Institut Spatial de McGill

McGill Space Institute

Annual Report 2017-2018

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A Message from the MSI Director

It is a genuine privilege to lead the MSI as it grows to be among the leading space sciences research centres in Canada.

Our world-class researchers are paving the way for innovation and discovery, be it in investigating the origins and history of the Universe since the Big Bang, building novel high-tech instruments for studying the Cosmic Microwave Background, Dark Energy, or the mystery of Fast Radio Bursts, using the world's most powerful telescopes to study black holes and neutron stars, probing Mars in search of evidence for life, or using observations of extrasolar planets to constrain Earth climate change models – and vice versa. MSI is at the forefront, thanks to its gifted faculty, post-postdoctoral scholars and students who make up our lifeblood, along with the dozens of distinguished visitors our stimulating yet friendly atmosphere attracts each year

Our commitment to outreach and communicating our science to the public is also laudable, but ultimately rendered easy by people's never-ending fascination with the cosmos – a sure hook to attract young people to scientific pursuits.

Lastly, but certainly not least, I express my tremendous gratitude on behalf of all MSI members to the **Trottier Family Foundation** for making MSI what it is today. Through their generous support, we at MSI have the opportunity to shine on the Canadian and global stage, to reach our research potential, train the next generation of researchers, and share our passion and accomplishments with the public.

A Message from the MSI Associate Director

As I look through this year's annual report, what strikes me is the "value-added" of MSI. In research, this comes from creating opportunities for faculty, postdocs and students to interact with one another and share their skills and discoveries. We see this in the bi-weekly MSI lunch seminars, which covers topics from all the different research areas within the scope of MSI, more focused events such as the Planet lunch that brings together researchers from across member departments, or simply in the daily discussions at tea in 3550 University. Other examples are our programs that bring international researchers to MSI, whether that is by offering support towards conferences and workshops, or to visiting scientists such as sabbatical visitors.

Outside research, an important outcome of MSI is the opportunities for professional development we offer to our postdocs and students. Examples are the many outreach activities they can become involved in, as well as internal programs such as the Educational, Public Outreach, and Diversity discussion group we run each week, usually involving a visiting seminar speaker, or the summer lunch discussions as part of MSI's summer undergraduate research program.

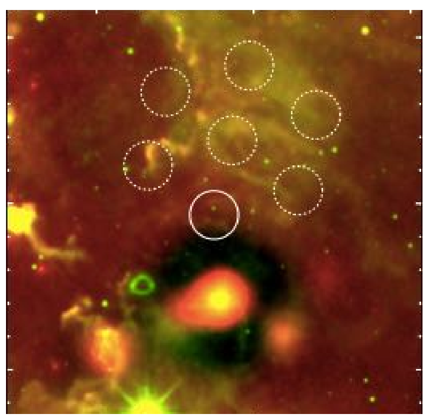
Many of these activities are organized and developed by our Institute coordinator. This year we said goodbye to our coordinator Kelly Lepo as she moves on to a position in the Department of Physics working on undergraduate curriculum development. We thank Kelly for all the important work she did during the first two years of MSI. We were delighted to welcome our new coordinator Carolina Cruz-Vinaccia who started in April.

About the McGill Space Institute

Mission

The McGill Space Institute advances the frontiers of space-related science by fostering world-class research, training, and community engagement.

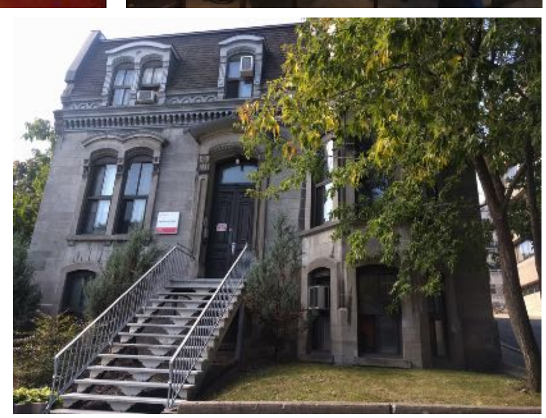
Vision



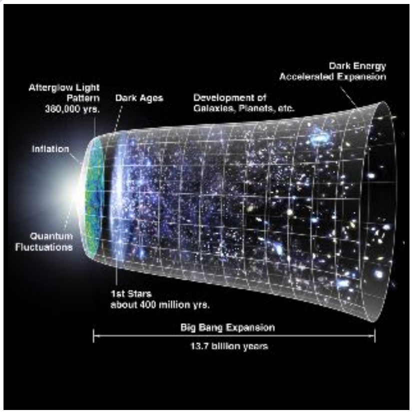
By 2022, MSI will be a world-renowned leader in space science research. This position will be built around the following:

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

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



Research Areas



Early Universe and Theoretical Cosmology

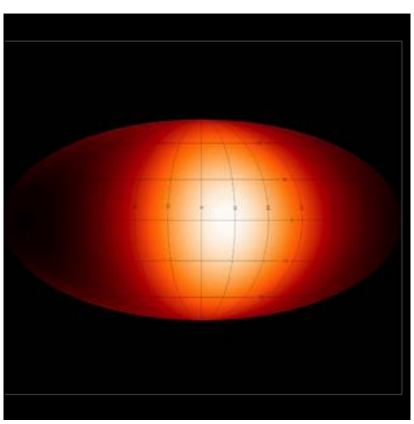
Robert Brandenberger, Jim Cline

The theoretical cosmology group works to explain the history of the very early universe and to provide an explanation of the large scale structure in the Universe. They create models using input from new fundamental physics such as superstring theory, dark matter particle theories, and particle physics beyond the standard model. They also explore ways to test these new models with cutting-edge observations of the cosmic microwave background, large-scale structure, the neutral hydrogen 21-cm line, cosmic rays, and data from the Large Hadron Collider.

Galaxy Evolution and Active Galactic Nuclei

Daryl Haggard, Tracy Webb

The galaxy evolution group is interested in understanding when galaxies form the bulk of their stellar mass and what drives and later shuts down this process; how the local environment of galaxies affect their evolution and growth; and how growing supermassive black holes (AGN) interact with galaxy clusters, their host galaxies and how our own Supermassive black hole, Sgr A* interacts with the Milky Way galaxy.



