Institut Spatial de McGill

McGill Space Institute

2015-2016 Annual Report

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About the MSI

About the McGill Space Institute

The McGill Space Institute is an interdisciplinary centre that brings together researchers engaged in astrophysics, planetary science, atmospheric science, astrobiology and other space-related research at McGill University.

The main goals of the Institute are to:

- Provide an intellectual home for faculty research staff, and students engaged in astrophysics, planetary science, and other space-related research at McGill.
- Support the development of technology and instrumentation for space-related research.
- Foster cross-fertilization and interdisciplinary interactions and collaborations among Institute members in Institute-relevant research areas.
- Share with students, educators, and the public an understanding of and an appreciation for the goals, techniques and results of the Institute's research.

The current research themes include:

- Early Universe
- Cosmology
- Galaxy Evolution
- Astrophysics
- Nuclear Astrophysics
- Compact Objects
- Exoplanets
- Planetary Science
- Planetary Analogues
- Astrobiology
- Microbial Diversity in Extreme Environments
- The Search for Extraterrestrial Biosignatures.

The intellectual hub of the Institute is at 3550 University, where many of the Institute members work, collaborate with visitors, and Institute events are held.

A Message from the Director

Prof. Victoria Kaspi
McGill Space Institute Director

It's hard to believe a full year has passed since the creation of the McGill Space Institute.

It seems like just yesterday that it was merely an idea — a concept we batted around, a vision of what could be accomplished with a novel type of research interaction, a way to bring talented professors, postdocs and graduate students working on related topics together, to stimulate new ideas and directions in space-related research.

And what a year it has been! The MSI is now nestled comfortably in our 'Space Shack' at 3550 University. The house has been equipped with tables, screens, and especially blackboards, to encourage and stimulate thought and new ideas. On a daily basis now, MSI is bustling with scientific discourse consisting of one-on-one conversations, weekly seminars, discussion groups, and workshops. Topics you'll hear covered in the MSI lounge range from the origins of the Universe to the beginning of life.

Prof. Victoria Kaspi meets with MSI students and professors

We have visitors from around the world coming through regularly. Most importantly, MSI has talented, enthusiastic students and postdocs, who, thanks to a generous gift by the Trottier Family Foundation, are being trained to be the next generation of scientists. All this occurs in a warm, stimulating, friendly environment where, for example, we take turns putting out the 3pm tea and cookies. And here the 'we' means that even the Director can occasionally be spotted preparing snacks for everyone!

Looking back, it was my 2-year adventure as Associate Dean of Research in the Faculty of Science that persuaded me that in spite of the impressive world-class research strengths at McGill, something key was missing from the landscape. As ADR I met dozens of brilliant, world-class McGill scientists I had never seen before my administrative stint, in spite of having been at McGill a full decade prior. How could there be so many talented, accomplished people in my own community, without me being aware?

For example, I saw that there was research on one of the foremost exciting topics of modern science — extrasolar planets — going on simultaneously in the Department of Earth and Planetary Science, the Department of Atmospheric and Oceanic Sciences, and in the Department of Physics, without these different researchers having their paths ever cross, or even knowing of each others existence! How could this make sense?

Prof. Victoria Kaspi, McGill Space Institute Director

Universities are traditionally

grouped into Departmental constructs that, while efficiently categorizing people for administrative purposes, ultimately limit the potential intellectual vision of their inhabitants, forcing them and their ideas into artificial knowledge 'silos.' Given the many responsibilities University faculty have, it is only natural that emergence from one's silo is difficult. Yet the reality is that the natural world represents an amazing continuum of phenomena; progress in many of the most interesting scientific problems demands breadth of expertise unhindered by artificial, bureaucratic barriers.

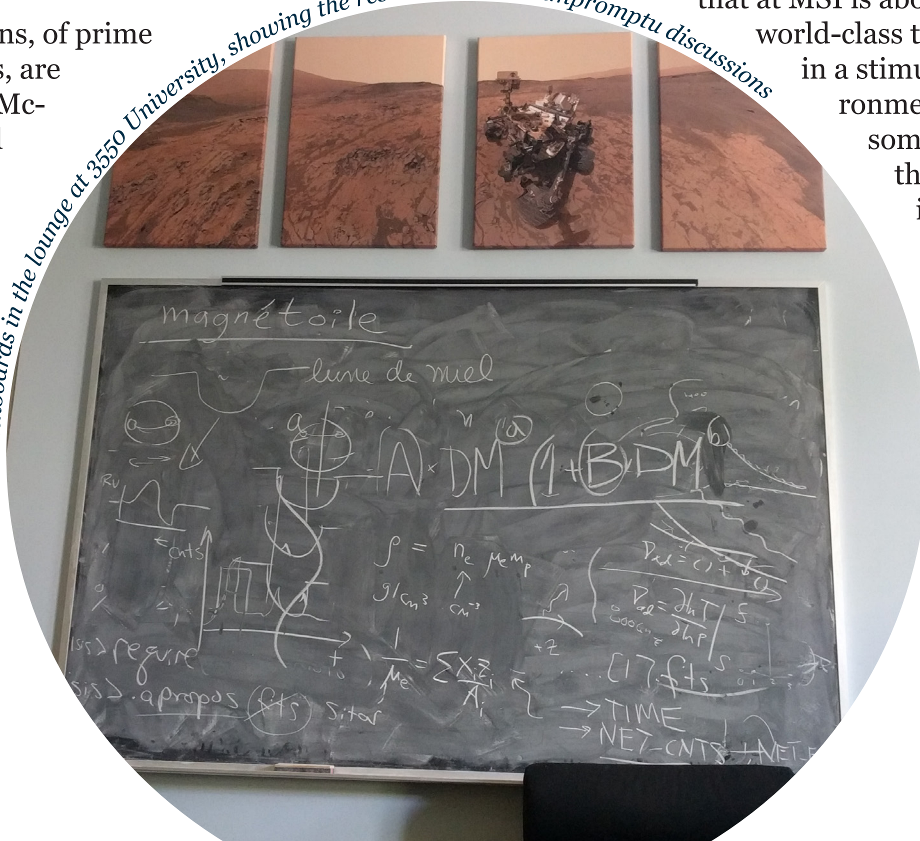
The McGill Space Institute was created to address this issue in the domain of space research. As a McGill research centre, our goal is to bring together top McGill minds — including faculty, postdocs and students — working on related space-relevant subjects that are at the cutting edge of modern science. MSI tackles some of the biggest questions out there: Are there worlds like our own elsewhere in our Galaxy? Does Planet 9 exist? What is the nature of the ubiquitous Dark Matter and Dark Energy in our Universe? How do black holes and neutron stars work and can they help us understand the nature of of gravity?

These same questions, of prime interest to scientists, are also exciting to the McGill community and the public at large. Astronomy, astrophysics, cosmology, the search for extraterrestrial life — these are all topics that inspire wonder in people regardless of their age or background. For this reason MSI also has outreach as a key item in its mission. Joining forces with AstroMcGill, a grass-roots astronomical student-run organization that promotes science to the public, MSI hopes to use the great popularity of its research as a tool with which to promote science broadly in the population. Whether telling the public about asteroid capture (as in our national-press-covered MSI Launch) or about Advanced LIGO's discovery of gravitational waves from a binary black hole merger via a standing-room only party with live feed from Washington, DC, MSI prides itself on making forefront research accessible to the public .

As you peruse our first Annual Report, I hope you'll be impressed by how far we have come in so short a time. With baby steps as large as these, we are on a decidedly upward trajectory, in which, quite fittingly, the sky is the limit.

I am very proud of what we have accomplished in forming the MSI. And here the 'we' means each and every MSI member, from student through faculty, as this is the lifeblood of our centre. The task of fostering research interaction like that at MSI is about bringing world-class talent together in a stimulating environment, to make something bigger than the sum of its parts and inspiring to the world.

Blackboards in the lounge at 3550 University, showing the results of several impromptu discussions



MSI Director Vicky Kaspi, Associate Director Andrew Cumming and Dean of Science Bruce Lennox

MSI pumpkin by Kelly Lepo

Vice Principal Rosie Goldstein and Lorne Trottier

McGill Space Institute Launch

The McGill Space Institute had its official launch event on October 28, 2015. We had a VIP reception at the 3550 University building. Attendees included **Vice Principal Rosie Goldstein** and **Dean of Science Bruce Lennox**, as well as **CSA President Sylvain Laporte**. In addition, our principal donor **Lorne Trottier** attended the event. He was presented with a high-quality print of mountains on the surface of Pluto from the recent New Horizons mission as a token of our gratitude.

Following the reception, there was a public lecture by **Prof. Tom Prince, Director of the Keck Institute for Space Studies and Professor of Physics at Caltech**, "Grabbing an Asteroid and Returning it to Earth: Making Audacious Ideas a Reality." Approximately 150 people attended the public lecture.

The MSI launch received nation-wide press coverage, including a Canadian Press article, which was picked up by newspapers across Canada.

Prof. Prince's lecture – Grabbing an Asteroid and Returning it to Earth

Prof. Tom Prince

The Search for Planet 9

Extrasolar planet expert **Prof. Nick Cowan** *joined the McGill Space Institute as a faculty member in Fall 2015. His office was down the hall from cosmologist* **Prof. Gil Holder**. *The two collaborated on a project to develop a method to search for Planet 9 — a hypothetical large planet in outer Solar System, announced to some fanfare in January 2016.*

What question were you trying to answer?

We wanted to know whether the thermal glow of planet nine was detectable with millimeter telescopes.

Why did you find this question interesting?

Cosmologists (e.g., Holder) look at the cosmic microwave background and aren't used to thinking about moving foreground objects. Planetologists (e.g., Cowan) use optical and IR telescopes and don't think about radio and millimeter telescopes. So it was a fun outside-of-the-box collaboration.

What does doing your research look like?

This project mostly involved pen and paper math, and noodling around on the blackboard. We used simple Python scripts to double check the math and make a figure. Our usual research usually involves using data from telescopes (on the ground and in space) and writing/running computer code to analyse it.

Neither of us could have done this project on our own. Fortunately, our offices are right next to each other, which made it easy to talk to each other as we worked through the problems.

What did you find?

We found that planet nine is readily detectable with many current and near-term millimeter-telescopes. Even if it ends up being discovered via reflected light, millimeter-telescopes would tell us the planet's temperature.

Did anything unexpected happen during this project?

