Western Physics and Astronomy

Our Research Plan

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Overview

This document is a roadmap to guide the future growth of The University of Western Ontario's Department of Physics and Astronomy. The document describes the Department's unique strengths relative to national and global peers, and long-term plans and resources required to capitalize on these strengths.

This document was written collaboratively by the research faculty and will be revisited on an annual basis.

Differentiation of Our Department from Our Peer Institutions

We differentiate ourselves from other Physics and Astronomy Departments in two critical ways. First, our Department is uniquely situated at the interface between materials science and medical physics, and the expertise in our Department is networked tightly with both the Schulich School of Medicine & Dentistry and the Faculty of Engineering.

The Department is also uniquely positioned due to our expertise stretching from the largest scales of structure in the universe to the small scale of planetary formation and atmospheres, in particular Earth but also exoplanets. Our team is highly adaptable and collaborations allow us to address questions at all scales in the life cycle of a star, including the star's place in the galaxy, the star's structure, planetary formation and the big questions of the potential habitability of exoplanets and terrestrial atmospheric change.

Many physics and astronomy programs contain large groups of specialists working in a few focussed areas. Our strength at Western is the broad coverage of topics our team encompasses in astrophysics, materials science, and medical physics. This breadth allows us to quickly form sub-groups collaborating on a particular problem across sub-disciplines. For instance, one of our astronomers is an expert in astrophysical studies of carbon nano-structures. This expertise was critical in helping solve a problem faced by our carbon film material scientists. Progress in that area helped linkages with medical sciences, resulting in an NSERC CREATE application for broad training in carbon materials.

The following two research questions elaborate on the types of important problems the members of our Department are tackling.

How can we manipulate the interactions between molecules to develop better materials for use in cutting-edge energy storage, electronic devices, or medical technology?

Our collaborative community of faculty, staff, and students in materials and medical physics excels at interdisciplinary research, which encompasses the study of the physics of structures and interactions ranging from the nanoscopic to human-body scale. Together our materials scientists and medical physicists improve advanced material and device performance in different medical and industrial applications by studying the connections between the underlying structure of materials, their properties, and the methods of fabrication. Through this synergy, we can aim to manipulate and exploit these structures to achieve advanced function and performance in cutting-edge technology.

Examples of this interdisciplinary knowledge translation include the following:

1. Investigation of carbon-based nanomaterials, encompassing studies of carbon in space, synthetic materials, and natural carbon resources. This highly interdisciplinary team is complemented by carbon material expertise elsewhere at Western (Chemistry, Mechanical & Materials Engineering).

2. Demonstration of the economic impact of basic science through the development of an industry-focused, ISO-17025 certified, MRI-compatible-device testing facility, and the design and production of point-of-care MRI systems with Ontario-based industry partners.

3. Design and development of new MRI systems and commercial translation of functional data analysis methods and software, resulting in deep connections with Western's Brain and Mind Institute and Bone and Joint Institute.

What are the fundamental processes at work in the universe that give birth to galaxies, stars and planets, and their atmospheres?

Research in this area encompasses all aspects of the birth, life, and death of planets and stars. Our department is unique in Canada as we have the expertise to study the formation of stars and their associated planetary systems, the evolution of these systems through to their "death" and ultimate re-cycling into the universe as *the* fundamental process operating in the Cosmos.

The range of scales studied encompasses individual planets and their atmospheres, through their parent stars, through vast galactic collections of stars, gas and dust, including the supermassive black holes that lurk in their centres. Our wide range of expertise on this fundamental cycle allows interdisciplinary approaches, involving connections with areas of expertise in the Faculty of Science and Engineering. The broad public interest in this topic drives our major outreach program at Western's Cronyn Observatory, reaching thousands of visitors every year.

Unique aspects of this group include the following:

1. Integration into Western's Centre for Planetary and Space Exploration (CPSX), which brings together researchers from across Science, Engineering, Law, Medicine, and Social Science. Collaboration with the broader university community interested in space-based research establishes the critical mass to significantly participate in space missions.