Climates and Atmospheres of Exoplanets

Nick Cowan, Andrew Cumming, Yi Huang, Tim Merlis

The extrasolar planet climate and atmosphere group works to characterize exoplanets using both observational evidence and climate modelling. Observational evidence for exoplanetary atmospheres comes from a variety of sources, including changes in brightness of the planet over time, spectroscopy, and upcoming next-generation direct-imaging experiments. Members also use computer models to expose the physical mechanisms of planet atmospheres by expanding climate models beyond the conditions found on Earth, to simulate the wide range of possibilities of atmospheres on exoplanets. Much of this work is carried out with the Institute for Research on Exoplanets.

Experimental and Observational Cosmology

Cynthia Chiang, Matt Dobbs, Adrian Liu, Jonathan Sievers

The McGill Experimental Cosmology group designs and builds new instrumentation for observational cosmology and develops analysis techniques for upcoming large cosmological surveys, including surveys of the cosmic microwave background and the 21 cm line of neutral hydrogen. They deploy and operate instruments wherever observing conditions are best — from the geographic South Pole to the top of the Stratosphere to the South African desert, as well as analyze and interpret the data from these experiments to gain a better understanding of the origin, fate, and fundamental constituents of the Universe.

Gamma Ray Astrophysics

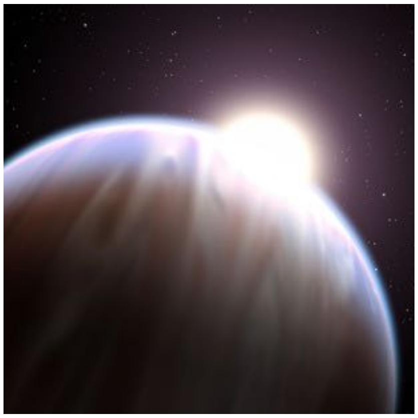
David Hanna, Ken Ragan

The Gamma Ray Astrophysics group is part of the VERITAS collaboration, which operates an array of four 12m imaging atmospheric Cherenkov telescopes in southern Arizona. With this instrument they carry out a program of very-high-energy (VHE) gamma-ray astronomy, observing photons with energy in the range from 50 GeV to 50 TeV. Sources of such photons are among the most violent and exotic in the Universe and include supernova remnants and pulsar wind nebula in our galaxy, as well as blazar-class active galactic nuclei (AGNs) at cosmological distances. The group also develops instrumentation for the VERITAS detector including calibration and characterization devices.

Formation and Evolution of Exoplanets

Andrew Cumming, Nicolas Cowan

The large number and diversity of known exoplanets provides an opportunity to learn about how planets form and evolve, and the physical processes that operate in their atmospheres and interiors. The challenge is to draw connections between the observed properties of exoplanets or Solar System planets and theories of their formation, structure, and evolution. At McGill, we are working on several different aspects of the evolution of gas giant planets, including the role of magnetic fields in hot jupiters, and models of gas giant formation with application to directly imaged planets.



Compact Objects

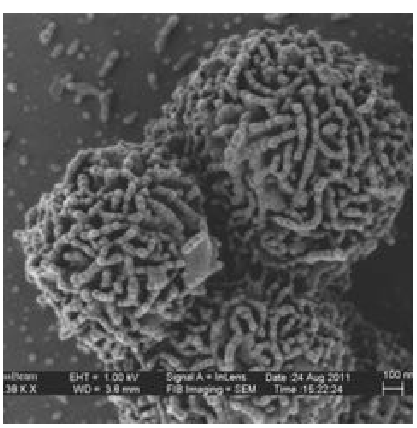
Andrew Cumming, Daryl Haggard, Vicky Kaspi

The observational pulsar and black hole groups are involved in several projects including: searches for radio pulsars, using pulsar timing arrays to detect gravitational waves (GW), detection of electromagnetic counterparts to GW sources, X-ray observations of magnetars and accreting black holes, and development of pulsar instrumentation and algorithms for the CHIME telescope. The theory group studies the structure of neutron stars and how to use observations to constrain the physical processes operating in their interiors. They investigate the origin and evolution of neutron star's spin and magnetism, their interior structure, and the properties of neutron stars in close binary systems.

Radio Transients

Matt Dobbs, Vicky Kaspi

The radio transients group studies short-duration flashes of radio waves from new and unexpected astrophysical phenomena. Their most active area of research is in Fast Radio Bursts (FRBs), mysterious, powerful, millisecond-long flashes of radio waves that originate outside of the Milky Way galaxy. To study these phenomena, the group uses several world-class radio observatories, including the Arecibo Observatory, the Green Bank Telescope, and the newly-built CHIME telescope, which is expected to be the most powerful FRB detector in the world once fully functional.



Astrobiology and Extraterrestrial Biosignatures

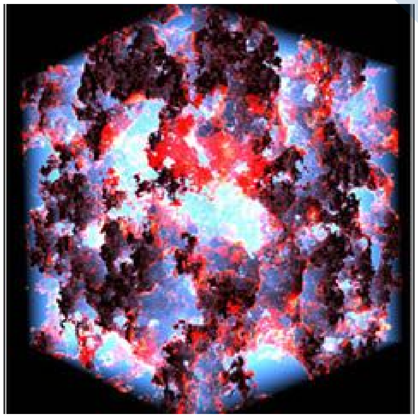
Lyle Whyte

Members of the Astrobiology and Extraterrestrial Biosignatures group focus on examining microbial biodiversity and ecology in the Canadian high Arctic and the Antarctic dry valleys where very unique habitats exist, using both classical microbiology and novel genomics-based molecular techniques for studying microbial communities. 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, for example), is important to understanding what future missions could look for in near surface water ice on Mars in the north polar regions or other cold, rocky places in the solar system.

