

NSERC UNDERGRADUATE STUDENT RESEARCH AWARDS
at
MCMASTER UNIVERSITY
SUMMER 2017

These prestige awards enable undergraduate students to spend the summer months (16 weeks) working with a research group. If you are interested in spending “Summer 2017” 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 3, 2017.**

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 2017, 2018, 2019 and 2020. 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 3, 2017.**

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

Low energy beta-ray spectrometry

Supervisor: Dr. Soo Hyun Byu (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. Particularly, we have been developing THick Gas Electron Multiplier (THGEM) detectors and digital signal processing systems for neutron dosimetry, neutron imaging and low energy beta-ray detection. We also developed an advanced gamma-ray spectrometer geared for ultra-low level radioactivity analysis.

Outline of Project:

The student will join our beta-ray spectrometry project. With the graduate students involved in this project, he or she will experimentally characterize the detector response to beta-rays for various beta energies and incident angles. Particularly, to analyze beta spectral data, the student will employ the existing unfolding (de-convolution) algorithms, write computer codes and evaluate the performance of each algorithm. Eventually, we aim at developing an optimized beta spectral analysis algorithm.

Requirement:

A senior Medical Physics student (level 4 or 5) is preferred.

Parallel Simulations of Astrophysical Systems

Supervisor: Dr. James Wadsley (wadsley@mcmaster.ca)

The research will focus on using parallel simulation programs to model systems such as galaxies, star forming clouds and young proto-stellar disks. The work will involve running and/or examining simulations. Simulations will be run using the parallel Gasoline program and similar parallel software (ENZO, FLASH) on the SHARCNET supercomputing facilities. The project can be adapted to match the interests of the applicant to focus on specific aspects such as coding and physical models (How should we add stars, supernovae and black holes?), designing and running specific cases (What set-up is likely to produce interesting galaxies or star clusters?) and/or analysis and visualization via movies of the simulations (Does it look like a real galaxy? Does it match the luminosity, size and other properties? What drives the evolution?).

Requirements: Applicants should have experience using at least one modern programming language, such as C/C++ and/or Fortran 90. Previous experience with Linux/Unix is highly desirable.

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.

Observations of gas and star formation in nearby galaxies

Supervisor: Dr. Christine Wilson (wilsoncd@mcmaster.ca)

Background: My research involves the analysis of millimeter-wave and far-infrared data from ground and space based telescopes to try to understand how star formation is regulated in galaxies by studying the gas that provides the fuel for star formation.

Project: This summer research project will involve working with cutting-edge data from the James Clerk Maxwell Telescope in Hawaii. You will be working with gas emission line data and/or dust continuum emission from one of the three large projects that I am involved in that focus on nearby galaxies. All three projects focus on understanding how the dust and gas properties vary inside galaxies and from one galaxy to another.

Requirements: I am looking for a student with an interest in observational astronomy. Computer skills at a level of Physics 2G03 or equivalent are important, as you will be working in a command-line linux environment. You will also need to be able to work independently as I anticipate being away for 3-4 weeks mid summer. No prior experience in astronomy is required but at least one previous course would be an asset.

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.

Evolution of Replicating RNA Sequences

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. It is also possible that self-replicating RNAs were the first living things. It is therefore important to understand how a living, self-replicating RNA system could have emerged from a non-living chemical system. Current laboratory studies show that RNA catalysts 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.

Project: The student will carry out computer simulations of simple models representing RNA replication. We wish to understand how molecules of different functions can combine to make a more complex system that replicates cooperatively. We will study models where molecules are distributed on a two-dimensional surface and interaction occurs between neighbours. We wish to determine how far molecular evolution can proceed in absence of cellular compartments.

Requirements: The student should have an interest in evolutionary biology and the origins of life. Some prior experience of scientific programming would be advantageous.

Growth and Characterization of Quantum Materials

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

Background: Quantum materials are substances which under extreme conditions such as low temperature, high magnetic field or high pressure exhibit new or exotic phenomena such as superconductivity or exotic magnetism. To study these systems, high quality single crystal specimens are most informative.

Project: This summer research project will involve growing high quality single crystal specimens of various systems using our traveling solvent floating zone furnace. These crystals will be characterized by x-ray and neutron scattering (using the McMaster Nuclear Reactor), as well as by magnetic susceptibility (SQUID magnetometry) and electrical transport down to temperatures of 0.5 K.