2. Establishment of the only cooperative agreement between NASA and a Canadian university. The Western Meteor Physics Group, unique in Canada and the world, provides real-time measurements of the meteoroid environment to NASA for spaceflight operations and develops meteoroid environment models for spacecraft impact hazard assessment.

3. Research presence in Canada's far North. Both atmospheric physicists and astronomers are involved with the PEARL Laboratory in Nunavut, operated by

the Canadian Network for the Detection of Atmospheric Change. This unique high latitude observatory is a critical part of international programs making long-term measurements of the effect of atmospheric change on global weather and climate.

Objectives

The department aims to build on existing research strengths to become Canadian leaders in three areas:

1. Space astronomy and physics
2. Industrially-relevant applications of physics to health
3. Carbon nanoscience and applications

The department will achieve these research objectives by pursuing goals over a range of timescales.

Goals to Achieve the Objectives

Objective 1 Goals

1. Near-term: establish a national reputation for interdisciplinary excellence through development of a first-of-its-kind program, StarTRAIN. This unique training program will place astrophysics trainees in internships with startups across Canada. To be supported via NSERC CREATE (to be submitted in 2019).
2. Near-term: enhance research productivity and interdisciplinarity by developing strong ties to Western's emerging data science initiatives. Astroinformatics is of particular relevance to space astronomy and meteor physics, where datasets are very expensive to obtain and extracting every last bit of information is important. Many readily available datasets have yet to be fully exploited, making them attractive for data scientists to test new algorithms and approaches. To be supported via a proposed CRC faculty hire, pending CFI proposals, and potentially the new Tri-Agency Research Fund and/or CSA.

3. Medium-term: enhance international reputation through leadership of large projects. These include leadership of scientific programs with the James Webb Space Telescope, development of new instrumentation for existing and upcoming facilities such as the Gemini Observatory and Thirty Meter Telescope, design of survey strategies for the Maunakea Spectroscopic Explorer. To be supported via CFI proposals and internal funding (e.g. distinguished research professorships).

4. Medium-term: develop research strength in astrochemistry of exoplanet atmospheres. The next frontier in the field of extrasolar planets is the physical and chemical characterization of their atmospheres, to be enabled by the upcoming generation of space-based and extremely large ground-based telescopes. To be supported by a future CRC faculty hire.

5. Long-term: develop the capacity to build instruments for (exo)-planetary science missions. By working with Canadian industry, we will gain expertise in developing space hardware for both large missions and smaller projects like the current Cube-Sat opportunity from the Canadian Space Agency. To be supported via a future CRC faculty hire and CSA funding.

6. Long-term: link research and outreach via the construction of a Science and Technology Centre at Cronyn Observatory, including a planetarium. This is a major infrastructure project. We have begun discussions with the relevant players at Western; our current status is given in the Appendix. To be supported via philanthropy and/or local, provincial and federal government funding.

Objective 2 Goals

1. Near-term: Establish a new multi-user Magnetic Resonance Imaging facility. Two new small-footprint MRI systems will support MRI system development activities, will further establish research links with researchers from both the Brain and Mind Institute and the Bone and Joint Institute at Western, and will enable new research connections with basic scientists within the Faculty of Science. To be supported via CFI proposal to be submitted in upcoming CFI call.

2. Medium-term: establish Canadian leadership through a National Centre for Excellence in MRI systems including application development, to be coupled with an existing industry partner, Synaptive Medical. To be supported via an NCE application.

3. Medium-term: develop a new facility/capacity for the development and application of magnetoencephalography ("MEG") imaging systems. This represents an expansion of our current medical imaging research and development capacity and would strengthen existing research and industrial connections. To be supported via a CFI application, a coordinated NSERC CRD, a CRC-Tier 2 request, and space allocation.

4. Long-term: develop a *new* research and development capability in the area of environmental electromagnetics. Our existing capacity in applied electromagnetics, and particularly in the area of large-scale computer simulation grounded with laboratory validation, will be extended to the study and evaluation of electromagnetic exposure in the environment and health sciences. Partners in this new area could include the Lawson Health Research Institute as well as industry-sponsored projects and support. To be supported via new CFI and/or NSERC CRD proposals, space allocation, and possibly an additional faculty hire.