Low-Frequency Cosmology

Cynthia Chiang, Adrian Liu, Jonathan Sievers

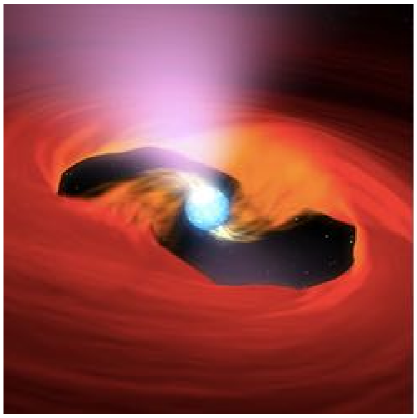
The low-frequency radio sky represents a new frontier in observational astrophysics and cosmology. This regime is a largely unobserved band of the electromagnetic spectrum, and thus holds the promise of revealing new astrophysical phenomenology. Moreover, our 21cm cosmology telescopes (PRIZM and HERA) targeting this band have the potential to provide the first observations of a poorly understood portion of the cosmic timeline, namely Cosmic Dawn (when the first stars and galaxies lit up our Universe) and the Epoch of Reionization (when these first luminous objects dramatically transformed our Universe by ionizing almost all the hydrogen in the intergalactic medium).

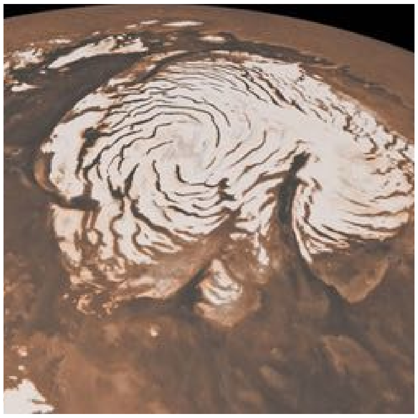


Nuclear Astrophysics

Andrew Cumming

Nuclear astrophysics, at the intersection of astrophysics and nuclear physics, is the study of the origin of the chemical elements in stars and supernovae, explosive events such as supernovae, classical novae, and X-ray bursts, and the properties of matter at high densities as found in the interiors of neutron stars. This field is rapidly developing. Only in the last couple of years have combined gravitational wave and electromagnetic observations shown that neutron star mergers are indeed a site for the r-process. New experimental capabilities such as the radioactive isotope accelerator FRIB will be coming online soon that will allow experimental measurements of heavy unstable nuclei for the first time. Nuclear astrophysics research at McGill is focused on developing connections between nuclear properties and astrophysical observations through the study of neutron stars. McGill is an Associate Member of the Joint Institute for Nuclear Astrophysics - Centre for Evolution of the Elements (JINA/CEE).





Planetary Surfaces

Natalya Gomez

Members of the planetary surface group, led by Natalya Gomez, research models of 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.

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.

MSI Postdoctoral Fellows 2017-2018

Erik Chan

EPS · Supervisor Natalya Gomez

Dr. Chan's research topics include planetary structure, tidal deformation, mass loads, and rotational dynamics.

Vanessa Graber

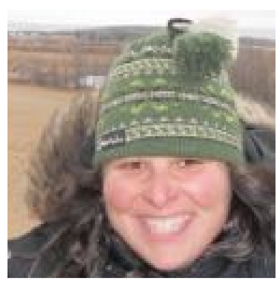
Physics · Supervisors Andrew Cumming & Vicky Kaspi

Dr. Graber's research focuses on the interface between astrophysics and condensed matter physics, as she studies the influence of superfluid and superconducting components on neutron stars.

John Ruan

Physics · Supervisor Daryl Haggard

Dr. Ruan's research focuses primarily on supermassive black hole growth, and its effects on galaxy evolution over cosmic time.



Isabelle Raymond-Bouchard

NRS · Supervisor Lyle Whyte

Dr. Raymond-Bouchard's research interests include astrobiology, the development of novel methods for life detection, and the study of microbes and their adaptations to extreme environments.

New MSI Postdoctoral Fellows 2018-2019

Yuwei Wang

Physics · Supervisor: Yi Huang

Dr. Wang's research interests include radiative, convective and dynamical adjustments, climate dynamics of Earth and exoplanets, and radiative transfer.

Heath Shipley

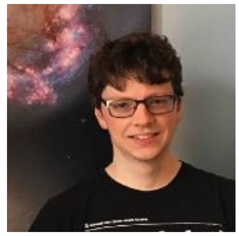
Physics · Supervisor: Tracy Webb

Dr. Shipley's research interests include extragalactic astronomy, particularly galaxy evolution with focus on active galaxies, active galactic nuclei, galaxy and supermassive black hole coevolution utilizing the entire electromagnetic spectrum.

MSI Graduate Fellows 2017-2018

Taylor Bell

Physics · Supervisor: Nicolas Cowan
Taylor's research focuses on the characterization of exoplanet atmospheres, especially highly-irradiated exoplanets



Élie Bouffard

Physics · Supervisors: Daryl Haggard & Nicolas Cowan
Elie is a part of the Compact Objects, Galaxy Evolution, and Active Galactic Nuclei research groups.

Jeremie Choquette

Physics · Supervisor: Jim Cline
Jeremie's research focuses on self-interacting dark matter models, both on the particle physics scale and astrophysics scale.

Bryce Cyr

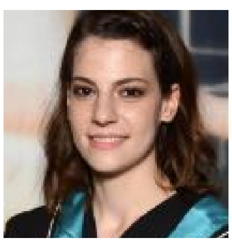
Physics · Supervisor: Robert Brandenberger
Bryce's research focuses on bridging the gap between upcoming data releases of cosmology telescope collaborations and explanations coming from topological defects in the early universe.

Erin Gibbons

EPS · Supervisors: Nicolas Cowan & Richard Leveille
Erin's research focuses on tracing the physical and chemical evolution of water in the Solar System through the analysis of sedimentary rocks.

Marie-Pier Labonté

AOS · Supervisor: Timothy Merlis
Marie-Pier's research interests include atmospheric hydrological cycle and Earth-like exoplanets' climate.



