

Supervisor: Dr. Kari Dalnoki-Veress (dalnoki@mcmaster.ca)

Soft matter physics is the physics of soft, squishy materials which includes biological systems. A ball of silly putty when thrown against a wall will bounce, yet the same material can also flow and fracture. A hydrogel can be so absorbent that it swells to hold up to 99% water - this is the miracle material that keeps a baby's bottom dry. Squirt shampoo into a puddle and it can rebound and squirt right back at you. The polymer molecules used to give the shampoo its preferred viscosity can also be used to stabilise your ice cream, or to make contact lenses less susceptible to degradation. Astonishingly, that same polymer may be used as a laxative, and more sophisticatedly in drug delivery and gene therapy! These are all examples of some of the amazing properties of soft materials. We are interested in the fundamental physics of soft materials on the micro and nanoscale. We use various experimental techniques (optical microscopy, atomic force microscopy, ellipsometry, various home made micro-mechanical tools, etc.) to study systems ranging from polymers to colloids to the locomotion of little worms. There are many projects related to soft and living matter at surfaces and interfaces. The exact project will depend on the preference of the candidate, what is most exciting at the time, and where we need help most urgently.

Further information: www.kdvlab.net

Requirements: Ambition, enthusiasm and a willingness to learn.

Observational Investigations of Galaxy Evolution

Supervisor: Dr. Laura Parker (lparker@mcmaster.ca)

Background: My research involves the analysis of data from ground- and space-based telescopes to try and answer questions about how galaxies in the universe form and evolve, as well as the connection between dark matter and the visible material in galaxies. See http://www.physics.mcmaster.ca/~lparker/ for more information.

Project: The summer research project would involve the study of observed properties of galaxies as a function of their host environment. We have a large multi-wavelength data set for samples of galaxies at distances ranging from relatively nearby to many billions of light years away (the light we receive was emitted when the universe was only half of its current age). Some specific questions we are trying to address concern the growth of central galaxies in large collections of galaxies called groups and clusters and the role of local environment on the dark matter properties of galaxies

Requirements: I am looking for an enthusiastic 2nd or 3rd year student with an interest in observational cosmology. No prior experience is required but at least one course in astronomy and computer skills are definitely an asset.

Kinetic Simulation of Catalytic RNAs

Supervisor: Dr. Paul Higgs (higgsp@mcmaster.ca)

Background: The RNA World is a period thought to have existed on the ancient Earth in which RNA molecules acted as both genes and catalysts. Ribozymes have been developed in the laboratory that can carry out many of the functions that would be required in an RNA world, although there is still no fully self-sustaining RNA system. Template-directed replication is an essential property of nucleic acids. We want to know how replication got started, and to understand how template directed reactions can speed up RNA synthesis and replication beyond what would occur via random polymerization without templating.

Project: The student will carry out computer simulations of chemical reaction systems to describe template-directed replication of RNAs, with applications to the origin of life and to laboratory experiments on ribozymes. Reaction steps include binding of short oligomers to templates, ligation of neighbouring oligomers on the same template, and separation of double strands. In order for repeated replication to occur, the reaction system must be kept out of equilibrium, either by temperature cycling, wet-dry cycling, or continued flow of reagents through the system. We will use simulations of sets of differential equations to investigate rates of replication in these different circumstances, and to understand in what conditions template-directed replication is feasible.

Requirements: The project involves investigation of chemical reaction systems using both mathematical and computational methods. Prior experience of scientific programming would be advantageous.