Requirements: This project will be well-suited to students interested in experimental condensed matter physics. Experience with LabView, Origin, Matlab or Maple would be helpful, but can be learned on the job.

Spin Liquids, Spin Ice, and Spin Glasses: Neutron and X-ray Scattering from Exotic Magnetic Ground States

Supervisor: Dr. Bruce Gaulin (gaulin@mcmaster.ca)

Background: The high temperature state of pretty much all materials is dominated by entropy, while that at low temperatures is usually dominated by energy. Most materials undergo phase transitions between these two regimes which takes them from a disordered, high temperature state to an ordered low temperature state. We are specifically interested in new magnetic materials where that doesn't happen. That is, the magnetic material retains an entropy-dominated, disordered state down to very low temperatures. There are several reasons why this may happen: the local geometry of the magnetic lattice may be incompatible with the local pair-wise interactions between the magnetic moments; and the quantum nature of the magnetic moments may be incompatible with an ordered state. The first of these is referred to as geometrical frustration, the second arises due to strong quantum fluctuations. These exotic magnetic states are known as Spin Liquids, Spin Ices, and Spin Glasses.

Project: The summer research project will involve growing large single crystals of these new materials by floating zone image furnace techniques, and then characterizing these new single crystals by a variety of techniques. The techniques involve powder and single crystal x-ray diffraction, magnetic susceptibility measurements, and different types of neutron scattering experiments.

Requirements: This project will be well suited for students interested in experimental methods in general, and experimental condensed matter physics, in particular. Experience with Matlab and or handling of large data sets would be helpful, and can be learned on the job.

Self-Assembly of Soft Matter

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

Background: Soft condensed matter physics is concerned with the study of 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 organized 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 at fluid/fluid interfaces. Under appropriate conditions, block copolymers can wet the interface between two immiscible fluids such as oil and water, forming a thin film at the interface. 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.

Instrumentation in the Low-Temperature High-Field Laboratory for Quantum Materials

Supervisor: Dr. Takashi Imai (imai@mcmaster.ca)

Background: We are specialized in experimental research into quantum materials. We conduct measurements on exotic superconductors (such as copper-oxide and iron-pnictide high temperature superconductors), spin liquids, and materials in the vicinity of quantum phase transitions. Their intriguing quantum properties manifest themselves generally at low temperatures near absolute zero, hence we need to develop experimental capabilities to conduct NMR (Nuclear Magnetic Resonance), electrical transport, and high pressure measurements in liquid helium 4 (down to 1.8 K) and liquid helium 3 (below 1.8 K) environments, in combination with high magnetic fields up to 16 Tesla.

See <http://www.physics.mcmaster.ca/~imai/> for additional information about our research group.

Projects: We have a variety of equipment in our lab, including: cold-bore 16 Tesla superconducting magnet; room-temperature-bore 9 Tesla superconducting magnets; helium-4, helium-3, and dilution refrigerators; NMR spectrometers; ac impedance bridge for electrical transport measurements; 30 kbar and 90 kbar high pressure cells; liquid helium-4 re-liquefier. (If we buy everything in our lab brand-new, the total cost would exceed \$2-million.) We need to develop cold temperature probes, sample holders and goniometers for our equipment. We also need to use LabView, Visual Basic etc. to interface and control the equipment with computers. Your potential project(s) might include: designing and fabrication of cryogenic probes, computer interfacing and/or setting up a NMR spectrometer or electrical transport measurement system, testing high-pressure piston cells, optimizing the operating conditions for the helium-4 re-liquefier. You will gain precious hands-on experience while working on cutting edge equipment.

Requirements: We are looking for a mature and dependable third or fourth year student who is eager to put their hands on various equipment and/or computer software. You must have good communication skills, so that you could contact with equipment manufacturers and machine shop personnel, as well as professional physicists. You also need to have a level of self-confidence, so that you could work independently if necessary. Experience in designing, machining, fabricating, soldering electrical parts, or programming is not essential as long as you are eager to learn new skills, but will certainly help.

Lost memories – Can we turn back time in Alzheimer’s disease?