Catherine Maggiori

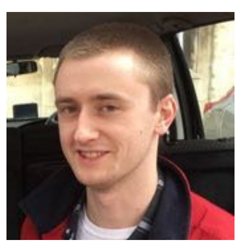
NRS · Supervisor: Lyle Whyte
Catherine's research interests include astrobiology and the search for extraterrestrial life.

Matthew Muscat

Physics · Supervisor: Robert Brandenberger
Matthew is a part of the theoretical cosmology group.

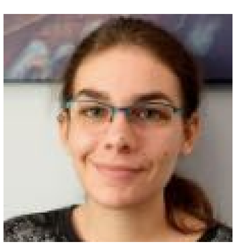
Gavin Noble

Physics · Supervisor: Matt Dobbs
Gavin's research focuses on the development of microwave detector and readout technology in the McGill Cosmology Instrumentation Lab, but is also interested in the future of Canadian radio astronomy.



David Purnell

EPS · Supervisor: Natalya Gomez
David's research focuses on observations of sea level and ice sheet interactions in Greenland using remote sensing techniques.



Ariane Trudeau

Physics, Universite de Montreal · Supervisors: Tracy Webb & Julie Hlavacek-Larrondo
Ariane's research focuses on deep radio observations of a high redshift galaxy cluster.

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MSI is very grateful for the generous support of MSI Fellows from the Trottier Family Foundation.

Research Highlight

GNSS Reflections: the future of observational sea level and ice sheet research?

Prof. Natalya Gomez *is an Assistant Professor of Earth and Planetary Sciences in the McGill Space Institute. Her research centres around the interactions between ice sheets, sea level and the solid Earth, and the response of these systems to past, present and future climate changes.* **David Purnell** *is an MSI fellow and a Ph.D. student in Prof. Gomez's group. His research focuses on observations of sea level and ice sheet interactions in Greenland using remote sensing techniques.*

Why this is important

GNSS-R is a promising new technique for measuring changes in sea level near ice sheets. Said measurements could be used to inform our understanding of how the ice sheets respond to changes in climate on Earth. The remote sensing techniques (and associated algorithms) developed in this project would help guide future endeavors to other ice-bearing planetary bodies.

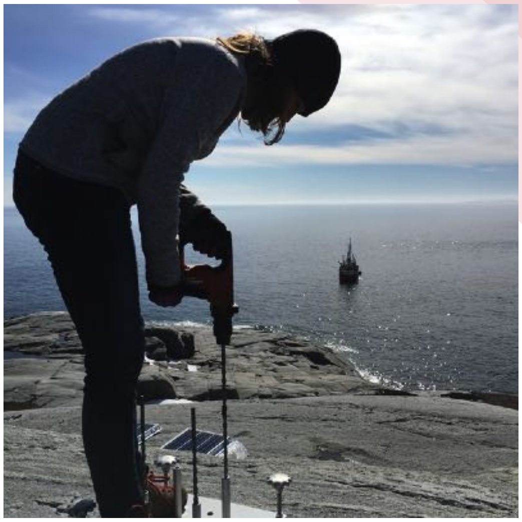
In June 2018, MSI Professor Natalya Gomez and MSI fellow David Purnell travelled to the west coast of Greenland, joining a team from New York University Abu Dhabi's Center for Global Sea Level Change to install instruments near Jakobshavn Glacier, one of the largest and most rapidly changing outlet glaciers of the Greenland ice sheet. Global Navigation Satellite System antennas (GNSS, a general term for satellite networks such as the familiar GPS) will be used to monitor local sea level using a new technique called GNSS Reflectometry (GNSS-R), along with various other instruments to monitor properties of the atmosphere and ocean to isolate changes in sea level due to ice mass changes at Jakobshavn.

When an ice sheet melts, the meltwater is redistributed around the oceans causing, on average, a rise in global sea levels. However, the oceans do not fill up evenly like in a bathtub; instead, sea level actually falls near the ice sheet and rises at a greater distance from the ice sheet. This pattern is caused by the solid earth rebounding elastically (popping up) in response to the reduced weight of the ice sheet and a weaker gravitational attraction of the ocean towards the ice sheet. The combination of these effects causes a local fall in sea level that is much larger in magnitude than the rise that occurs farther away. Therefore, sea level measurements near an ice sheet could theoretically be used to improve estimates of ice mass changes, a key challenge in observational ice sheet and sea level research.

A GNSS antenna in a Fjord near Jakobshavn glacier in Greenland, installed by Natalya Gomez, David Purnell and collaborators at NYU as part of field work in June.

Traditionally, sea level has been monitored using instruments called tide gauges, which are difficult and expensive to maintain in harsh polar climates. There are currently very few tide gauges in polar regions, which has limited the possibility of using sea level measurements to estimate ice mass changes. By contrast, multiple networks of GNSS instruments currently exist in polar regions. It has recently been proposed that a GNSS antenna installed on the coast could be used as an alternative to traditional tide gauges. GNSS-R sea level measurements are obtained by analyzing the interference between microwaves emitted from satellites that reach an antenna directly and indirectly after reflecting off the sea surface.

The purpose of the fieldwork was both to test the capability of GNSS instruments to monitor sea level and to test the hypothesis that sea level measurements near an ice sheet could be used to improve estimates of ice mass changes. If the project is a success then these stations may be the first members of a larger network of GNSS-R stations in similar polar regions. The remote sensing techniques (and associated algorithms) developed in this project would help guide future endeavors to other ice-bearing planetary bodies.



From top right: Natalya Gomez drilling the foundations for a GNSS antenna at a site in Disko Bay; David Purnell and Professor David Holland (NYU) preparing an ocean mooring; David Purnell and Natalya Gomez in Disko Bay, Greenland, with a large iceberg originating from Jakobshavn glacier that can be seen behind.