Self-Assembly of Soft Matter

Supervisor: An-Chang Shi (shi@mcmaster.ca)

Background: Soft condensed matter physics studies soft materials such as polymers, liquid crystals, surfactant solutions, colloidal suspensions, and lipid membranes. The application of basic physics ideas to the study of soft matter is one of the major growth areas of modern physics. My research program focuses on the self-assembly of these materials into complex ordered structures. The goals of the research are to elucidate fundamental principles and guidance for the design and optimization of polymeric materials with controlled internal structures, and to obtain understanding of the self-assembly of amphiphilic systems such as block copolymers, surfactants and lipids.
Project: The specific project is the study of self-assembly of block copolymers. Block copolymers are macromolecules composed of chemically distinct sub-chains or blocks. Under appropriate conditions, block copolymers can self-assemble to form long-range ordered phases similar to the usual crystals but with a much larger lattice constant. The studies aim at the structure and phase transition of block copolymers, focusing on the occurrence of complex ordered structures. These studies will be carried out by a combination of analytical and numerical calculations.

Requirements: I am looking for one highly motivated 3rd or 4th year students with strong background knowledge in statistical physics and mathematical physics. Experiences with computational physics, simulation techniques and programming will be very helpful.

Phase transitions in ultrathin magnetic films

Supervisor: Dr. David Venus (venus@physics.mcmaster.ca)

Background: The magnetic properties of ultrathin films (a few atomic layers in thickness) grown on a non-magnetic substrate differ greatly from those of thick films or bulk materials. This is because of the dominant influence of surfaces, interfaces and two-dimensionality. As a result, these films are grown and studied in an ultrahigh vacuum environment where the surface and surface cleanliness can be controlled. We have studied the magnetic phase transitions of a number of classes of films that exhibit different magnetic properties due to their different geometries. One fascinating line of research is the magnetic properties of true two-dimensional (2D) magnets – that is, films that are just one atomic layer thick. We have developed specialized techniques to grow and characterize these films and to measure the magnetic response of a very small amount of material.

Project: A famous theorem states that long-range ferromagnetism is not possible in a uniform 2D system because there are not enough nearest neighbour atoms to stabilize it. However, a film grown on a crystal substrate is not really uniform in all directions because of the crystal lattice. If the structure of the lattice distinguishes one special direction (for example, the surface atoms may be arranged into rectangles that distinguish the x and y directions in the surface) then ferromagnetism can exist. We have studied and confirmed this prediction in great detail.

The 2016 Nobel Prize was (in part) awarded to Kosterlitz and Thouless for their theory about the magnetic state of a uniform 2D film. It predicts a state that is not technically ferromagnetic, but appears to be ferromagnetic because the system gets trapped in a non-equilibrium state that is similar to ferromagnetism. It has also been predicted that this state will be present in magnetic films grown on a lattice where the surface atoms form a square, so that the x and y directions are equivalent. We wish to test this prediction, and, if the Kosterlitz-Thouless transition is present, to study it in detail using 2D magnetic films.

The project involves growing and characterizing these films, and measuring their magnetic susceptibility using an optical technique. In the initial stages, you will be working with a graduate student who will teach you the experimental procedures. Later in the summer, we will discuss a detailed project that you can work on independently to advance our understanding of this type of 2D magnetism.

Requirements: A successful applicant will be confident working with her/his hands, respectful but not intimidated around complicated equipment, and have lots of patience.

Bloody Mari: Red Blood Cell Membranes

Supervisor: Dr. Maikel Rheinstadter (rheinstadter@mcmaster.ca)

Background: Blood is one of the main transport mechanisms in mammal bodies and has been the focus of research for many centuries. Its importance in diagnosis and treatment makes the study and characterization of blood essential in modern medicine. We have developed new protocols and techniques to study the structural and mechanical properties of human red blood cell (RBC) membranes using the bloody-mari-system (Multilamellar Array of Red-blood-cell Interfaces). This assay is particularly suited for biomedical applications: sensors and artificial hybrid vesicles can be designed based on the developed protocols.

Project: You will prepare red blood cell membranes in our lab and investigate their molecular structure using X-ray diffraction, optical and atomic force microscopy, UVvis spectroscopy and molecular dynamics (MD) computer simulations. You will further develop the protocols to prepare hybrid membranes to tune properties of native human red blood membranes by changing their elasticity, charge, etc. through the inclusion of synthetic lipids. These membranes will then be reassembled into artificial red blood cells for drug delivery and for the development of sensors to detect bacteria.