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

The Laboratory for Membrane and Protein Dynamics at McMaster is specialized in determining molecular structure and dynamics in membranes and other biomaterials. We work with native and synthetic membranes, which we fabricate in our lab, to study elementary processes, such as lipid diffusion, formation of rafts, drug interactions and non-specific side effects. In terms of biomaterials we study biological fibres, chitin, hair and nail to link their molecular structure to macroscopic appearance and properties. The topics most related to the proposed project are the questions how

peptides interact with membranes and the role of membranes in peptide-peptide interactions and in particular aggregation of peptides in membranes.

Background: About 200,000 people in Ontario suffer from some type of mental deterioration; millions of people are affected world-wide. Aggregation of amyloid peptides in the brain plays a key role in Alzheimer's disease. We have shown that Alzheimer's peptides incorporate in brain-like membranes and that their interaction depends on the molecular composition of those membranes. We recently succeeded in fabricating Alzheimer's plaques in synthetic brain-like membranes in-vitro, which mimic the properties of senile plaques found in Alzheimer's patients. These systems now allow for a detailed study of peptide-peptide interactions and plaque formation under controlled lab conditions including testing of anti-Alzheimer's drugs in the safe environment of a Petri dish.

Project: You will prepare synthetic brain-like membrane in our lab and investigate the molecular structure using X-ray scattering and molecular dynamics (MD) computer simulations. You will mimic Alzheimer's disease by preparing membranes that contain synthetic Alzheimer's plaques under controlled lab conditions in-vitro. You will then study the impact of small molecules and in anti-Alzheimer's drugs on the properties of these plaques. The outcome of this project will be used to aid in early diagnosis and treatment of dementia. The project involves preparing samples in our preparation lab, conducting X-ray experiments and MD simulations and analyzing the data to develop molecular models.

Requirements: I am looking for 1-2 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 Molecular Origin of Life on Earth and other Planets

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

Background: There is no satisfying explanation of how the earliest forms of cellular life first emerged on Earth at least 3.5 billion years ago. This question is directly related to the fundamental question of the formation and existence of life in the universe, on Mars and other potentially habitable exoplanets. It is postulated that prior to today's DNA, RNA, and protein dominated world, RNA (ribonucleic acid) was used as genetic storage and a catalyst to chemical reactions. RNA is a polymer chain of nucleotides bound together forming a ribose-phosphate backbone. The polymerization of nucleotides occurs in a condensation reaction in which phosphodiester bonds are formed. This reaction cannot occur in aqueous solutions; however guided polymerization in an anhydrous or confined environment could promote a non-enzymatic condensation reaction in which oligomers of single stranded nucleic acids are synthesized.

Project: By mimicking early Earth and other planetary conditions, you will test if guided polymerization in an anhydrous lipid environment or under confinement could promote the synthesis of single stranded nucleic acids into RNA-like structures. You will study complexes of different nucleotides confined by a lipid matrix, in nanometer sized films, inorganic salts and mineral surfaces, such as clay. You will use X-ray diffraction and molecular dynamics (MD) computer simulations to investigate the lateral organization of the confined nucleotide molecules to detect and characterize the

formation of RNA-like polymers to understand the fundamental process of how first RNA has formed. The project involves preparing samples in our preparation lab, conducting X-ray experiments and MD simulations and analyzing the data to develop molecular models. This research is part of the recently funded new Origins of Life Laboratory that we will build at McMaster, which will offer exciting opportunities for this kind of research.

Requirements: I am looking for 1-2 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.

Quantum Mechanics of Electrons in Semiconductor Heterostructures

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, which is a useful asset for anyone going on to graduate study. For examples, see J. Applied Phys. 93 (2003) 4395, Euro. J. Phys. 26 (2005) 121, Can. J. Phys. 86 (2008) 515, Am. J. Phys. 77 (2009) 552-61, Am. J. Phys. 80 (2012) 734-7; Erratum ibid. 80 (2012) 1010; Finite Fourier transforms computed by a modified Filon-Euler-MacLaurin method, Comp. Phys. Comm. 184 (2013) 607-616.