Research Highlight

A 'hot Jupiter' with unusual winds

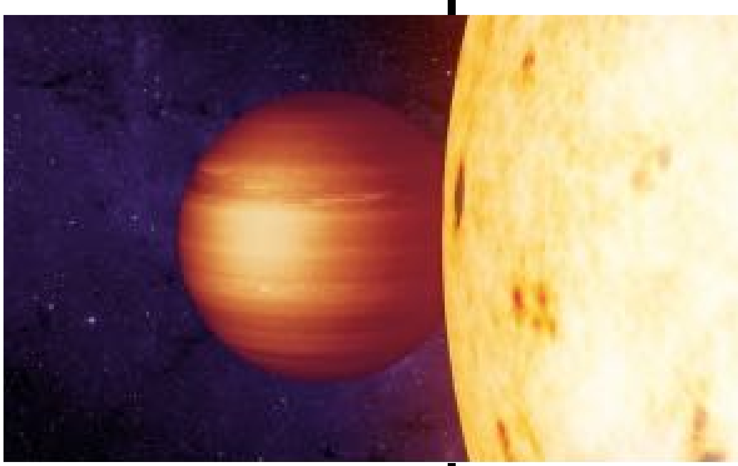
Lisa Dang *is a Ph.D. student in Prof. Nicolas Cowan's research group. Her research is focused on the characterization of Hot Jupiter's atmospheres*

Why this is important

The westward hotspot offset on a hot Jupiter is the first of its kind. All plausible explanations call into question our current understanding of exoplanet science. CoRoT-2b presents an ideal opportunity to improve our understanding through further observation and modelling.

Dang, L., Cowan, N.B., Shwartz, J.C., et al (2018) Detection of a westward hotspot offset in the atmosphere of hot gas giant CoRoT-2b, Nature Astronomy, 2(3), 220.

Below: Artist's rendition of gaseous exoplanet CoRoT-2b with a westward hot spot in orbit around its host star. Credit: NASA/JPL-Caltech/T. Pyle (IPAC)



* Funding for this project was provided in part by the Natural Sciences and Engineering Research Council of Canada and the California Institute of Technology's Infrared Processing and Analysis Center.

The hottest point on a gaseous planet near a distant star isn't where astrophysicists expected it to be – a discovery that challenges scientists' understanding of the many planets of this type found in solar systems outside our own.

Unlike our familiar planet Jupiter, so-called hot Jupiters circle astonishingly close to their host star, so close that it typically takes under three days to complete an orbit. And one hemisphere of these planets always faces its host star, while the other faces permanently out into the dark.

Not surprisingly, the "day" side of the planets gets vastly hotter than the night side, and the hottest point tends to be the spot closest to the star. Astrophysicists theorized and observed that these planets also experience strong winds blowing eastward near their equators, which can sometimes displace the hot spot toward the east. All hot Jupiters observed so far have had winds blowing to the east, as theory would predict, until now.

In the mysterious case of exoplanet CoRoT-2b, however, the hot spot turns out to lie in the opposite direction: west of center. Research led by MSI student Lisa Dang made the discovery using NASA's Spitzer Space Telescope. CoRoT-2b, discovered a decade ago by a French-led space observatory mission, is 930 light years from Earth. With an inflated radius and a remarkably featureless spectrum, this target is not a typical hot Jupiter. Now, a westward offset can be added to the list of unusual characteristics, and this may not be coincidental.

The researchers offer three possible explanations for the unexpected discovery, each of which raises new questions:

- The planet could be spinning so slowly that one rotation takes longer than a full orbit of its star; this could create winds blowing west rather than east, but it would also undercut theories about planet-star gravitational inter-action in such tight orbits.
- The planet's atmosphere could be interacting with the planet's magnetic field to modify its wind pattern; this could provide a rare opportunity to study an exoplanet's magnetic field.
- Large clouds covering the eastern side of the planet could make it appear darker than it would otherwise – but this would undercut current models of atmospheric circulation on such planets.

"We'll need better data to shed light on the questions raised by our finding," Dang says. "Fortunately, the James Webb Space Telescope, scheduled to launch next year, should be capable of tackling this problem. Armed with a mirror that has 100 times the collecting power of Spitzer's, it should provide us with exquisite data like never before."

First detection of Fast Radio Bursts by CHIME/FRB

This past July saw a major milestone in the history of the CHIME telescope: its first detection of Fast Radio Bursts (FRBs) as part of the CHIME/FRB project.

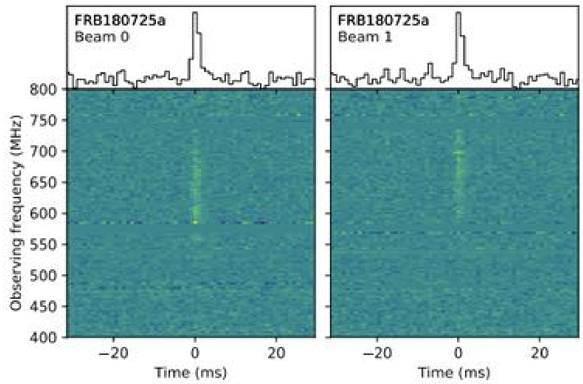
The Canadian Hydrogen Intensity Mapping Experiment (CHIME) is a revolutionary ``software'' radio telescope recently built near Penticton, BC, on the grounds of the National Research Council's Dominion Radio Astrophysical Observatory, by a team led by McGill, U. Toronto and UBC researchers. CHIME is a Canada Foundation for Innovation-funded initiative to map the cosmos, originally to study the accelerating expansion of the Universe and Dark Energy. CHIME's great sensitivity and very wide field of view – thanks to its unusual cylindrical reflectors coupled to the world's most powerful correlator – also make it the world's most powerful FRB detector.

The **CHIME/FRB Collaboration** *is led by McGill and involves nearly two dozen MSI undergraduates, graduate students, postdocs and staff, led by* **MSI Professors Vicky Kaspi** *and* **Matt Dobbs.**

Why this is important

Going forward CHIME/FRB is poised to detect hundreds of Fast Radio Bursts, far more than any experiment. This will lead to great progress on this new astrophysical mystery.

MSI faculty, staff, postdocs and students played a leading role in the design, implementation and commissioning of the CHIME/FRB instrument and software pipeline, and saw the first fruits of their labours in Summer 2018 with the detection of FRB 180725A. This event demonstrated for the first time that the FRB phenomenon is observable to frequencies down to 400 MHz, far lower than had been seen prior.