Requirements: I am looking for one or two enthusiastic students. You will work in an experimental biophysics lab. As such, you should have good hands, be a good team player and have a passion for science. Background in biophysics, biochemistry or life sciences and computing skills, such as Matlab and Linux would be helpful but is not a prerequisite.

The Origin of Life on Earth and other Planets

Supervisor: Dr. Maikel Rheinstadter (rheinstadter@mcmaster.ca)

Background: How did life emerge on Earth 3.5 billion years ago? Can life form and exist elsewhere in the universe, on Mars and other potentially habitable exoplanets. Prior to today's DNA and protein dominated world, RNA (ribonucleic acid) most likely acted as genetic storage and catalyst to biochemical reactions. Life has most likely formed in warm little ponds in the hydrothermal field of volcanic sites. Cyclical wetting and drying of the edge of these volcanic ponds, due to tides, seasons, or day night cycles is crucial to promote the synthesis of the first RNA and the formation of first primitive cells. Compounds found in those ponds such as clays, inorganic salts and amphiphilic molecules are important to polymerize nucleotides and form simple cells, so–called protocells.

Project: You will work in the brand new Origins of Life lab and use the Planet Simulator to create conditions as on the early Earth, Mars or other Earth-like planets. You will model different warm little ponds by mixing the different components and use the Planet Simulator to mimic day/night and seasonal cycles to determine under which conditions RNA and protocells form. The equipment in the Origins of Life Lab includes optical and atomic force microscopy, UVvis spectroscopy, X-ray diffraction and Molecular Dynamics (MD) computer simulations to study the structures that form during these processes. You will use the biochemistry equipment in the lab to isolate and purify the RNA polymers that have formed and determine their length. The project involves preparing samples, conducting the different experiments and computer simulations and analyzing the data to develop molecular models. By running those models you will identify key parameters for the formation of proto-cells and RNA formation and replication.

Requirements: I am looking for one or two enthusiastic students. You will work in an experimental biophysics lab. As such, you should have good hands, be a good team player and have a passion for science. Background in biophysics, biochemistry or life sciences and computing skills, such as Matlab and Linux would be helpful but is not a prerequisite.

Building exoplanets

Supervisor: Dr. Ralph Pudritz (pudritz@physics.mcmaster.ca)

Background: The origin and composition of the thousands of exoplanets discovered around other stars is one of the great questions of astrophysics and planetary science. The great majority of exoplanets are rocky worlds of up to 10 Earth masses and one of the great puzzles about them is the relation between their masses and planetary radii. These vary enormously (rocky worlds, to water worlds, and perhaps systems with very extensive dense atmospheres too) in their properties which is a direct consequence of the inventory of materials that they accreted from their host protoplanetary disks as they formed. My research group has developed extensive theoretical and computational modeling of how planets move in disks, accrete various materials predicted by our astrochemistry simulations, and end up with final orbits and masses.

Project: We would like to compute the resulting structure of planetary atmospheres and their rocky cores for SuperEarth type of planets produced in our simulations. The project(s) involve computing the structure of planetary bodies using codes that solve the basic equations for planet structure. The student will use as initial compositions for planets those computed from our extensive library of planet formation simulations. The goal is to compute the resulting mass-radius relations for exoplanets, which will be then directly compared with the observations. A parallel project would use atmosphere codes to compute the structure of exoplanet atmospheres, using the initial gas compositions from our models.

Requirements: This is an exciting opportunity to engage in front line research on exoplanets. I am looking for 2nd or 3rd year students who are highly motivated, conversant in computer programming in languages such as Python, and happy to learn.