Objective 3 Goals

1. Near term: increase capability to train the next generation of Canadian researchers in carbon-based nanomaterials through an NSERC CREATE initiative. This will be an industry-based CREATE program, in which academic and professional training are supplemented by internships at participating companies. To be supported via NSERC/CREATE (submitted).

2. Near-term: enhance expertise in polymer physics and links to chemistry via completion of CRC-2 hire in polymers with Chemistry. To be supported via allocated CRC position.

3. Medium-term: pursue development of energy-efficient water purification systems through creation of a new spinoff company. The expertise to do this

derives from recent IP in porous carbon-based materials. To be supported via a proposal to the Ontario Research Fund – Research Excellence (ORF-RE).

4. Long-term: expand materials science expertise to include computational materials research. Pursue support of a computational materials scientist focused on materials design and modelling, specifically related to energy applications, which would complement current strengths in nanofabrication and testing. To be supported via new faculty renewal.

5. Long-term: enhance capacity for materials characterization and fabrication of advanced nanoprobes, through upgrades to the Tandetron Accelerator and Nanofab laboratory. This capability will enable characterization of soft and organic materials as well as electronic and energy devices. To be supported via CFI and ORF proposals, industry partnerships, and core facility funding to the Machine Shop.

Summary

The recent report Investing In Canada's Future: Strengthening the Foundations of Canadian Research (the "Naylor report") states under *A Case for Scientific Inquiry*:

> *... Research is essential to the health, prosperity, and security of Canadians and to our efforts to foster a creative, inclusive, and vibrant society. Our universities, colleges, and research institutions are responsible for providing the right environment and tools not only to perform this research at the highest levels of excellence, but also to inspire, teach, and shape each new generation of students through research-led education.*

Our Department differentiates itself not just by its expertise in materials science, medical physics, astrophysics, and planetary science, but in its ability to combine skills in these areas to address big questions like the study of the cosmos from galaxies to atmospheres and manipulation of molecules to develop new materials for medical applications. We are strongly positioned to train students in a unique interdisciplinary context and to link this education to the world beyond university.

Appendix

Detailed Overview of the Department

The Department of Physics and Astronomy at Western has 32 primary faculty members and more than 50 graduate students. Another 20 faculty members are involved in teaching and/or supervision of students in our graduate program. We also have 6 emeritus professors with membership in the School of Graduate and Postdoctoral Studies, most of whom are actively supervising graduate students. Our department teaches more than 2,300 undergraduates each year. Students obtain degrees in programs including physics, medical physics, and astrophysics.

We are housed in the Physics and Astronomy Building (PAB), which is the second-oldest building on campus, dating from 1924. The building has recently been completely renovated with a design that encourages collaboration and communication among all members of the Department.

Research and Scholarly Development Facilities

On-campus research facilities at Western that are available to members of the Department include the Nanofabrication Laboratory, a well-equipped user facility operated by the Faculty of Science and housed in the Physics and Astronomy Building. Surface Science Western is an independent research facility within the Faculty of Science, currently located in the Western Research Park. Western Science Center houses a Tandetron accelerator that is used for ion-beam research. Western is a node of SHARCNET, a high-performance computing facility that is used by several of our faculty. The department has a fully equipped machine shop staffed by two highly skilled machinists. Individual researchers in the Department of course have their own facilities and equipment, much of which is made available to other researchers on request.

The Elginfield Observatory

The Elginfield Observatory is located 30 min north of campus near the town of Lucan. It consists of a 1.22m telescope housed in an Observatory building with a 15m dome, an observer's house and surrounding land, mainly wooded. The telescope was used extensively from the founding of the Observatory in 1968/1969 until 2010 when telescope operations ceased. The facility (but not the Observatory) continues to be used mainly by

the Physics and Astronomy department, principally by the Meteor Physics Group (Brown, Campbell-Brown and Wiegert). Other departments in the Faculty of Science also use the Observatory grounds, such as Earth Sciences (for seismic work) and Biology (field studies of plants and animals). The Faculty of Engineering has used the facility for rover testing and field testing of the Engineering Baja vehicles while the Department of Psychology uses the grounds for bird studies. A unique aspect of the Observatory building is the Coudé room, which is a large, climate-controlled space.