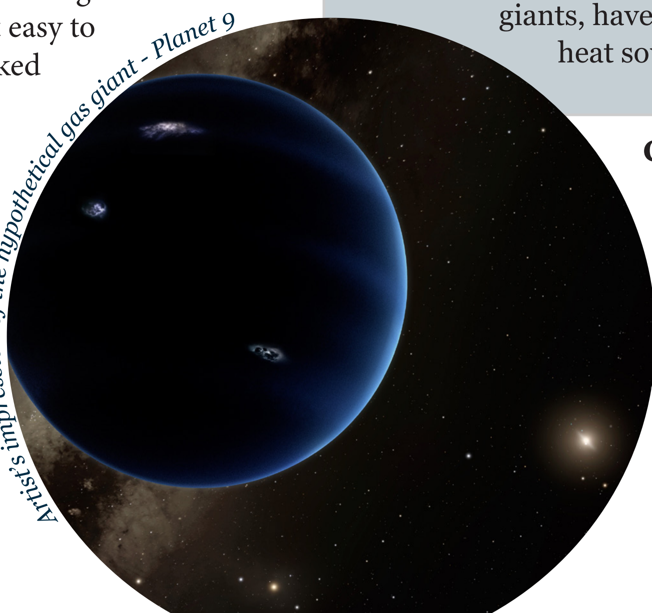
Cowan: The entire project was surprising. Neither of us expected to collaborate on such a paper!

Holder: I would add that I was pleasantly surprised by the enthusiastic embrace of solar system science by my cosmologist colleagues; there is clearly a strong appetite for this sort of research, it just needs a way to happen.

Why this is important

The search distant Solar System objects, including Planet Nine, has focused on reflected sunlight. Our study was the first to show that searches for *thermal* flux, in particular mm radiation, was a viable method to search for Planet Nine or any other planets lurking beyond the Kuiper belt.

Cosmologists build mm telescopes to study the cosmic microwave background, so it was surprising to us (and indeed most cosmologists) that their experiments might also do compelling planetary science. We also showed that thermal radiation would constrain Planet Nine's temperature and radius (and hence its formation history and subsequent evolution). This might help us understand why Uranus and Neptune, our two familiar ice giants, have vastly different internal heat sources.



Artist's impression of the hypothetical gas giant - Planet 9

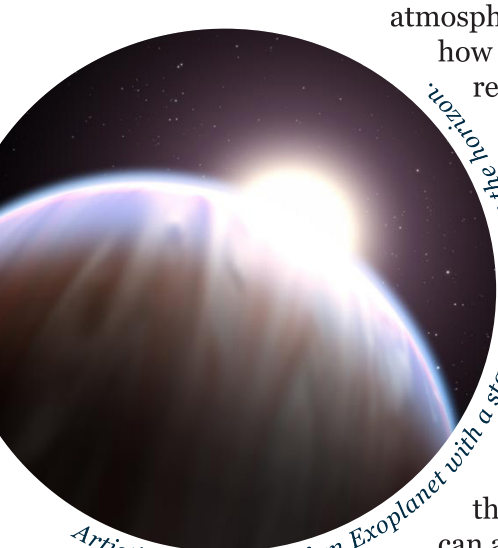
Cowan, N B, G. **Holder**, and N. A. Kaib (2016), *Cosmologists in Search of Planet Nine: The Case for CMB Experiments*, ApJ. Lett. 822, L2.

Simulating Exoplanet Atmospheres

Prof. Tim Merlis' *research uses computer models to expose the physical mechanisms underlying changes in both past and future climates. While his previous work primarily focused on Earth's atmosphere, he recently was part of a collaboration that worked to simulate exoplanet atmospheres.*

What question were you trying to answer?

Radiative transfer calculations---tracking the emission and absorption of light by the atmosphere and determining how much heating or cooling results---are a critical component of climate models. The codes used to make these calculations are typically developed for Earth's atmosphere, but we wanted to use them understand the climate of Earth-like exoplanets! We also wanted to understand how the ways of doing this important calculation can affect how close a planet can be to its star before its climate is unstable and therefore uninhabitable.



Artist's impression of an Exoplanet with a star peaking over the horizon.

Why did you find this question interesting?

I joined this informal international project with the aim of understanding differences in fully three-dimensional climate simulations. A big focus for my research is atmospheric winds and their impact on precipitation and surface temperature for Earth's climate, so it was really exciting to join a comparison of different climate simulations for exoplanet climates. It turns out there are big differences even before you consider the turbulent atmospheric flow, which led to the research on one-dimensional differences from radiative transfer.

What did you find?

It *does* matter how the radiative transfer calculations are done. There can be big differences. The differences between calculation methods for exoplanets have a much bigger (several fold) effect on climate than all of the carbon dioxide emissions humans have produced over the last century for Earth's climate.

What does doing your research look like?

We performed numerical calculations. Some sit behind a computer ... though the adventurous ones stand behind a computer.

Did anything unexpected happen during this project?

I joined the McGill Space Institute! While I was doing this research, I was pleasantly surprised to learn there was a new Institute being proposed at McGill that would be devoted, in part, to exoplanets.

What role did collaboration play in your research?

This project was 100% collaboration! It is the definition of the sum being greater than the parts: any one calculation on its own would not be too exciting. But by comparing across different methods revealed important differences that meaningful alter the range of planetary orbits that are habitable.

Why this is important

We are still the early stages of using numerical models to simulate the climates of exoplanets (5 years ago when I started doing this, you could count them on one hand). The numerical models are based on those used to simulate Earth's climate, but they are pushed out of the comfort zone where we can compare to Earth observations. There are many comparison projects where identical boundary conditions are used for well controlled sensitivity studies for projections of future changes for Earth's climate. This is one of the first efforts to do so for exoplanet atmospheres.

Yang, J, J. Leconte, E. T. Wolf, **T. Merlis**,et al. (2016), *Differences in Water Vapor Radiative Transfer among 1D Models Can Significantly Affect the Inner Edge of the Habitable Zone*, Astrophys. J. 826, 222..

Dark Energy and Structure Growth

Prof. Matt Dobbs' *research group at McGill specializes in the design, construction, and operation of novel instrumentation and experiments to explore the early universe. They were involved in building and analyzing data from the 2500 square-degree South Pole Telescope - Sunyaev-Zeldovich (SPT-SZ) Survey.*

What question were you trying to answer?

The effect of Dark Energy on the expansion history of the universe (the size of the universe vs. time) is well measured through a combination of supernovae, galaxy distribution surveys, and other probes. We wanted to measure how dark energy affected the growth of structures in the universe and see if those effects were consistent with predictions from models.

Why did you find this question interesting?

In my view, the dark sector, with dark energy at the helm, is the biggest mystery in physics. Anything that probes it in a different way, to find cracks in our (lack of) understanding, is really interesting!

What did you find?

Dark energy affects the growth of structure exactly as one would expect from a simple cosmological constant. The lambda CDM standard model of cosmology has held up to yet another test, despite us being no closer to understanding the dark sector.

What does doing your research look like?

Building the world's most sensitive millimeter-wave telescope in one of the world's most hostile environments – the South Pole. The data analysis is tricky and time consuming, taking a team of physicists several years. But this analysis is not the unique thing that sets our measurements above others – instead, it is the technology that was custom built for the South Pole Telescope (SPT) that gives us the edge on this and other Cosmic Microwave Background (CMB) measurements.

Did anything unexpected happen during this project?

We built this project 10 years ago to measure the effect of dark energy on the growth of structure. However, with a combination of the CMB power spectrum and our galaxy cluster survey, we can very precisely measure the signatures neutrino masses. Our cosmology telescope can place some of the most precise limits to date on the sum of the neutrino masses — well beyond what is possible in particle physics laboratories!

The South Pole Telescope and the Antarctic night sky

I am going to the South Pole in November to install an upgrade to the SPT camera. The new camera's primary purpose is to provide the most sensitive measurements (or limits) of gravitational waves emitted from a period of inflation in the early universe (a land mark discovery if robustly seen). The camera will also substantially improve our sensitivity to neutrino mass signatures.

Why this is important

The SPT provides the most precise measurements of the CMB at small angular scales. These data are used by the collaboration to make detailed measurements of dark energy and neutrino properties. They are also used by the broader community to combine with other probes and test many aspects of cosmology and astrophysics.

The neutrino results are particularly important — they provide a window to particle physics that may never be available to terrestrial laboratories or collider-based experiments. This has spurred major new investments by funding agencies and private foundations to build more powerful millimeter-wave telescopes, such as the Simons Observatory, which recently received more than $50m of private, government and institutional funding.

de Haan, T, B. A. Benson, L. E. Bleem, **M. A. Dobbs**, **G. P. Holder**, et al. (2016a), *Cosmological Constraints from Galaxy Clusters in the 2500 square-degree SPT-SZ Survey*, ArXiv e-prints arXiv:1603.06522.

The Atmospheres of Hot Jupiters

Dr. Joel Schwartz *finished his PhD in Earth and Planetary Science in 2016 and will begin a Postdoctoral research position at the McGill Space Institute in the Fall of 2016. His research uses computer models to simulate how energy moves through extremely large exoplanets that are extremely close their stars.*

What question were you trying to answer?

There were actually several questions, but it all boils down to, "What can the public data tell us about the atmospheres of very big, very hot exoplanets?" These are what we call "Hot Jupiters."

Imagine if you took Earth, dumped hydrogen on it until it turned into a liquidy-gassy ball 10x bigger across, then shoved it 50x closer to the Sun — that's like a Hot Jupiter. They have day/nightsides that never change and there's nothing like them in our Solar System.

What did you find?

We learned that Hot Jupiters are dark in visible light but would look shinier if you could see infrared light, so these planets could have interesting clouds. The more you bake Hot Jupiters with starlight, the worse their winds are at warm up their nightsides (in most cases, at least).

What does doing your research look like?