Radiation fields and RNA formation on early Earth and Earth-like planets

Supervisor: Dr. Ralph Pudritz (pudritz@physics.mcmaster.ca)

Background: The origin of life on the Earth and Earth-like planets around other young stars is one of the greatest scientific questions. The Origins of Life Laboratory has developed a special planetary simulator instrument that is capable of examining the process of forming the first genetic molecules – widely thought to be RNA – in different kinds of planetary environments. The experiments focus on how polymerization of basic building blocks of RNA occurs in typical pre-biotic conditions which feature wet-dry and temperature cycles, different kinds of radiation fields from the host stars, atmospheric composition, etc. One of the important problems to address is what effect UV radiation from the early Sun (and other host stars) has on RNA formation. In the absence of life, planetary atmospheres are not expected to have protective ozone layers that can screen the chemistry from damaging photodissociation effects. The simulator was designed to "dial a star"- that is, to expose the chamber to irradiation of different stellar spectra, from dwarf (red) stars to solar type stars that are known to have Earth-like planets in or near the habitable zones (orbits wherein surface water on a planet remains liquid).

Project: The flux of irradiation from the simulator's lamps range from the infrared through optical and into the UV. The project will be to set up "scripts" using the simulator's programming capability, that provide a grid of different stellar radiation spectra. We would also like to develop cycling of the irradiation with the other cycles (dry-wet, temperature) to fully mimic planetary surface conditions. The goal of such capabilities will be to measure what these different radiation fields do to polymerization and other kinds of related RNA chemistry in different planetary environments. This is a wide open project, with many different kinds of extensions. This work will be done in the Origins of Life Laboratory under the close collaboration with Dr. Maikel Rheinstadter and his group. The programming of the instrument is not difficult.

Requirements: I am looking for excellent students who are keenly interested in and have an aptitude for experimental work. This is interdisciplinary research so that the student will learn to also run and analyze the results of the experiments using the various biochemical and biophysical instruments in the lab. A background in programming (eg. Python) is desirable. Some background in basic astrophysics is also very useful. The ability to take the initiative is essential.

Accelerator-Based Experiments and Nuclear Data Evaluation for Nuclear Astrophysics

Supervisor: Dr. Alan Chen (chenal@mcmaster.ca)

Background: Our research focuses on the study of nuclear reactions and nuclear properties that are crucial to the energy generation and element synthesis in various stellar environments, such as classical novae and supernovae. The project will comprise aspects of one or both of the areas described below. For more information, check out our group's website at https://www.physics.mcmaster.ca/~psaltisa/nuclear_astro/

Accelerator-based experiments: In stellar explosions, where the temperatures and densities become extreme, reactions and decays involving unstable nuclei become important in governing the star's nucleosynthesis and evolution. A key input to modeling simulations of such events are the rates of the key reactions. Our group uses both radioactive and stable beam accelerator laboratories (e.g., TRIUMF) to measure these reaction rates and nuclear properties. Detector simulations and data analysis are carried out locally at McMaster.

Nuclear data evaluation: This effort focuses on compiling and critically evaluating the latest published data from nuclear physics experiments. The evaluated data sets are made available to the research community through the National Nuclear Data Center at the Brookhaven National Laboratory (USA). The Data Center serves as the main authoritative nuclear data source for nuclear physicists and nuclear astrophysicists worldwide.

NEUDOSE satellite – radiation instrumentation work

Supervisor: Dr. Soo-Hyun Byun (soohyun@mcmaster.ca)

Background: My research group has been working on advanced radiation detector and nuclear instrumentation developments to address the current challenges in radiation detection and measurement. An exciting project I recently created with Dr. Andrei Hanu is the McMaster NEUtron DOSimetry and Exploration (NEUDOSE), which aims at developing a satellite for measuring neutron and charged particle dose rates in space. (http://mcmasterneudose.ca/)

Project: The student will join the radiation instrumentation team of the NEUDOSE project. Under the supervision of Drs. Andrei Hanu, Eric Johnston and myself, she/he will do the following work in collaboration with NEUDOSE team members: i) Fabricate and assemble the detectors. ii) Design, build and test signal processing system. iii) Characterize the detector responses to alpha, beta, gamma and neutron radiation. iv) Data analysis.