The team continues to commission the CHIME/FRB system and hopes to have it fully operational by the end of the 2018 calendar year. Simulta-neously, the CHIME/FRB team is poised to make major progress on the FRB puzzle this coming year as it pours through the wealth of data offered by this extraordinary telescope.

Boyle, P. C., & CHIME/FRB Collaboration. (2018). First detection of fast radio bursts between 400 and 800 MHz by CHIME/FRB. The Astronomer's Telegram, 11901.

Right, from top: Dynamic spectrum plot of first detection of a fast radio burst between 400 and 800 MHz by CHIME/FRB; CHIME at night - the telescope consists of 4 parabolic cylinders 20 m wide and 100 m long, with a focal length of 5 m. It has no moving parts, relying instead on the Earth's rotation to move the across its field of view.

Research Highlight

Superstring Theory & the Resolution of the Big Bang Singularity

Prof. Robert Brandenberger *is a Canada Research Chair (Tier 1) and Professor of Physics in the McGill Physics Department and the MSI.* **Guilherme Franzmann is a** *PhD student in Prof. Brandenberger's group and a key member of the team which is developing an understanding of how superstring theory leads to an understanding of what replaces the "Big Bang".*

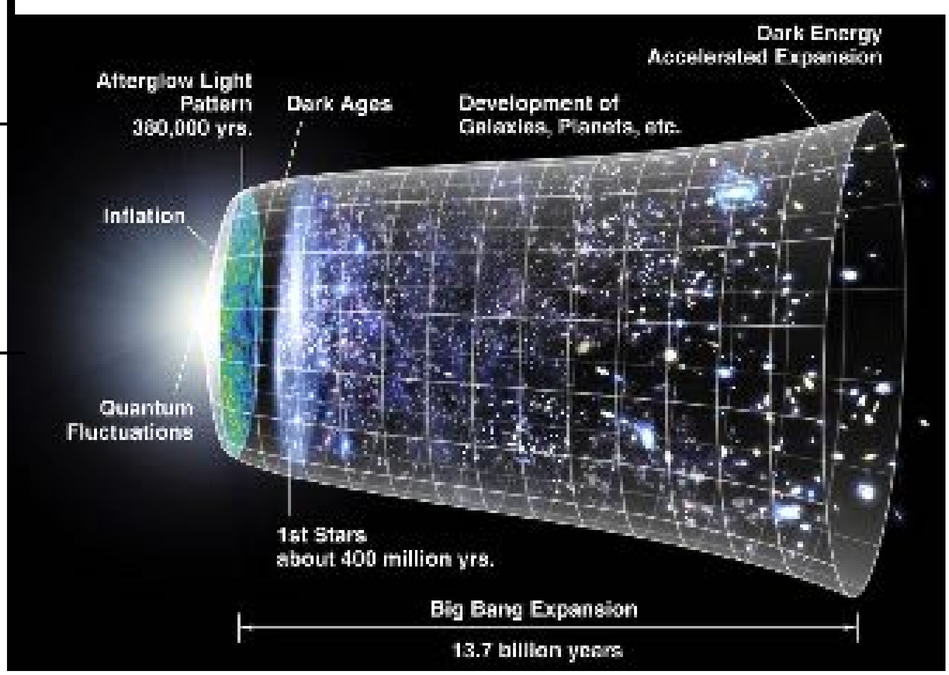
Why this is important

Close to the Big Bang', the usual physical laws based on Einstein's theory of General Relativity break down. Superstring theory holds the promise to be able to replace the Big Bang by an understanding of the earliest moments of the universe which makes physical sense. ``String Gas Cosmology'' is a scenario (based on string theory) which promises to provide a new picture of the early universe.

The origin and early evolution of the universe remains a mystery. According to the Standard Big Bang scenario, there was a beginning of time at which the temperature of matter was infinite. For a physicist, the presence of such a ``singularity'' indicates the breakdown of the theory which yields such a conclusion. The inflationary universe scenario, the current paradigm of how the early universe evolved, does not resolve this singularity problem. New physics is required if we are to obtain a better picture of how the universe evolved at very high temperatures.

Prof. Brandenberger's group is using tools from superstring theory to attempt to obtain an improved understanding of how space-time evolved at very high densities. Superstring theory is a very ambitious attempt to unify all forces of nature at the quantum level. According to superstring theory, the basic indivisible objects of nature are strings rather than point particles. Strings have many more degrees of freedom than point particles: like violin strings, fundamental strings have oscillatory modes, and they can wind space.

Brandenberger, R., Costa, R., **Franzmann, G.**, & Weltman, A. (2018). Dual Space-Time and Nonsingular String Cosmology. arXiv preprint arXiv:1805.06321.



Right: Artist's depiction of the expanding universe according to standard and inflationary cosmology. The horizontal axis is time.The universe is assumed to begin with a "Big Bang" after which the structures which we currently observe with telescopes such as the WMAP satellite (depicted on the right side) form. (Credit: NASA/WMAP Science Team)

A gas of strings has interesting properties: in contrast to a gas of point particles, there is a maximal allowed temperature. If we take a box of strings and shrink its radius, the temperature of the gas of strings will increase then eventually decrease. This conclusion arises from a new symmetry of string theory, the ``T-duality symmetry''. "String Gas Cosmology'' a cosmological scenario based on these fundamental principles of superstring theory, was proposed by Brandenberger and his Harvard colleague Prof. Cumrun Vafa a number of years ago. This scenario can provide an alternative to the inflationary paradigm for explaining the observed large-scale structure of the universe.