In the immediate future, three additional robotic observatories are being built at Elginfield as part of a CFI project led by S. Metchev. Other existing robotic and/or automated camera systems deployed by the Meteor Physics Group consist of the Canadian Automated Meteor Observatory, all-sky video cameras of the Southern Ontario Meteor Network and testbed cameras from the Australian Desert Fireball network and NASA Meteoroid Environment Office. Together with ongoing remote and in-situ rover testing led by Earth Sciences and Engineering, Elginfield has become a focus for operations and testing for robotic and autonomous systems.

Environmental Sciences Western Field Station

Environmental Sciences Western is a Faculty of Science field station located approximately 20 minutes from campus. Environmental research is conducted by groups from the Faculty of Science including Biology, Earth Sciences, and Physics and Astronomy, along with researchers from the Faculty of Engineering and Agriculture and Agri-Food Canada. Primary Department users are W. Hocking, who has a radar system (CLOVAR) for measuring atmospheric winds and R. Sica, who has a lidar system (laser radar) which measures composition, temperature, and aerosols.

Other Off-campus locations

Across Ontario, Brown operates an array of cameras, radars, and infrasound detectors for meteor detection. Hocking operates a network of radar systems around the world for making measurements of atmospheric dynamics. Sica is also involved in the Polar Environment Research Laboratory, located in Eureka, Nunavut.

Outreach and Research: Cronyn Observatory

The Hume Cronyn Memorial Observatory is the focal point for astronomy activities in the greater London community. It is used intensively year-round for astronomy outreach,

teaching and training programs that currently host about 6,000 (and increasing) visitors per year, mostly young people. However, the Cronyn Observatory is one of the oldest buildings on campus, and its aging infrastructure makes it increasingly more difficult to offer our visitors an experience that matches present-day expectations. Renovations to bring the Observatory into the 21st century are a necessity for fulfilling Western's goals for public outreach.

We propose to upgrade and expand the Hume Cronyn Memorial Observatory to become a modern, accessible, high-tech, hands-on STEM Centre for Interactive Learning with a state-of-the-art digital visualization theatre (planetarium). This facility will be a self-sufficient hub for science education and outreach in southwestern Ontario that can adequately respond to the enormous and increasing demand for hands-on activities in the STEM fields, with a market of over 400,000 school children between Windsor and Hamilton alone. A cutting-edge planetarium is lacking in southern Ontario: Toronto does not have a large planetarium[1] and the nearest other facility is a small planetarium at McMaster University. A Cronyn planetarium would be a unique recruitment and outreach facility, where we could showcase the Department's (as well as Western's) diverse research strengths in spectacular high-definition and inspire the next generation of scientists.

Planetarium facilities, moreover, offer an opportunity for *researchers* to communicate with each other about data while being immersed in it, leading to new and otherwise unavailable scientific insight. A challenge of growing proportions and importance in data science is the visualization of (sometimes complex) high-definition big data sets, often with many parameters. Planetarium visualization tool kits allow easy adaptation from raw data to immersive visualization, and have been applied to topics as diverse as neuronal activity in the brain, CT/MRI scans, hurricanes, global earthquake prediction models, atmospheric circulation patterns and large scale structure of the Universe. Such a facility would be a boost for the interdisciplinary research done across Western, stimulating collaboration between scientists from many disciplines with computer scientists, communication professionals and specialists from arts and graphics. Filling the planetarium void would allow us to become a national and international leader in research visualization and training in data visualization and science communication.

[1] The University of Toronto is developing a new planetarium with a goal of completing design by 2020: http://www.astro.utoronto.ca/about/newtorontoplanetarium/