Observations of gas and star formation in galaxies

Supervisor: Dr. Christine Wilson (wilson@physics.mcmaster.ca)

Background: My research involves using observations from powerful radio telescopes to try to understand how gas is turned into stars in some of the most active galaxies in the nearby universe. My goal is to understand what causes the star formation rate in certain galaxies to shoot up by factors of 10-100 compared to more quiescent galaxies like our own Milky Way.

Project: The summer research project involves analyzing data from ALMA (the Atacama Large Millimeter Array) for nearby starburst and merging galaxies to help understand the links between the different phases of the gas and the star formation rate. Some of the galaxies also contain super-massive black holes that may affect the the gas properties and "contaminate" our measures of the star formation rate. One of the specific questions we are trying to answer is how best to obtain accurate measurements of the very densest gas that is most closely linked to star formation

Requirements: I am looking for an enthusiastic 2nd or 3rd year student with an interest in observational astronomy. No prior experience is required but at least one course in astronomy and computer skills are definitely an asset.

Probing the Intergalactic Medium

Supervisor: Dr. William Harris (harris@physics.mcmaster.ca)

Background: In rich, populous clusters of galaxies, the member galaxies interact with each other quite a lot through orbital encounters, sometimes even completely merging. These collisions and encounters are messy, and lead to large numbers of stars being stripped off their host galaxies and thrown into the Inter-Galactic Medium -- the space between galaxies. Finding and measuring just how much material is in the IGM is an intriguing challenge and is directly related to the evolutionary history of these rich environments.

Project: I am the Principal Investigator of an international team carrying out the analysis of a set of images from the Hubble Space Telescope. These are designed to survey the IGM in the Perseus cluster, one of the richest nearby galaxy clusters. Part of this project is to find and measure the globular star clusters (GCs) that are scattered throughout the IGM and act as very nice tracers of the IGM population of stars. There are also dwarf galaxies such as the fascinating Ultra-Compact Dwarfs (UCDs) that may be nuclei of stripped dwarfs, or giant GCs, all of which can be found throughout the cluster.

Requirements: I would like to work with a 3rd or 4th year student keenly interested in observational astronomy and data analysis. At least one previous astronomy course would help but is not required. Applicants should be familiar with at least one scientific computing language such as Python, C, or Fortran.

Physics of Quantum Materials

Supervisor: Dr. Graeme Luke (luke@mcmaster.ca)

Background: Quantum materials are those in which quantum effects overwhelm thermal effects, resulting in new electronic and magnetic properties. We are actively involved in the discovery/creation, characterization and understanding of materials displaying macroscopic quantum phenomena and novel physical properties.

Geometrical magnetic frustration arises when spins are arranged on a lattice such that the individual magnetic interactions cannot all be satisfied (such as antiferromagnetic interactions on a triangular lattice) and can lead to the emergence of novel magnetic ground states including both classical and quantum spin ice and quantum spin liquids.

Project: This project involves the synthesis of single crystals of geometrically frustrated magnetic materials using our 3 optical image furnaces. In addition to crystal growth, this project will involve powder and single crystal x-ray diffraction as well as neutron scattering in the McMaster Nuclear Reactor. Magnetic susceptibility and specific heat measurement will be used to characterize the magnetic and thermodynamic properties of grown single crystals.

Requirements: Completion of at least second year in physics. Enthusiasm and interest in a broad range of subjects a definite plus.

Quantum caustics

Supervisor: Dr. Duncan O'Dell (dodell@mcmaster.ca)

Background: The bright lines on the bottom of swimming pools, rainbows, twinkling of starlight: these are all examples of caustics, i.e. the natural focusing of light. They are not the perfect point foci we usually learn about in optics with man-made lenses, but they have their own structure and remarkably caustics only take on certain geometrical shapes. Despite the long history of optics, it was only realized relatively recently that these commonly occurring phenomena can be described using a mathematical theory of singularities called catastrophe theory. Thus far, this theory has only been applied to classical waves: I am interested in applying catastrophe theory to quantum waves to try and describe quantum caustics (one example is Hawking radiation).