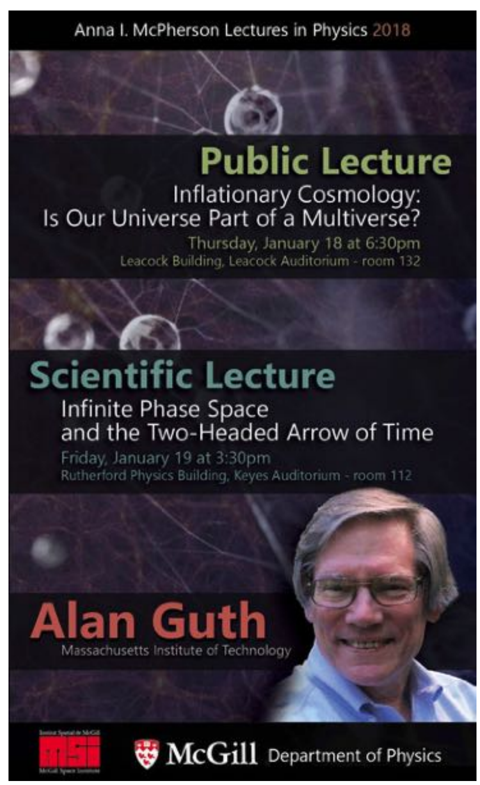
Supported in part by a ``twinning'' grant which he has obtained in order to collaborate with South African Research Chair Professor Amanda Weltman from the University of Capetown, Prof. Brandenberger, his PhD student Guilherme Franzmann, postdoctoral fellow Dr. Renato Costa and Professor Weltman have been studying the dynamics of String Gas Cosmology using new tools from superstring theory. Making use of the T-duality symmetry of string theory mentioned above, they were able to show that the resulting cosmology has no beginning of time - it resolves the singularity problem which plagues Standard Big Bang cosmology. Key to this conclusion is the realization that lengths have to be measured with measuring sticks made up of strings, and clocks which reflect the basic symmetries of string theory.

The research team has been able to show that the resulting cosmology has a bounce: it starts with a contracting phase, dissolves into an "emergent" phase where the usual description of space has to be changes (the number of measurable spatial coordinates doubles) and the expands again. So far, the conclusions have been reached using rather restrictive approximations, but the research team is working on an improved understanding

Prof. Alan Guth visits the McGill Physics Department

Dr. Alan Guth, the Victor Weisskopf Professor of Physics in the Massachusetts Institute of Technology, visited the McGill physics department in January 2018 to give a public and a scientific Anna I. McPherson lecture about his work on inflationary cosmology. Dr. Guth, is the physicist who first developed the idea of "cosmic inflation" -- the idea that the Universe underwent a period of rapid growth shortly after the Big Bang.

During his visit, he met with students from MSI and the physics department.



Research Highlight

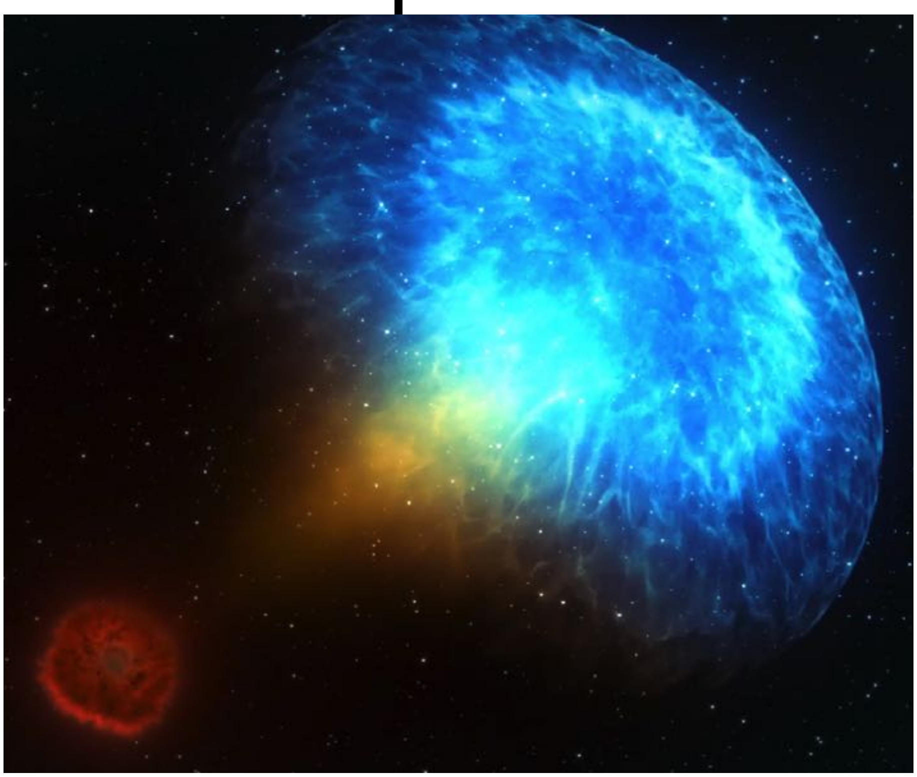
The Life, Death, and Afterlife of GW170817

Prof. Daryl Haggard *is an Assistant Professor of Physics at McGill University in the McGill Space Institute. She studies the Galactic centre and Sgr A*, electromagnetic counterparts to gravitational wave sources, accreting compact objects, supermassive black holes and their host galaxies, and multi-wavelength and time domain surveys. Dr.* **Melania Nynka** *is a MSI and Trottier Chair Postdoctoral Fellow at the MSI. Her primary research interests are in X-ray observations of neutron stars and the Galactic centre.* **Dr. John Ruan** *is a MSI and Trottier Chair Postdoctoral Fellow at the MSI. His research interests span from rapidly-growing supermassive black holes to observations gravitational waves.*

In Fall 2017, McGill Professor Daryl Haggard and MSI/Trottier Postdoctoral Fellows John Ruan and Melania Nynka contributed substantially to the discovery of the neutron star merger GW170817, which resulted in the first groundbreaking joint detection of a gravitational wave source and its electromagnetic counterpart. Together with the whole multi-messenger community, they recently marked the first anniversary of this exciting discovery, which has broad implications for astro-physics, cosmology, and fundamental physics.

GW170817 has garnered many firsts:

- The first gravitational waves detected from a neutron star (NS) binary,
- The first electromagnetic counterpart to a gravitational wave (GW) source,
- The first binary NS coalescence definitively associated with GWs and short gamma-ray bursts (GRBs),
- The first binary NS coalescence associated with a kilonova explosion,
- The first definitive proof that binary NS collisions produce elements heavier than iron, including gold, platinum, and uranium,
- The first collision to provide constraints on neutron star diameters and equations of state,
- The first standard siren measurement of the Hubble constant.