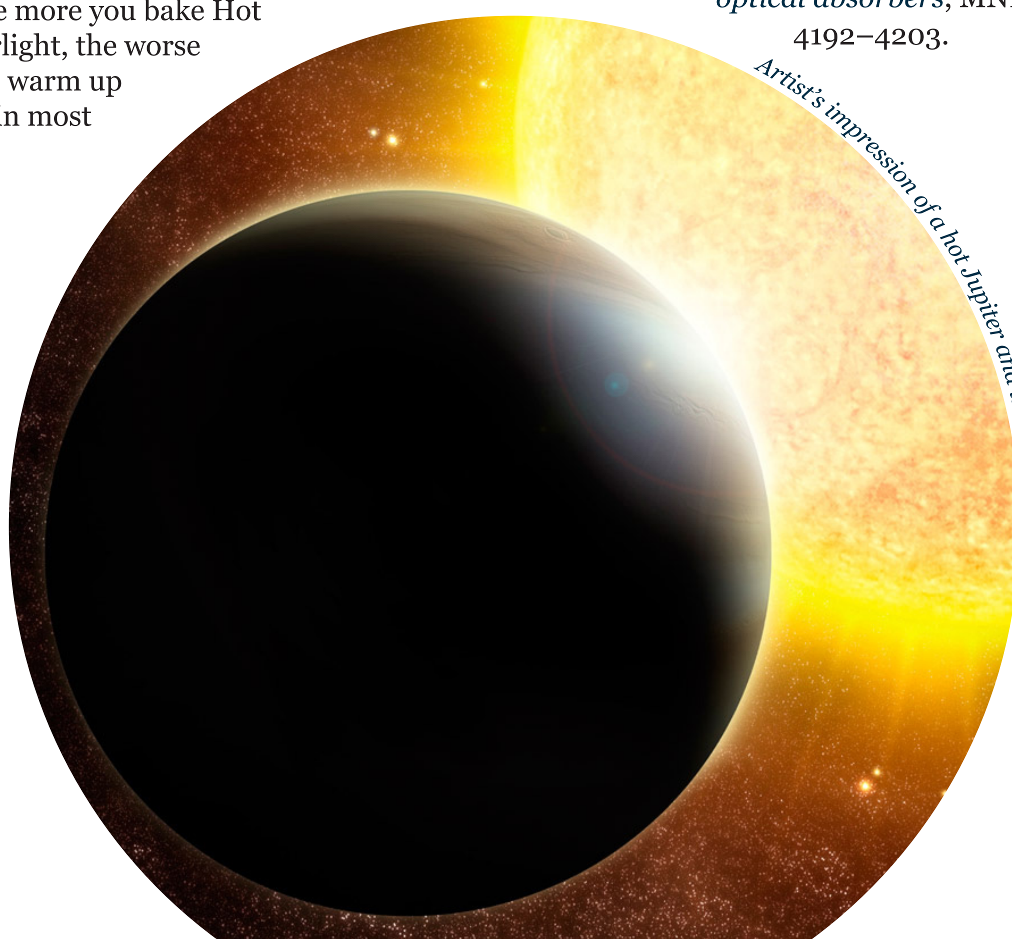
Computer work all the way: I search and collect data online, calculate things with software code I write, and make colorful graphs and pictures to help explain it all.

But the second I could do field work on an exoplanet...I'm there!

Why this is important

This study represents the best statistics we have about the bulk atmospherics of irradiated giant planets. We confirmed trends that previous studies had seen (e.g. more stellar irradiation means less day-to-night heat transport) and found other trends of our own (e.g. Hot Jupiters having reflective infrared clouds based on Bond albedos). And most importantly, our technique for inferring these atmospheric properties could be applied to temperate terrestrial planets down the line.

Schwartz, **J C**, and **N. B. Cowan** (2015), *Balancing the energy budget of short-period giant planets: evidence for reflective clouds and optical absorbers*, MNRAS 449, 4192–4203.



Artist's impression of a hot Jupiter and its host star.

Dark Matter and Gamma Rays

Dr. Jonathan Cornell *is a postdoctoral fellow at the McGill Space Institute, who works with Prof. Jim Cline. He recently completed a project to develop a theoretical model that describes the excess GeV gamma rays that come from the galactic centre.*

What question were you trying to answer?

One possible explanation for the excess of high energy gamma rays observed in the centre of our Milky Way galaxy by the Fermi-Large Area Telescope (LAT) is that these gamma rays are the product of the annihilation of dark matter particles.

However, many people argue that this explanation is not viable because a similar excess would be expected from dark matter annihilation in dwarf spheroidal galaxies [low-luminosity galaxies that are companions to the Milky Way], and the Fermi-LAT has not observed this.

This leads to the question: Is it possible to construct a dark matter model in which the dark matter annihilates at a much greater rate in the galactic centre than in dwarf spheroidals?

Why did you find this question interesting?

One of the most significant mysteries remaining in particle physics is the nature of dark matter, which up until now we have only seen interact via its gravitational interactions with normal matter.

The gamma ray signal from the galactic centre is one of the most promising possible signals of dark matter interactions beyond the gravitational, so it is important to try to understand what dark matter models explain this.

What does doing your research look like?

As theorists our research is done with computers and old fashioned pencil and paper.

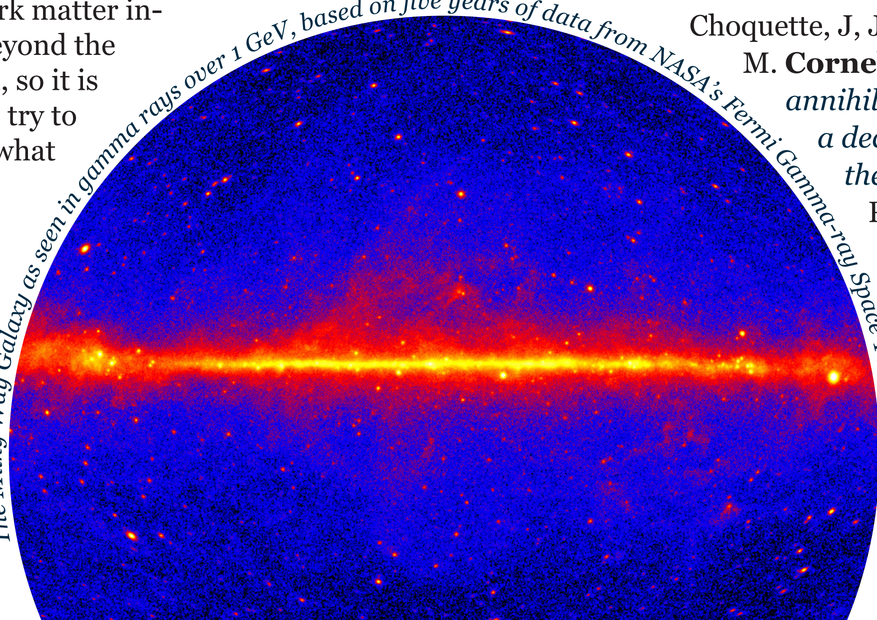
What did you find?

Since dark matter is moving much faster in the Galactic centre than in dwarf spheroidal galaxies, we developed a model in which the dark matter annihilation rate is dependent on its velocity, leading to an enhanced gamma ray signal in the Galactic centre.

To make this model work, we had to develop a new method for how the dark matter is made in the early universe.

Why this is important

The project pushes back against one of the major criticisms of a dark matter interpretation of the Galactic centre gamma-ray excess: namely, that at this point we should have expected to see a similar signal from dwarf spheroidal galaxies. It does so in a simple way, by positing a p-wave dark matter annihilation cross section. People usually discard such models because this cross section would be quite large in the early universe, leading to dark matter freezing out at late times with a relic density that is much too small. However, we show that this problem can be overcome by introducing another particle species in the dark sector which freezes out with the right relic density and then decays to the dark matter.



The Milky Way Galaxy as seen in gamma rays over 1 GeV, based on five years of data from NASA's Fermi Gamma-ray Space Telescope.

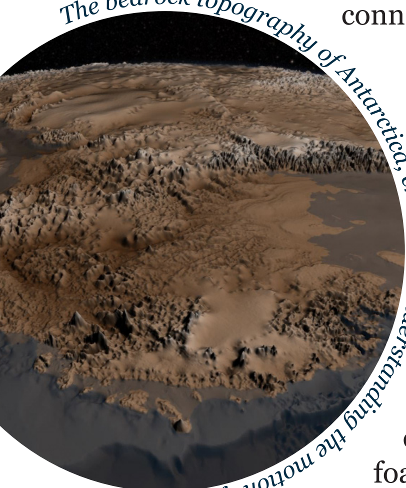
Choquette, J, J. M. **Cline**, and J. M. **Cornell** (2016), *p -wave annihilating dark matter from a decaying predecessor and the Galactic Center excess*, Phys. Rev. D 94 (1), 015018

Ice, Water and Earth in Antarctica

Prof. Natalya Gomez *joined the MSI as a faculty member in Fall 2015. Her group's research models the interactions between ice, water, climate and planetary interiors, and how these connections change planets surfaces through time. These models are applicable to both the Earth and other rocky, icy planets and moons in the Solar System.*

What question were you trying to answer?

I wanted to understand and model how the ice, water and solid Earth in Antarctica are connected and influence each other.



The bedrock topography of Antarctica, critical to understanding the motion of ice sheets

In particular, I wanted to know whether retreat of the Antarctic Ice Sheet in response to climate warming, and its contribution to future sea level rise was sensitive to the structure of the Earth's interior below the ice sheet. The Earth rebounds in response to removing ice mass from the continent, much like a memory foam mattress would. This uplifting of the bedrock below the ice sheet in turn feeds back onto how the ice itself flows off the continent and into the ocean. I wanted to know whether this effect is significant or not for the type of rapid ice loss we may see in the next hundreds to thousands of years.

Why did you find this question interesting?

My research bridges the gap between the communities that study the solid Earth and sea level changes, and those that study ice sheet evolution. This problem is a perfect example of why bridging that gap is important. It will take an interdisciplinary approach to refine predictions of future ice loss, if the answer requires in-depth knowledge of the solid Earth as well as the ice sheet.

What did you find?

My results suggested that knowing the structure of the solid Earth hundreds of kilometers below the Antarctic Ice Sheet may be needed in order to accurately predict how the ice sheet itself will evolve in response to future climate changes.

What does doing your research look like?

Sitting behind a computer, developing complex numerical models and running simulations on high performance computing equipment, and standing in front of a white board or talking over Skype, screen sharing with colleagues around the world in other disciplines.

What role did collaboration play in your research?

A very important role! I started out as an expert in sea level change, but the types of problems I work on require collaboration with people who specialize in measuring and modeling ice sheets, ocean circulation and climate change. This is one of the reasons I love my field of research — my colleagues and I get to learn a lot from each other.