Simulating the Formation of Massive Stars and Star Clusters

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

Background: Massive stars, of more than ~ 15 times the mass of the Sun (known as O stars), play a key role in the formation and evolution of galaxies. How these monsters form remains a central question at the frontier of astrophysics because their radiation fields are intense enough to disperse the very gas that is collapsing to form them. Advanced computer simulations over the last 5 years have focused on simple gravitational collapse of dense, 100 solar mass regions within filamentary molecular clouds, resulting in the formation of massive disks in which these stars form. Recent observations at the Atacama Large Millimeter Array (ALMA) have now seen these disks and one can start to compare observations with computer simulations. Most stars form as members of star clusters. Massive stars within clusters, and the radiative feedback from these regions can heat and

disperse entire star forming clouds. Is there a limit to the mass of stars that can form (observations suggest 150 times the mass of the Sun)? Why do massive stars prefer to form in pairs rather than singly? How do clusters form in filamentary clouds and how effective are their radiation fields in shutting off their formation and ionizing the gas in the galaxy and the gas between galaxies?

Projects: My group has developed one of the world's leading computer codes that can address these "radiative feedback" problems. It is a 3D Adaptive Mesh Refinement code into which we have built a cutting edge treatment of radiation flow from a young forming star or star cluster. We have already shown how massive disks form, become gravitationally unstable, and drive strong inward flows along spiral arms to pump gas onto the central massive star (Klassen et al 2016). The question of whether these disks themselves break up into several massive stars, or produce only one massive star is a key question that we will explore in a set of new simulations. Star clusters drive radiation fields that can disperse gas clouds (Howard et al 2016) and my group has a large numerical data set which can be analyzed to determine how cluster formation begins evolves.

Requirements: I am looking for one or two enthusiastic students with a keen interest in astrophysics and computation who enjoy a research challenge. You will be working in my research group where you will learn state of the art computer techniques and running state of the art 3D simulation codes and an existing software suite to investigate these forefront problems. Some programming will be required. Applicants should have some experience using at least one modern programming language, such as C/C++ and/or Fortran 90.

Substructure in the Halos of Giant Galaxies

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

Giant galaxies in the universe keep on growing by capturing smaller satellite galaxies. In the outer regions of the giant, traces of these satellite accretions are left behind by tidal streams, arcs, and shells of stars that formerly belonged to the satellite; these features can last for several Gigayears before they finally dissolve away into the bulk of the bigger galaxy. The project will involve using the data for "tracer particles" in galactic halos, globular clusters and planetary nebulae, to search for these features and to gain a better idea of what fraction of the giant's halo is built from accretion.

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. Applicants should be familiar with at least one scientific computing language such as python, C, fortran, R, or IDL. Computational work will be done in a linux environment.

Medical Physics Summer Research

Supervisor: Dr. David Chettle

In analysing a gamma-ray spectrum it is important to extract as much information as possible with the greatest possible precision. Conventionally, analysis concentrates on the peak corresponding to the full energy of the gamma-ray in question. However, the response of the detector to a gamma-ray of a particular energy nearly always includes Compton scattering events observed at lower pulse heights than the full energy peak. A library of seed spectra from individual radioisotopes is collected.. These seed spectra are then fitted to an unknown spectrum by varying the weights of the seeds to achieve a

least squares difference from the observed spectrum. In principle, by using more information, results are extracted with improved precision. We have implemented this approach with neutron activation spectra from the high efficiency 4π NaI(Tl) assembly. The outcome was only a marginal improvement on the more conventional analysis. We wish now to explore this further in three possible ways. One is to use seed spectra with much more prominent features than in the unknown in an attempt to reduce variance. Secondly, we could expand the energy region we have used so far. This would include somewhat more information, could increase the range of radioisotopes covered, but would also expand the range of features covered, which might tend to increase uncertainties. Thirdly, we should like to examine this approach using high resolution Ge detectors which, however, have lower efficiency than the NaI(Tl).

We use neutron activation to analyse living human subjects for a number of elements, including aluminum, manganese, magnesium and selenium. An important objective is to achieve the best precision for the lowest radiation dose. However, optimisation is complicated by the fact that some of the radioisotopes concerned have short half lives, so there is also a premium on a short, high intensity irradiation. We wish to use the ${}^7\text{Li}(p,n){}^7\text{Be}$ reaction on the Tandetron accelerator to produce neutrons and counting induced radioactivity with the 4π NaI(Tl) detector assembly to optimise irradiation conditions for different analyses. One will be aluminum, for which the radioisotope in question, ${}^{28}\text{Al}$ has a half life of 135 s. Another optimisation could be for selenium, for which ${}^{77\text{m}}\text{Se}$ has a half life of only 17.4 s.