Project: This project is theoretical in nature and concerns studying the dynamics of quantum waves such as those that occur in atomic Bose-Einstein condensates that have been created in many labs around the world. We will use catastrophe theory to analyze caustics in these systems as "quantum catastrophes". Along the way we will learn how to apply quantum mechanics to many-particle systems which is an essential part of modern condensed matter physics. This project will also be very visual due to the geometrical nature of caustics: apart from `pen and paper theory' the project will also involve lots of visualization using Mathematica or Python. I want the student to generate lots of pictures of quantum caustics!

Requirements: I am looking for a motivated third or fourth year student with an interest in theoretical or mathematical physics. Experience in programming would be an asset.

Theoretical Physics problems in Quantum Mechanics and Optics

Co-Supervisors: Dr. Donald Sprung (dwsprung@mcmaster.ca) and
Dr.Wytse van Dijk (vandijk@physics.mcmaster.ca)

This summer project deals with the quantum mechanics of a particle in a finite periodic potential, such as an electron in a semiconductor hetero-structure, or an EM wave in a layered medium. There are many problems in this area that are within the capability of a theoretically inclined undergraduate student. Recent summer students have worked for example on systems under applied bias, or with inelastic effects, and a Fano-Anderson model of a decaying quantum system. The background required for the project is completion of an introductory course in quantum mechanics and the associated mathematical skills. You will be exposed to a number of facets of a research project in theoretical physics, which may include reading background papers on the subject, deriving expressions, using symbolic mathematics software, writing computer code, producing graphs, and writing a scientific report. The aim is to provide you with an experience of scientific investigation, and an opportunity to hone some marketable skills. Several previous students have become co-authors of published papers, a useful asset for anyone going on to graduate study.
For examples, see

DWLS et al. Can. J. Phys. 86 (2008) 515,
DWLS et al. Am. J. Phys. 77 (2009) 552-61,
DFWLS t al. Am. J. Phys. 80 (2012) 734-7; Erratum ibid. 80 (2012) 1010;
DWLS et al. Finite Fourier transforms by a modified Filon-Euler-MacLaurin-method,
Comp. Phys. Comm. 184 (2013) 607-616.
A. Ibrahim et al. Floquet-Bloch analysis of solvable HIll equations with smooth potentials: JOSA-B 35 (2018) 1223-32.

Liquid crystal phases of filamentous bacteriophages

Supervisor: Dr. Cecile Fradin (fradin@physics.mcmaster.ca)

Background: Virus are the simplest living creatures, being made of a single nucleic acid (DNA or RNA) molecule covered by a protein armour. Filamentous bacteriophages, that is elongated virus that attack bacteria (and are therefore not dangerous to work with!) can be cross-linked to form soft materials with interesting properties. Because the proteins forming the coat of the virus can be genetically engineered, these properties can be tuned depending on the application. The goal of this project is to characterize the structure of filamentous phage-based materials.

Project: The project will concentrate on a virus called M13, and be carried out in close collaboration with the group of Dr. Zeinab Hosseini-Doust (Dept. of Chemical Engineering). M13 is a filamentous phage with a very elongated shape, both very long (about a micron) and very thin (a few nanometers). Because of this elongated shape, it can behave like a liquid crystal at high concentration and form a nematic phase. Specific aims for the project will be: 1) Determine conditions (concentration, temperature, buffer) in which M13 does form a nematic phase. 2) Use polarization microscopy and fluorescence microscopy to study the alignment of the virus (measurement of the order parameter of the liquid crystal phase) and 3) measure the diffusion coefficient of small fluorescent molecules mixed with the phage (to assess the permeability of the filamentous phage-based material).

Requirements: We are looking for a student interested in microscopy and image analysis, enthusiastic, independent and not afraid working in an interdisciplinary field and getting their hands dirty.