Why this is important

The fate of the polar ice sheets in a progressively warming world is a focus of climate research and a concern for policy makers and the general public. Our models include two geophysical elements that are not adequately reflected in computer simulations of Antarctic Ice Sheet collapse — the gravitational pull of the ice sheet on surrounding water, and the viscous flow of the mantle beneath the bedrock that the ice sits on. We show that the combination of bedrock uplift and sea-surface drop associated with ice-sheet retreat reduces ice sheet mass loss relative to a simulation without these effects included. The degree to which this stabilization occurs is dependent on the structure of the Earth's deep interior, which is currently poorly known. Improving measurements and models of that structure may be needed to constrain projections of future ice loss and sea level change.

This understanding of planetary-scale processes may provide insights into the evolution of other planets and moons and the interpretation of the measurements we make of those bodies.

Gomez, **Natalya**, David Pollard, and David Holland (2015b), *Sea-level feedback lowers projections of future antarctic ice-sheet mass loss*, Nature Communications 6, 8798 EP

The Limits of Microbial Life

This year **Dr. Jackie Goordial** *finished her PhD and began a Postdoctoral fellowship at McGill in Microbiology, with a focus on astrobiology. As part of her research, she went to University Valley, Antarctica, to study microorganisms living in the permafrost in one of the coldest and driest places on Earth.*

What question were you trying to answer?

When we went to University Valley, we were hoping to find some extremely cold-adapted microorganisms. Our original questions were along the lines of: how many, and which microorganisms are present in the permafrost, and how cold-adapted are these communities?

When we started to get our results back, our questions shifted — Can we detect ANY microbial activity at in situ temperatures, and does the permafrost in University Valley host an active microbial ecosystem at all?

Why did you find this question interesting?

We are so used to microorganisms being present just about everywhere, including places where we actively try to eradicate them. This work was interesting to me because it touches on several fundamental questions: What are the limits of life on Earth? Are there places that are even too extreme for microorganisms to thrive? And finally- what are the limits to life on other cold planetary bodies, if there was life present, how could we detect it?

What did you find?

To our surprise we weren't able to detect any microbial activity in these soils, thus University Valley may represent an example of a natural ecosystem that is too harsh to support microbial life. This informs us about the limits of life on Earth, but also other cold planetary bodies.

What does doing your research look like?

This research involved a lot of different types of work: Field work (which is high up there in terms of things I love about this work), a lot of wet lab work - sitting behind a microscope, plating microorganisms on petri dishes, doing DNA extractions for molecular work, and countless hours behind a computer crunching the data. Sequencing data is huge, and a lot of my time was spent processing that, and trying to make sense of it in an ecological context.

Collaboration plays a huge part in my research. For example, NASA developed a prototype permafrost drill called IceBite which they wanted to test in a Mars like environment, such as University Valley. It's extremely hard to get to these remote environments and this provided the means to get us there to do some microbiology research.

University Valley, Antarctica

Why this is important

Prior to this work, essentially all that was known about permafrost microbial communities in the Dry Valleys was that microorganisms are present. We greatly expanded what is known about the ecology of microorganisms that are found in Dry Valley permafrost at high elevations, by surveying the microorganisms using next generation sequencing techniques, by culturing the organisms, and more interestingly by doing activity assays both in situ and in the lab. Thus, greatly increasing our understanding of the microbial ecology in a rare spot on earth where the only potential living things are microorganisms.

This site is one of the best Mars analogue sites that we have on Earth, similar to the dry and ice-cemented permafrost found in the north polar region of Mars where Phoenix landed. Understanding what types of microorganisms could survive or be active in these types of soils, as well as detecting biosignatures (in the form of dormant or dead cells, and nucleic acids in our case), is important to understanding what we could be looking for in near surface water ice on Mars in the north polar regions.

Goordial, Jacqueline, Alfonso Davila, Denis Lacelle, **Lyle G Whyte**, et al. (2016b), *Nearing the cold-arid limits of microbial life in permafrost of an upper dry valley, Antarctica*, ISME J 10 (7), 1613–1624.

Hands-on Radio Interferometers

Dr. Sean Griffin *is a postdoctoral fellow in the McGill Cosmology Instrumentation Laboratory. He leads a project to design hardware for small, portable radio interferometers.*

Can you describe your project?

High-resolution radio astronomy is typically performed using arrays of many telescopes spread across a large area. The information from each telescope is combined in order to reconstruct the information about the part of the sky the telescopes are observing. In practice, this is called interferometry. Conceptually, this material is taught in undergraduate courses, but we wanted to produce a hands-on experiment that students could use to learn how interferometry is actually done in practice.

In addition to the teaching tool, this project can be adapted in order to build tools for identifying sites for future radio astronomy arrays (an "RF monitor"), or to use in conjunction with current telescopes (such as CHIME) to make ultra-high-resolution measurements of transient events (such as fast radio bursts) using very-long-baseline interferometry (VLBI).

Why did you find this project interesting?

I think that hands-on experience learning "real-life-astronomer" skills is an important part of a student's training; a tool like this one is something I would have appreciated having access to when I was an undergraduate.

What did you learn?

We've learned (unsurprisingly) that it is tricky to build a radio telescope in the middle of a big city like Montreal. There's so much radio frequency (RF) noise around us that it makes measuring any astrophysical source difficult because their signals are much dimmer than those coming from FM radio, TV, and cellphone transmitters.

However, this just means that we need to be more clever about how we go about building our experiment. What we are learning about characterizing the radio noise in the city is also directly applicable to our goals of building an RF monitor to identify radio quiet sites.

At first, we expected that we would only be able to look at the brightest objects in the radio sky due to how much RF noise there is in the city. After having worked on this project for some time, we now believe that it might be possible to expand out targets to include dimmer objects like pulsars. It is exciting to see that we are not necessarily as limited as we thought we once were.

What does doing your research look like?

My research consists mainly of working with electronics in a lab, but involves taking trips outdoors to make measurements of the sky with our experiment. I also write a lot of software to read and analyse data from the various instruments that I use, and to help me predict what the signals I observe will look like.

Once the full system is ready for deployment, we will be driving out into the field with our telescopes to make measurements of different sites in an attempt to identify 'radio-quiet' zones as possible future radio telescope sites. In the long term, we hope to build a small telescope array on the roof of the Rutherford Physics building to use as a teaching instrument and a platform for testing new radio astronomy hardware. This will require actually heading up to the roof and building it, which is very exciting.

What role did collaboration play in your research?

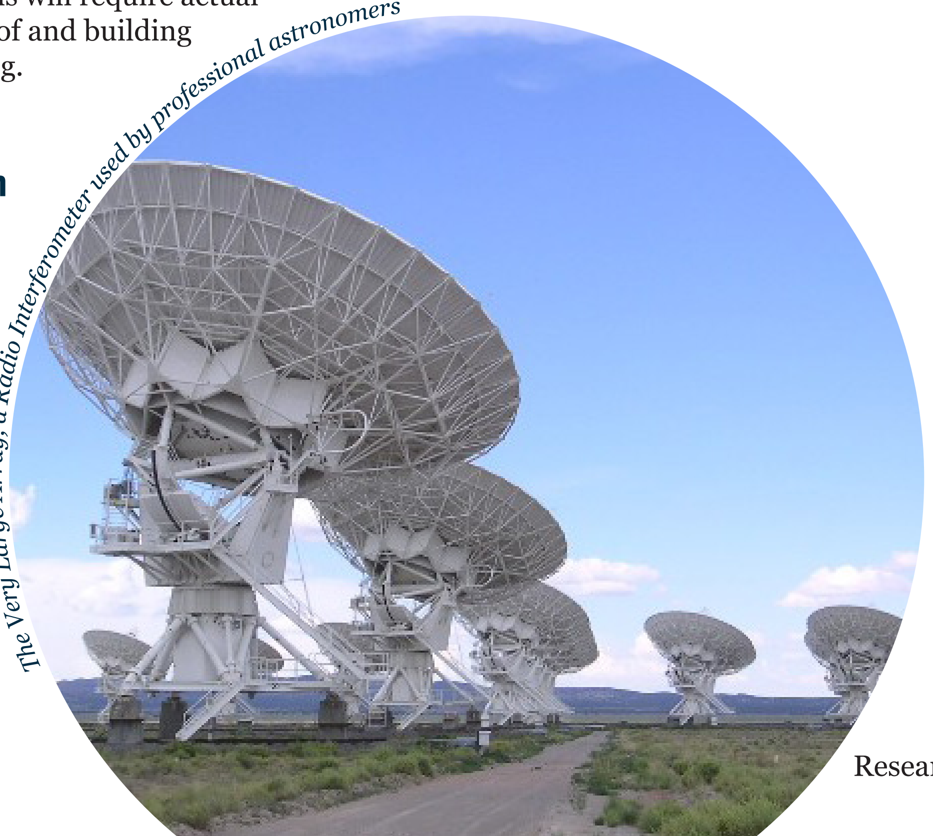
Different parts of our telescopes are being designed and tested by different people; there is too much work for any one person to do. Collaboration allows us to bring in specialists to work on the different components of the experiment, helping maximize our efficiency.

Why this is important

The first stage of this project is an instrument to give young astronomers hands-on experience with a real radio interferometer. This differs from traditional undergraduate lab experiments where students often repeat a historical measurement and do not represent modern experiments.

This instrument will allow undergraduates to work with state-of-the-art hardware and take make astronomical measurements in the same way that modern telescopes do. It is my hope that this will help motivate future experimentalists and get them excited about working in astronomy.

The second stage of this project is an instrument to help identify sites for future radio arrays. The hardware will allow us to characterise the environment in terms of both an absolute measurement of how noisy (or not) a given site is over a wide bandwidth with fine frequency resolution, and a measurement of the structure of that noise in time, which allows for the optimisation of data taking strategies in order to minimise the impact of any ambient RF interference.



The Very Large Array, a Radio Interferometer used by professional astronomers

A Repeating Fast Radio Burst

Prof. Vicky Kaspi *leads a group of graduate and postdoctoral researchers at the MSI, who observe of pulsars and related objects including magnetars and Fast Radio Bursts. This year they discovered a repeating Fast Radio Burst in data from the Aracebo Observatory.*

What question were you trying to answer?

Fast Radio Bursts (FRBs) are a new astrophysical mystery. FRBs consist of short (few millisecond) bursts of radio waves. These events are very common in the sky: our best estimates suggest that several thousand go off every day across the whole sky. However, the origin of FRBs is unknown. They appear to come from extragalactic distances, suggesting a very luminous, but mysterious source.

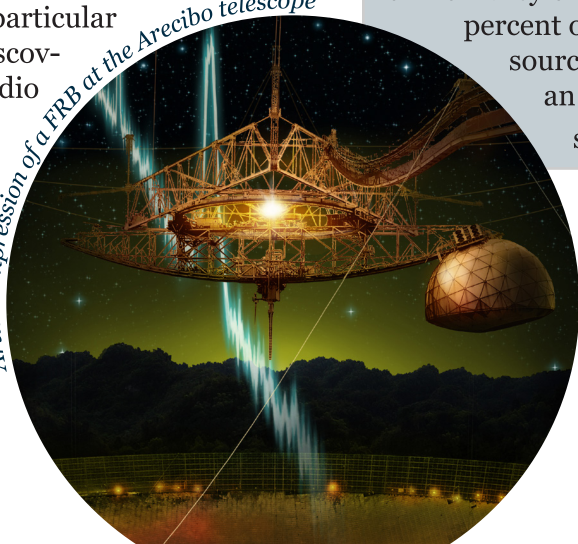
We were trying to understand the nature of FRBs and specifically whether they repeat. Some models of FRBs have them being the result of a cataclysmic event such as the merger of two neutron stars. If these models are correct, then FRBs should never show repetition. So searching for repetition is a very important test of FRB models.

Why did you find this question interesting?

It is rare in science to be presented with so fresh and interesting a puzzle as we have in FRBs. The FRB phenomenon must represent a very common occurrence in the Universe, and yet is totally unpredicted. This serves as an important reminder that we must remain humble about our understanding of the Universe — there's a lot out there that is still surprising to us!

What did you find?

We discovered that one particular FRB, a source that we discovered using the 305–m radio telescope in Arecibo, Puerto Rico, repeats! This came as a shock to us since previous searches for repeat bursts from the locations of other FRBs came up empty. We found no fewer than 10 new bursts from this source in follow-up observations made over a few weeks, and have subsequently seen many more from this source. Interestingly,the source seems to show these bursts in clusters: sometimes it is totally quiet and emits nothing, and other times it will burst several times in just a few minutes.



Artist's impression of a FRB at the Arecibo telescope

What does doing your research look like?

While we use observations from the Arecibo radio telescope, locally, at McGill, our research involves using a large super computer, along with enormous data files. In the end, our research 'looks' like representations of our data sets in different types of plots, scoured by small groups of people who also discuss the nuances in these plots and in how the data were obtained, and what new data we need to make more progress in understanding.

What role did collaboration play in your research?

Our research was part of the international PALFA collaboration which is led out of MSI. It was with the help of our colleagues that we were able to write a publication for the magazine Nature in a fairly short time, and garner significant interest from the public and press. We have also recently put together a detailed follow-up publication on the source.

Why this is important

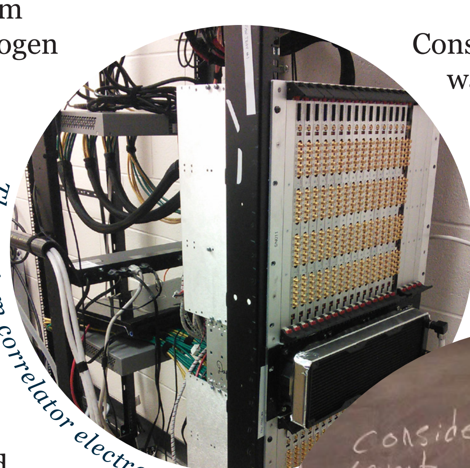
FRBs are a mysterious astrophysical phenomenon. Previous follow-up observations have failed to find additional bursts at the same location as the original detections. This first detection of a repeating Fast Radio Burst helps put important constraints on how they originate — it eliminates at least 50 percent of all models. We now know that the source of (at least some FRBs) must be an energetic event on an object that survives the original burst.

Spitler, L G, **P. Scholz**, J. W. T. Hessels, **R. D. Ferdman**, **V. M. Kaspi**, **E. C. Madsen**, **C. Patel**, et al. (2016), *A repeating fast radio burst*, Nature (London) 531, 202–205.

Canadian Hydrogen Intensity Mapping Experiment

Canadian Hydrogen Intensity Mapping Experiment (CHIME) is a new radio interferometer located at the Dominion Radio Astrophysical Observatory (DRAO) in British Columbia. At the McGill Space Institute, **Prof. Matt Dobbs**, **Prof. David Hanna** and **Prof. Vicky Kaspi** are involved with CHIME along with nearly 2 dozen McGill students, postdoctoral fellows and technicians

CHIME will map the 21 cm emission of neutral Hydrogen from redshifts 0.8 to 2.5 culminating in the largest-volume survey of the distribution of matter in the Universe ever made. This redshift range encompasses the critical period when Dark Energy becomes comparable to the energy density of matter and drives the late accelerated expansion of the Universe.

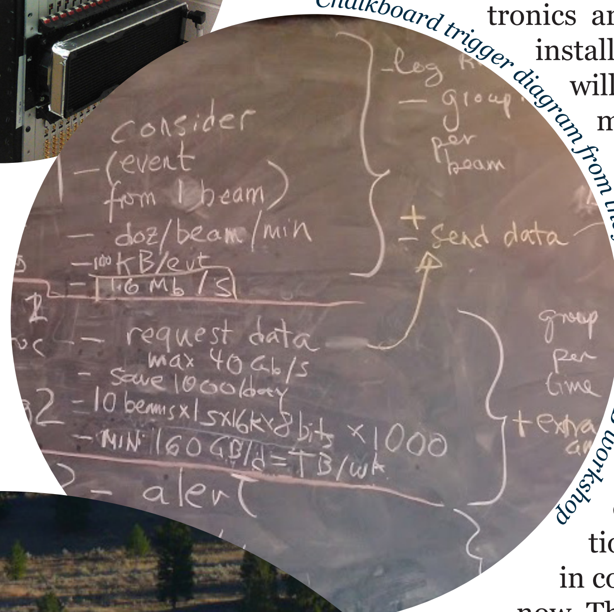

The custom correlator electronics

The survey will allow the team to measure the expansion rate of the Universe through this critical epoch, thus helping to constrain the Dark Energy equation of state. In addition, the CHIME telescope will be a powerful instrument to detect Fast Radio Bursts.

A separate back-end processor to perform the high-cadence de-dispersion has recently been funded by the CFI.

CHIME will also act as a scientific and technical pathfinder for the Square Kilometre Array (SKA), pioneering the measurement of very low-surface brightness phenomena and developing key correlator hardware.

Construction of the structure for the telescope was completed in late 2015. At 8,000 m^2, CHIME is now the largest telescope in continental North America with 2% more collecting area than the Green Bank telescope.



Chalkboard trigger diagram from the first CHIME/FRB workshop

The custom correlator electronics are now being installed on site and will be commissioned in late 2016. It will be the world's largest radio correlator. The analog chain, including the 1024 dual-polarization feeds, are in construction now. The telescope will see first light in 2017 and be commissioned that year.


Construction of the structure for the telescope was completed in late 2015

Education and Public Outreach

AstroNights

On the third Thursday of every month, AstroMcGill holds *Public AstroNight*. These events consist of a public talk given by a professional astronomer, usually a McGill student or professor, aimed at a broad audience. After the talk, there are night sky observations with portable telescopes (weather permitting).

Over the past academic year, AstroNight talks have exploded in popularity. We went from filling the largest lecture hall in the Rutherford Physics Building (the Keys Auditorium, 145 seats), to filling the largest lecture hall on campus (Leacock 132, 601 seats). The most popular public talks were:

- August 2015: AstroNight Pluto Palooza by Dr. Kelly Lepo, approx. 550 people attending
- September 2015: Le côté obscur de l'Univers / The Dark Side of the Universe by Gabrielle Simard, approx. 400 people attending
- January 2016: The Dark Energy of the Universe by Prof. Jim Cline, approx. 400 people attending
- February 2016: Into the Heart of the Milky Way by Prof. Daryl Haggard, approx. 650 people attending

We found that 45-50% of all audience members were at their first AstroNight and a small contingent (10-20%) have come to 10 or more public lectures. Most survey respondents heard about AstroNight through word of mouth, with a significant minority learning about it through social media. Our audience is about 40/60 female/male, with a median age in the 25-35 age group. About 55% of our audience members speak English at home, coming from either English-only, bilingual English/French or bilingual English/other language households. This suggests that although most talks are in English, our reach is beyond the Anglophone community in Montreal.

Space Explorers Programme

In the past, school visits by AstroMcGill volunteers have typically been one-time, half-day events, where volunteers lead children through a few activities. During the 2015-2016 school year, we decided to make major changes to our K-12 outreach strategy, partnering with Physics Outreach for the McGill Space Explorers programme.

Over the course of five visits over one school year, the future astronauts have the opportunity to learn about heat and temperature, collisions, light and colours, gravity, magnetism and the Solar System.

Students play with magnets in the McGill Space Explorers programme

Students observe the Sun through AstroMcGill telescopes

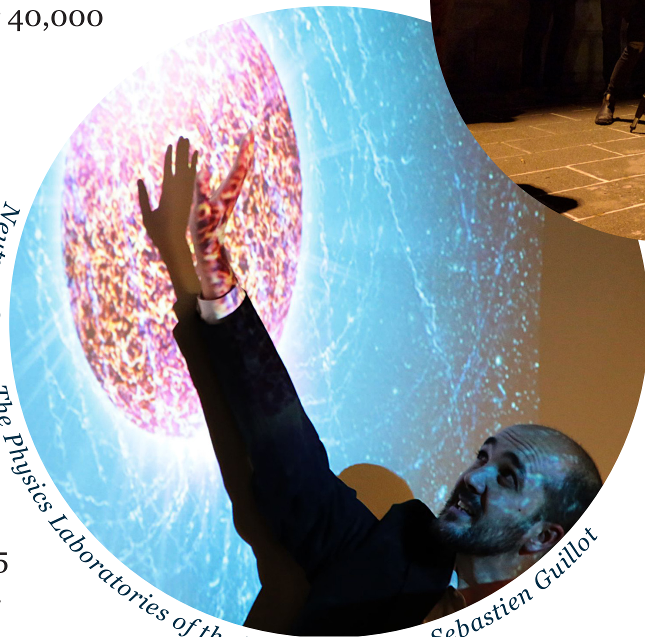
650 people come to "Into the Heart of the Milky Way" by Prof. Daryl Haggard

The AstroMcGill Podcast

The podcast consists of interviews of visiting astronomers discussing their research. It is aimed at a general audience and has had over 40,000 downloads and streams since 2012.

We recorded six episodes to date during the 2015-2016 school year. We are in the process of retooling the podcast to reach a wider audience, including introducing a new format and advertising more widely.

Braving the cold to observe the moon



Neutron Stars: The Physics Laboratories of the Universe by Dr. Sebastien Guillot

Social Media

The AstroMcGill Facebook page has increased from 1481 to 2070 'likes' since August 1, 2015. The AstroMcGill twitter account gained 335 followers over the same time period.

MSI in the News

Prof. Nicolas Cowan

14 May 2016 • **Sommes-nous seuls dans le cosmos?** • Québec Science

25 April 2016 • **Can CMB Experiments Find Planet Nine?** • AAS Nova — Research highlights from the journals of the American Astronomical Society

7 April 2016 • **How Astronomers Are Going to Find Planet Nine** • Gizmodo

30 March 2016 • **The super-Earth 55 Cancri may have a magma ocean or windblown clouds of vaporized rock** • Scientific American

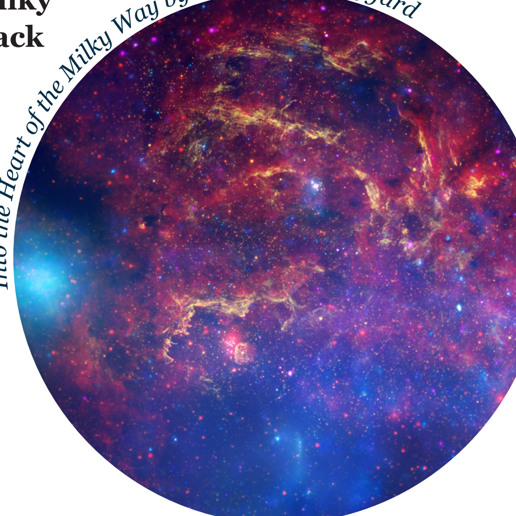
24 February 2016 • **Planet Nine hunters enlist big bang telescopes and Saturn probe** • New Scientist

17 February 2016 • **The truth about exoplanets** • Nature News

Prof. Daryl Haggard

1 February 2016 • **Into the Heart of the Milky Way** • Sky and Telescope

26 October 2015 • **Milky Way's Monster Black Hole Belches Big, But Why?** • Space.com



Into the Heart of the Milky Way by Prof. Daryl Haggard

Prof. Gil Holder

2 May 2016 • **Astronomers discover dark matter galaxy, by accident** • Space.com

14 April 2016 • **Dwarf dark galaxy hidden in ALMA gravitational lens image** • Astronomy Magazine

Prof. Victoria Kaspi

2 February 2016 • **Exploding Stars** • TVO The Agenda

Minister of Science Kirsty Duncan, Prof. Vicky Kaspi, Prime Minister Justin Trudeau, President of NSERC Mario Pinto

3 February 2016 • **Victoria Kaspi named winner of the Gerhard Herzberg Canada Gold Medal for Science and Engineering, First Woman to Win the Prize** • Many publications including: The Washington Post, National Geographic, CBC.ca, Agence France-Presse, Montreal Gazette

2 December 2015 • **Mysterious radiowave blast may have come from starquake**• Nature News

29 June 2015 • **Misbehaving pulsar's sudden slow-down may teach us how they tick**• New Scientist

Prof. Tracy Webb

5 October 2015 • **Massive galaxies rob gas from little neighbours** • Cosmos Magizine

10 September 2015 • **NASA Telescopes Find Galaxy Cluster with Vibrant Heart** •HubbleSite

Prof. Lyle Whyte

16 December 2015 • **Vie sur Mars** • TVr9

Dr. Robert Ferdman

15 February 2016 • **Understanding gravity waves** • CBC Montreal News

Dr. Jacqueline Goordial

19 January 2016 • **Study reveals life's outer limits in Antarctic valley** • The Globe and Mail

NASA Telescopes Find Galaxy Cluster with Vibrant Heart

Dr. Kelly Lepo

13 December 2015 • **Geminid meteor shower: How to catch the cosmic light show** • CBC Montreal News

29 June 2015 • **The Science Behind the Leap Second** • CBC Montreal News

23 July 2015 • **Kelly Lepo discusses the discovery of Kepler 452b — an Earth-like planet around a Sun-like Star** • CBC Montreal Radio

Dr. James Lowenthal

5 February 2016 • **Montreal's push for outdoor LED lights isn't just a night-sky problem. It's unhealthy, scientists warn** • CTV Montreal News

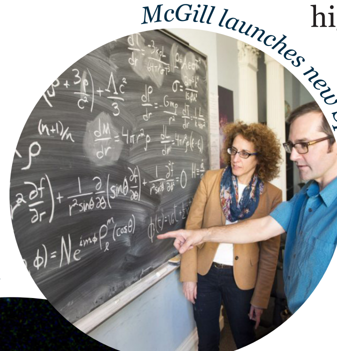
2 December 2015 • **The perils of light pollution** • Montreal Gazette

Paul Scholz

2 March 2016 • **McGill Space Institute Graduate Student discovers a repeating fast radio burst** • Many publications including: The Washington Post, National Geographic, CBC.ca, Agence France-Presse, Montreal Gazette

Robert Archibald

30 September 2015• **A Pulsar Eases Off the Brakes** • AAS Nova — Research highlights from the journals of the American Astronomical Society



McGill launches new Space Institute

McGill launches new Space Institute

28 October 2015 • Montreal Gazette

Montreal universities launch new space research centres

1 November 2015 • The Canadian Press, article appeared in many publications across Canada including: The Toronto Star, CBC.ca, CTV news Montreal

MSI Fellowships

McGill Space Institute Fellowships are made possible by a generous $1 million donation from **the Trottier Family Foundation** to support MSI postdoctoral researchers and graduate students.

McGill Space Institute Fellowships are awarded by a committee of faculty members who span different fields of the MSI. They recognize excellence in research among the centre's PhD and MSc students, as well as support several postdoctoral researchers affiliated with the centre.

In the 2015-2016, the McGill Space Institute awarded one 2-year MSc fellowship and one 3-year PhD fellowship to graduate students beginning their degrees. We also recruited 4 graduate students and 2 postdoctoral fellows, who will hold MSI fellowships beginning in the 2016-2017 academic year.

2015- 2016 McGill Space Institute Fellows

David Berardo

Supervisor: Andrew Cumming

David graduated from the honors Physcis program at McGill before starting a MSc in Physics in the Fall of 2015.

David models the formation and evolution of gas giant planets around other stars using the MESA open-source stellar evolution software.

Jeremie Choquette

Supervisor: Jim Cline

Jeremie completed a MSc in physics at McGill, working on several aspects of dark matter model building. He began a PhD in physics in the Fall of 2015.

Jeremie works to develop models that suggest ways to directly and indirectly detecting dark matter particles through astrophysical signals.

Jackie Goordial

Supervisor: Lyle White

Dr. Jackie Goordial finished her PhD and began a Postdoctoral fellowship at McGill in the Winter of 2015.

Jackie studies microorganisms living at Mars analogue sites such as University Valley, Antarctica. She works to identify the types of microorganisms that could survive such regions as well as their biosignatures.

Preview of 2016-2017 MSI Fellows

MSc Students

Taylor Bell • University of Saskatchewan
Prof. Nicolas Cowan, Physics
Marie-Pier Labonté • Université Laval
Prof. Tim Merlis, AOS
Catherine Maggiori • University of Waterloo
Prof. Lyle White, NRS
Gavin Noble • University of British Columbia
Prof. Matt Dobbs, Physics

Postdoctoral Researchers

Erik Chan • Harvard University
Prof. Natalya Gomez, EPS

Vanessa Graber • University of Southampton
Prof. Andrew Cumming and Prof. Vicky Kaspi, Physics

MSI Seminars

MSI Faculty Jamboree
15 Sep 2015
Short presentations from all MSI faculty about their research

Sarah Hörst
John Hopkins University
22 Sep 2015
Understanding Haze Formation in Planetary Atmospheres: Lessons from the Lab

Caroline Morley
UC Santa Cruz
6 Oct 2015
Seeing Through the Clouds: The Thermal Emission and Reflected Light of Super-Earths with Flat Transmission Spectra

Roger O'Brient
NASA Jet Propulsion Laboratory
3 Nov 2015
One Photon, two photon red(shifted) photon, blue photon: Superconducting devices for Astrophysics

Michele Bannister
NRC Herzberg
17 Nov 2015
Exploring the Outer Solar System: Now in Vivid Colour

Edwin Kite
University of Chicago
1 Dec 2015
Why Material From Enceladus' Ocean Keeps Getting Ejected Into Space

Omer Blaes
UC Santa Barbara
19 Jan 2016
Outbursts Around Dead Stars: How Dwarf Novae Are Testing Our Fundamental Fluid Dynamics Theory of Accretion Disks

Vikram Ravi
California Institute of Technology
2 Feb 2016
A tale of two fast radio bursts

Sabine Stanley
University for Toronto
16 Feb 2016
Planetary Dynamos: The Curious Case of Saturn

Ram Jakhu
McGill University
Centre for Research of Air and Space Law
8 Mar 2016
Space law for Astronomers

Betul Kacar
Harvard University
5 Apr 2016
Lessons from the Past: Synthetic Biology and Experimental Evolution for Space Exploration

Workshops

CRAQ Student Workshop
September 9-11, 2015
Workshop for astrophysics graduate students of the Centre for Research in Astrophysics of Quebec (CRAQ), coming from Laval, Montreal and McGill University

NANOGrav
October 19-20, 2015
Search for gravitational waves using pulsars collaboration meeting.

NRAO Live!
February 18-19, 2016
NRAO staff members and local experts described the latest telescope capabilities and the science they enable, with an emphasis on ALMA and the VLA.

A Week at the MSI

Monday

MSI lunch Seminar (alternate weeks)	*12:00 pm*
Tea and Cookies	*3:00 pm*
French language discussion class	*4:00 pm*

Tuesday

Random Papers Discussion	*10:30 am*
Education, outreach and diversity discussion	*2:00 pm*
Tea and Cookies	*3:00 pm*
MSI or Astronomy Seminar	*3:30 pm*

Wednesday

Exoplanet Lunch	*12:00 pm*
N-body discussion group	*1:00 pm*
Tea and Cookies	*3:00 pm*
Neutron Star Discussion	*3:30 pm*

Thursday

iREx cafe (alternate weeks at UdeM)	*10:30 am*
Tea and Cookies	*3:00 pm*
Cosmology Journal Club	*3:30 pm*

Friday

Astronomy Journal Club	*10:30 am*

Education, Outreach and Diversity

The McGill Space Institute education, outreach and diversity discussion group meets Tuesday afternoons in the MSI lounge, chaired by **MSI coordinator Dr. Kelly Lepo**.

These informal, hour-long discussions cover a variety of topics, from analyzing recently published physics education research journal articles or blog posts by scientists about diversity and equity issues, to an overview of the literature on a particular topic (like stereotype threat or using active learning techniques in the classroom), to postmortems of outreach activities.

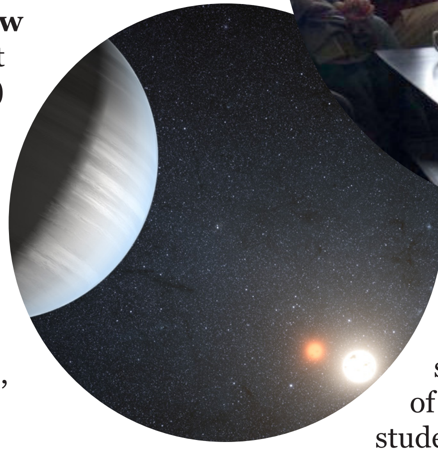
Since the discussion is held on the same day as Astrophysics and MSI seminars, we often invite visiting speakers to lead a discussion on a topic of their choice.

MSI coordinator Dr. Kelly Lepo uses active learning techniques to engage the audience in a public lecture

iREX

iREx café in the MSI lounge

Prof. Nick Cowan and **Prof. Andrew Cumming** are members of the Institut de recherche sur les exoplanètes (iREx) which consists of 44 students, post-docs, research staff and faculty members at the Université de Montreal and McGill.



iREx brings together researchers who focus on the characterization of exoplanets, understanding their formation, evolution, composition of their atmospheres and whether they harbor life.

Every other week, MSI hosts the iREx café, at which researchers discuss their latest findings and new results in the field.

Each summer, iREx offers Trottier Excellence Grants to undergraduates to support summer research projects, some of which are held at McGill. The students have desks in the MSI building where they can interact with McGill Space Institute researchers.

Google Summer of Code

The McGill Space Institute was accepted in March 2016 as a mentor organization for the Google Summer of Code. **Dr. Kelly Lepo**, **Prof. Nick Cowan** and **Prof. Boswell Wing** mentored students, who worked on open source software development projects.

Google selects the mentor organizations, provides the application platform and pays stipends to students and mentor organizations.

Due to the large amount of student interest, the McGill Space Institute received slots for three students from Google, which is an unusually high number for first-time mentor organizations (most new organizations only receive slots for one or two students).

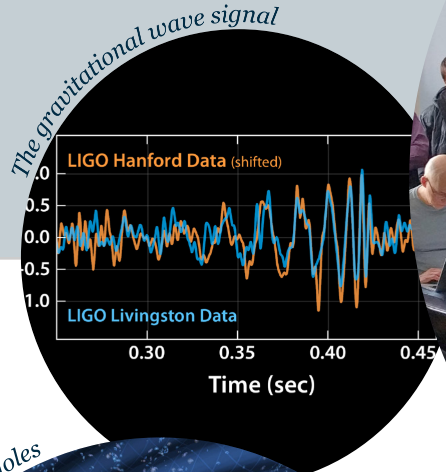
Projects included an open source data reduction pipeline to process images from the Spitzer Space Telescope (Cowan), an open-source modular code modeling microbial stable isotope fractionation for astrobiology (Wing), and adapting the open-source lightcurve-modelling code Icarus to model accreating white dwarf systems (Lepo).

LIGO Press Conference Event

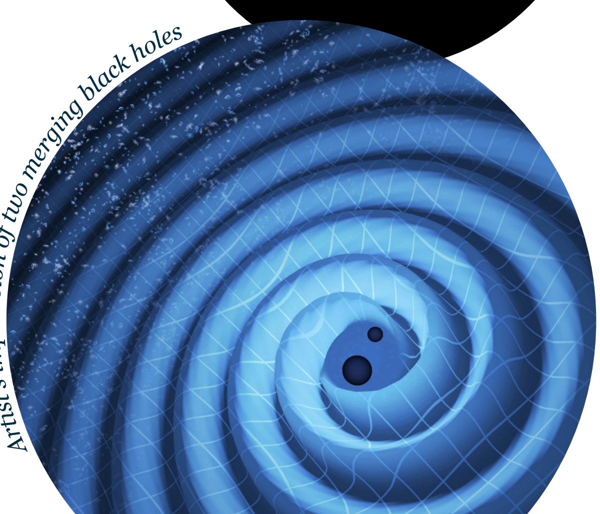
On February 11, 2016 the LIGO (Laser Interferometer Gravitational-Wave Observatory) collaboration held a press conference to announce that they had detected gravitational waves for the first time, receiving a signal from the last 0.2 seconds of a merger and "ringdown" of a pair of 36 and 29 solar mass black holes, 410 Mega-parsecs away.

The McGill Space Institute hosted a viewing party in the 3550 University building where we watched a livestream of the announcement to commemorate this historic event in non-electromagnetic wave astronomy. About 100 McGill astronomers and physicists crowded into the MSI lounge, overflowing out into the hallway and into the nearby conference room.

Standing room only as McGill astronomers and physicists watch the LIGO press conference



The gravitational wave signal



Artist's impression of two merging black holes

Awards

Faculty Awards

Robert Brandenberger
Fellow of the Royal Society of Canada
Simons Fellowship in Theoretical Physics
Senior Fellowship - ETH Institute for Theoretical Studies

Nicolas Cowan
Kavli Frontiers Fellow

Matt Dobbs
Awarded membership in the Royal Society of Canada College of New Scholars

Natalya Gomez
Appointed a Tier II Canada Research Chair

Daryl Haggard
Kavli Frontiers Fellow

Victoria Kaspi
NSERC Gerhard Herzberg Gold Medal for Science and Engineering

Tim Merlis
Appointed a Tier II Canada Research Chair

Ken Ragan
SALTISE teaching award

Student Awards

Nina Bonaventura
McGill Schulich Fellowship

Étienne Bourbeau
Centre for Research in Astrophysics of Quebec (CRAQ) student workshop – best student presentation
Mexican National Science and Technology Council (CONACYT) – Organization of American States (OAS) – Mexican Agency for International Development Cooperation (AMEXCID) scholarship

Peter Crockford
Mitacs - Japan Society for the Promotion of Science (JSPS) Fellowship
GSA Travel Award
McGill GREAT Award
Northern Science Training Program Award
NSERC Postgraduate Scholarships – Doctoral

Emilie Parent
NSERC Canada Graduate Scholarships – Master's
Fonds de recherche du Québec (FRQNT) - Nature et technologies scholarship

Paul Scholz
McGill Schulich Fellowship

Jerome Quintin
NSERC Vanier Canada Graduate Scholarship
Walter C. Sumner Memorial Fellowship
Graduate Excellence Award

MCGILL SPACE INSTITUTE BY THE

NUMBERS

109 Journal articles published by MSI members

69 Invited seminars given by Faculty Members in **14**[1] Countries

3600 Attendees at **10** Astro McGill Public Astro Nights

$4.1 MILLION[2] Grants received by Faculty Members

27 International Conferences attended by faculty members in **10**[3] Countries

10[4] McGill Space Institute Seminars

8 Undergraduate Students

13 Masters Students

25 PhD Students

16 Faculty Members

17 Postdoctoral Fellows

2 Visiting Faculty Members on Sabbatical

1 Coordinator

2720 Cups of afternoon tea

5440 Cookies

• 1 Canada, China, Denmark, Finland, France, Ireland, Italy, Netherlands, Spain, Sweden, Switzerland, UAE, United Kingdom, United States • 2 Total number of grants received by MSI faculty members for the 2015-2016 academic year. In the case of multi-year grants, this includes the total amount of the grant divided by the number of years the grant covers. • 3 Australia, Canada, China, Ireland, Italy, Japan, Netherlands, Spain, Sweden, United States • 4 Comets: From Harbingers of Doom to the Scientific Revolution by Dr. Kelly Lepo, The Dawn of Gravitational Wave Astronomy by Elinore Roebber, Into the Heart of the Milky Way by Prof. Daryl Haggard, The Dark Energy of the Universe by Prof. Jim Cline, Distant Galaxies and the Cosmic Time Machine by Dr. James Lowenthal, Le côté obscur de l'Univers by Gabrielle Simard, Pluto Palooza by Dr. Kelly Lepo, Neutrinos: The Most Tiny Quantity of Reality Ever Imagined By a Human Being by Lidia Iarotsky, Neutron Stars: The Physics Laboratories of the Universe by Dr. Sebastien Guillot

2015-2016 MSI Members

Faculty Members

Victoria Kaspi *MSI Director*	Phys
Andrew Cumming *MSI Associate Director*	Phys
Robert Brandenberger	Phys
James Cline	Phys
Nicolas Cowan	Phys & EPS
Matt Dobbs	Phys
René Doyon	Phys
Natalya Gomez	EPS
Daryl Haggard	Phys
David Hanna	Phys
Gil Holder	Phys
Yi Huang	AOS
Timothy Merlis	AOS
Ken Ragan	Phys
Tracy Webb	Phys
Lyle Whyte	NRS
Boswell Wing	EPS

Postdoctoral Fellows

Dan Capellupo	Phys
Jonathan Cornell	Phys
Qi Feng	Phys
Robert Ferdman	Phys
Alfonso Diaz Furlong	Phys
Adam Gilbert	Phys
Leila Graef	Phys
Sean Griffin	Phys
Andrew McCann	Phys
Seth Siegel	Phys
Shriharsh Tendulkar	Phys
Ben Zitzer	Phys

Graduate Students

David Berardo *MSI Fellow*	Phys
Jeremie Choquette *MSI Fellow*	Phys
Simon Archambault	Phys
Robert Archibald	Phys
Hossein Basrafshan	Phys
Nina Bonaventura	Phys
Étienne Bourbeau	Phys
Pragya Chawla	Phys
Gabriel Chernitsky	Phys
Ryan Chown	Phys
Jesse Colangelo-Lillis	Phys
Peter Crockford	EPS
Disrael Cunha	Phys
Bryce Cyr	Phys
Anna Delahaye	Phys
Grace Dupuis	Phys
Elisa Ferreira	Phys
Guilherme Franzmann	Phys
Jackie Goordial	NRS
Gilbert Hsyu	Phys
Tony Lin	Phys
Erik Madsen	Phys
Evan McDonough	Phys
Juan Mena	Phys
Joshua Montgomery	Phys
Yuuki Omori	Phys
Emilie Parent	Phys
Chitrang Patel	Phys
Tristan Pinsonneault-Marotte	Phys
Jerome Quintin	Phys
Elinore Roebber	Phys
Paul Scholz	Phys
Joel Schwartz	Phys
Gabrielle Simard	Phys
Benjamin Tam	Phys
Jonathan Tyler	Phys

Undergraduate Students

Dhruv Bisaria	Phys
Miles Cranmer	Phys
Lisa Dang	Phys
Kays Haddad	Phys
Diana Jovmir	Phys
Jyotsana Singh	EPS
Benjamin Tam	Phys
Reinhold Willcox	Phys

Staff

Kelly Lepo
MSI Coordinator

Phys: Physics

EPS: Earth and Planetary Sciences

AOS: Atmospheric and Oceanic Sciences

NRS: Natural Resource Sciences

Joined the MSI in 2015

Nicolas Cowan
Daryl Haggard
Natalya Gomez
Kelly Lepo

Departing for other adventures in 2016

Gil Holder
Boswell Wing

2015-2016 MSI Board

External Members

Lorne Trottier
Co-founder of Matrox

Marc Guilbert
Senior Associate
Power Corporation of Canada

Vassiliki Kalogera
Director CIERA Institute at Northwestern University

McGill Internal Members

Chris Manfredi
Provost

Bruce Lennox
Dean of Science

Rose Goldstein
VPR of Research

McGill Space Institute Internal Members

Victoria Kaspi
Director McGill Space Institute
Professor of Physics

Andrew Cumming
Associate Director McGill Space Institute
Associate Professor of Physics

Matt Dobbs
Associate Professor of Physics

Robert Brandenberger
Professor of Physics

Timothy Merlis
Assistant Professor of Atmospheric and Oceanic Sciences

Jackie Goordial
Postdoctoral Fellow

Peter Crockford
PhD Student

Visitors 2015-2016

Sabbatical Visitors

Prof. Ingrid Stairs
University of British Columbia

Prof. James Lowenthal
Smith College

Short-term visitors

Dr. Yuri Cavecchi
University of Amsterdam

Prof. Froney Crawford
Franklin and Marshall College

Dr. Cherry Ng
University of British Columbia

Weicong Huang
Beijing Institute of Theoretical Physics

Facilities used by MSI members

Laboratory and Computing facilities

The McGill Stable Isotope Laboratory
Makes high precision measurements of natural abundance stable isotope ratios in earth and planetary materials. (Wing)

The McGill Cosmology Instrumentation Laboratory
Develops complex digital and ultra-low noise analog cryogenic electronics for astrophysics. Includes separate labs for radio instrumentation and mm-wave instrumentation. (Dobbs)

The Gamma-ray Astronomy Laboratory
Develops instrumentation for astroparticle and particle physics detectors. (Hanna, Ragan)

Prof. Whyte's laboratory
One of the few laboratories worldwide with the facilities to perform fundamental studies at subzero temperatures for molecular biology/microbiology and astrobiology-related investigations.

The McGill High Arctic Research Station (MARS)
Supports field research activities consisting of sample acquisition, some limited laboratory microbial and molecular analyses, and in situ analyses for microbial activity. (Whyte)

Guillimin supercomputer
Owned and administered by Compute Canada and Calcul Quebec (Cowan, Huang, Kaspi, Gomez)

Ground-based Telescope Facilities

The Canadian Hydrogen Intensity Mapping Experiment, CHIME (Dobbs, Hanna)

Pulsar backend recording and analysis system for CHIME (Kaspi, Dobbs)

VERITAS Gamma-ray Telescope (Hanna, Ragan)

South Pole Telescope, mm-wave, Cosmic Microwave Background (Dobbs, Holder)

POLARBEAR and the Simon's Array, mm-wave, Cosmic Microwave Background (Dobbs)

Arecibo Observatory, Radio wavelengths (Kaspi)

Green Bank Telescope, Radio wavelengths (Kaspi)

Jansky Very Large Array, Radio wavelengths (Haggard, Kaspi, Webb)

Gemini Observatory (Haggard, Webb)

Canada France Hawaii Telescope (Webb)

Observatoire du Mont-Mégantic (Cowan)

Atacama Large Millimeter Array (Webb)

Space-based Telescope Facilities

EBEX stratospheric balloon telescope , Co-built in the McGill Cosmology Instrumentation Laboratory, funded by NASA and the CSA. (Dobbs)

NASA/Hubble Space Telescope (Cowan, Webb)

NASA/Swift X-ray Telescope (Cumming ,Haggard, Kaspi)

NASA/NuSTAR X-ray Mission (Cumming, Kaspi)

NASA/Chandra X-ray Observatory (Haggard, Kaspi, Webb)

ESA/XMM-Newton X-ray Telescope (Cumming, Kaspi, Webb)

NASA Spitzer Space Telescope (Haggard, Cowan, Webb)

MSI Faculty Collaborations

McGill-lead collaborations

CHIME *The Canadian Hydrogen Intensity Mapping Experiment, Cosmology* **(Dobbs, Hanna)** *and Fast Radio Burst* **(Kaspi, Dobbs)** *groups*

Other participating institutions: Dominion Radio Astrophysical Observatory • University of British Columbia • University of Toronto • U.S. National Radio Astronomy Observatory

PALFA *Pulsar Arecibo L-Band Feed Array survey* **(Kaspi)**

Other participating institutions: Albert Einstein Institute • ASTRON • Columbia University • Cornell University • Franklin and Marshall College • Jodrell Bank Center for Astrophysics • Lafayette College • Max-Planck-Institut für Radioastronomie • National Radio Astronomy Observatory • National Radio Astronomy Observatory • Naval Research Laboratory • University of British Columbia • University of East Anglia • University of New Mexico • University of Texas at Brownsville • University of Wisconsin - Milwaukee • West Virginia University

VERITAS **(Hanna, Ragan)**

Other participating institutions: Adler Planetarium and Astronomy Museum • Argonne National Lab • Barnard College Columbia University • Cork Institute of Technology • Georgia Institute of Technology • Iowa State University • National University of Ireland, Galway • Purdue University • Smithsonian Astrophysical Observatory • University College Dublin • University of California, Los Angeles • University of California, Santa Cruz • University of Chicago • University of Delaware • University of Iowa • University of Minnesota • University of Utah • Washington University in St. Louis

Other collaborations

FINESSE *Fast Infrared Exoplanet Spectroscopy Survey Explorer* **(Cowan)**

Other participating institutions: California Institute of Technology • INAF-Osservatorio Astronomico di Palermo • Jet Propulsion Laboratory • Max Planck Institute for Astronomy • NASA Ames Research Center • Princeton University • Queen's University of Belfast • University of Arizona • University College London

GBNCC *The Green Bank North Celestial Cap pulsar survey* **(Kaspi)**

Other participating institutions: ASTRON • National Radio Astronomy Observatory • Universiteit van Amsterdam • University of British Columbia • University of New Mexico • University of Texas at Brownsville • University of Virginia • West Virginia University

JINA/CEE *Joint Institute for Nuclear Astrophysics - Centre for Evolution of the Elements* **(Cumming)**

Other participating institutions: Argonne National Laboratory • Arizona State University • Cluster of Excellence Origin and Structure of the Universe • GSI Helmholtz Centre for Heavy Ion Research • Florida State University • Los Alamos National Laboratory • Michigan State University • Monash University • North Carolina State University • Nuclear Astrophysics Virtual Institute • Nuclear Computational Low Energy Initiative • Ohio State University • Ohio University • Princeton University • Shanghai Jiao Tong University • TRIUMF • University of Chicago • University of Minnesota • University of Notre Dame • University of Sao Paulo • University of Victoria • University of Washington • Western Michigan University

NANOGrav *The search for gravitational waves using pulsars* **(Kaspi)**

Other participating institutions: California Institute of Technology • Cornell University • Franklin and Marshall College • Hillsdale College • Huazhong University of Science and Technology • Jet Propulsion Laboratory • Lafayette College • Montana State University • NASA Goddard Space Flight Center National Radio Astronomy Observatory • Naval Research Laboratory • Notre Dame of Maryland University • Oberlin College • Penn State University • University of Alabama • University of British Columbia • University of California, Berkeley • University of East Anglia • University of Maryland • University of Texas Rio Grande Valley • University of Vermont • University of Washington Bothell • University of Wisconsin Milwaukee • West Virginia University

NICER *NASA's Neutron Star Interior Composition Explorer* **(Kaspi)**

Other participating institutions: MIT Kavli Institute for Astrophysics and Space Research • NASA Goddard Space Flight Center • Noqsi Aerospace

NIRISS *Near-InfraRed Imager and Slitless Spectrograph, James Webb Space Telescope* **(Cowan)**

Other participating institutions: Cornell University • COM DEV • National Research Council Canada • Saint Mary's University • Space Telescope Science Institute (STScI) • Swiss Federal Institute of Technology Zurich • Université de Montréal • University of Rochester • University of Toronto • York University

POLARBEAR **(Dobbs)**

Other participating institutions: Cardiff University • Imperial College • KEK, High Energy Accelerator Research Organization • Lawrence Berkeley National Lab • Paris Diderot University • University of California, Berkeley • University of California, San Diego • University of Colorado at Boulder

SPT *The South Pole Telescope* **(Dobbs, Holder)**

Other participating institutions: Argonne National Lab • Case-Western Reserve University • Fermilab • University of California, Berkeley • University of Chicago • University of Colorado, Boulder • University of Illinois at Urbana-Champaign

The Simons Array **(Dobbs)**

Other participating institutions: Cardiff University • Dalhousie University High Energy Accelerator Research Organization, KEK • Imperial College London • Japan Aerospace Exploration Agency • Lawrence Berkeley National Laboratory • McGill University • NASA Goddard Space Flight Center • National Institute for Fusion Science • Osaka University • Princeton University • The Graduate University for Advanced Studies • Three-Speed Logic, Inc. • University of California, Berkeley • University of California, San Diego • University of Chicago • University of Colorado at Boulder • University of Melbourne • University of Paris Diderot • University of Tokyo

The Simons Observatory **(Dobbs)**

Other participating institutions: Lawrence Berkeley National Laboratory • Princeton University • University of California, San Diego • University of California, Berkeley • University of Pennsylvania

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