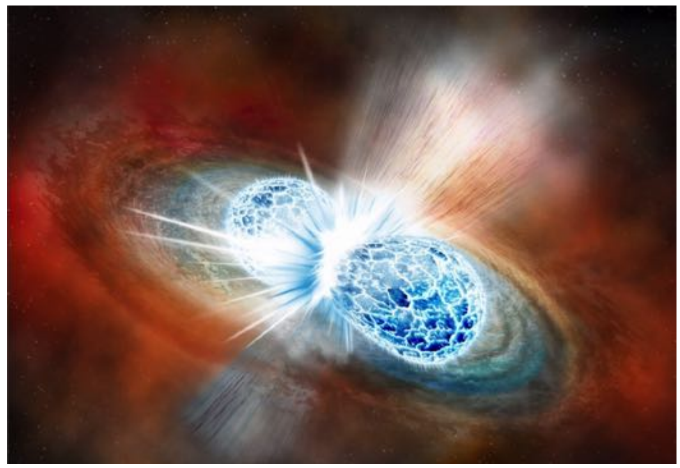
Left: Screenshot from an animation of the GW170817 outflow. (Image Credit: NASA Goddard Space Flight Center / CI Lab)

Many of these discoveries were made in the days and weeks immediately following the discovery, but the team at McGill has continued to study GW170817's energetic outflow at X-ray wavelengths over much longer time scales. GW170817's outflow, which current theories and observations indicate may be a quasi-spherical blast wave or a structured jet, continued to shine in the most recent Chandra X-ray Observatory observations collected in mid-August 2018, 358.6 days after detection of the merger. During summer 2018, McGill undergraduate students Hannah Dykaar and Marion Burnichon also joined the Haggard team to analyze X-ray observations of GW170817 from the XMM-Newton X-ray Observatory, which independently verified previous conclusions.

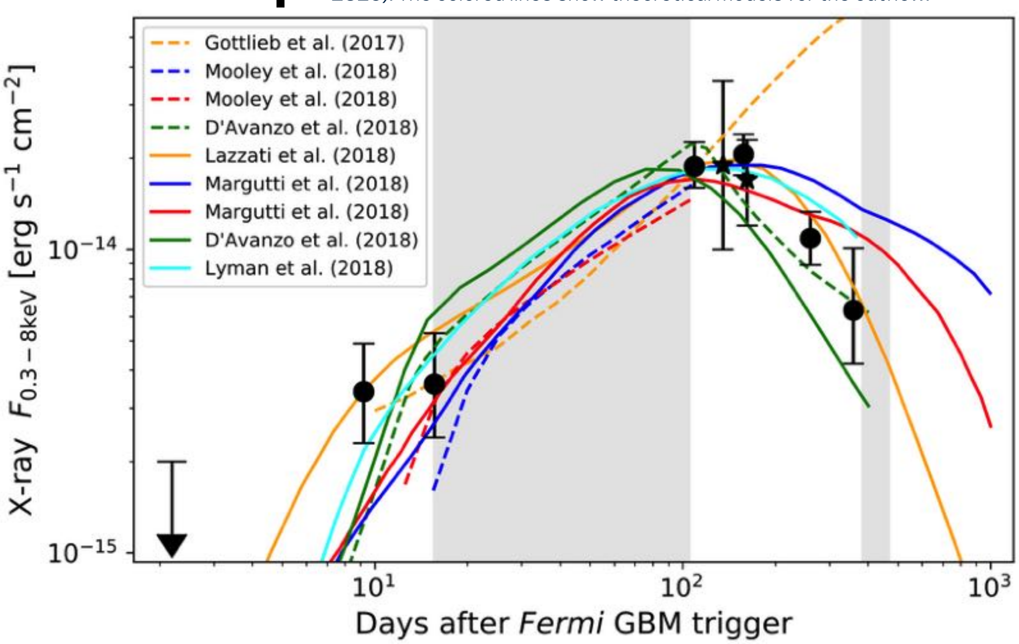
Haggard and her team are gearing up for another exciting season of discovery when LIGO-Virgo come back online in February 2019. Through multiple approved programs on space- and ground-based observatories, they will be chasing new neutron star collisions and hoping to detect the first neutron star-black hole merger. Stay tuned for another exciting year to come!

Why this is important

The discovery of GW170817 offered both the first gravitational waves detected from a neutron star binary and the first electromagnetic counterpart to a GW source. Our ongoing detection of an energetic outflow from this magnificent collision has challenged every model and brings new insight into the physics of neutron stars and short gamma-ray bursts.



Above: Artist's impression of the final moments of the neutron star merger, GW170817. (Image Credit: NASA)
Below: X-ray light curve of GW170817 from Chandra (black circles) and XMM (black stars), updated to include Chandra observations 358.6 days post-merger (Haggard et al. 2017, Ruan et al. 2018, Nynka et al. 2018). The colored lines show theoretical models for the outflow.



Nynka, M., Ruan, J.J., Haggard, D., Evans, P. (2018) Fading of the X-ray Afterglow of Neutron Star Merger GW170817/GRB170817A at 260 days, ApJL, 862, 19

Ruan, J.J., **Nynka, M.**, **Haggard, D.**, Kalogera, V., Evans, P (2018) Brightening X-ray Emission from GW170817/GRB170817A: Further Evidence for an Outflow, ApJL, 853, L4 (Erratum: 2018, ApJL, 859, L16)

Haggard, D., **Nynka, M.**, **Ruan, J.J.**, Kalogera, V., Cenko, B., Evans, P., Kennea, J. (2017) A Deep Chandra X-ray Study of Neutron Star Coalescence GW170817, ApJL, 848, L25

Research Highlight

The Strongest Material in the Universe

Dr. Matthew Caplan *is a Trottier Chair postdoctoral fellow and Canadian Institute for Theoretical Astrophysics National Fellow working with* **Prof. Andrew Cumming**. *His research primarily concerns the structure and properties of the materials in neutron star crusts.*

Why this is important

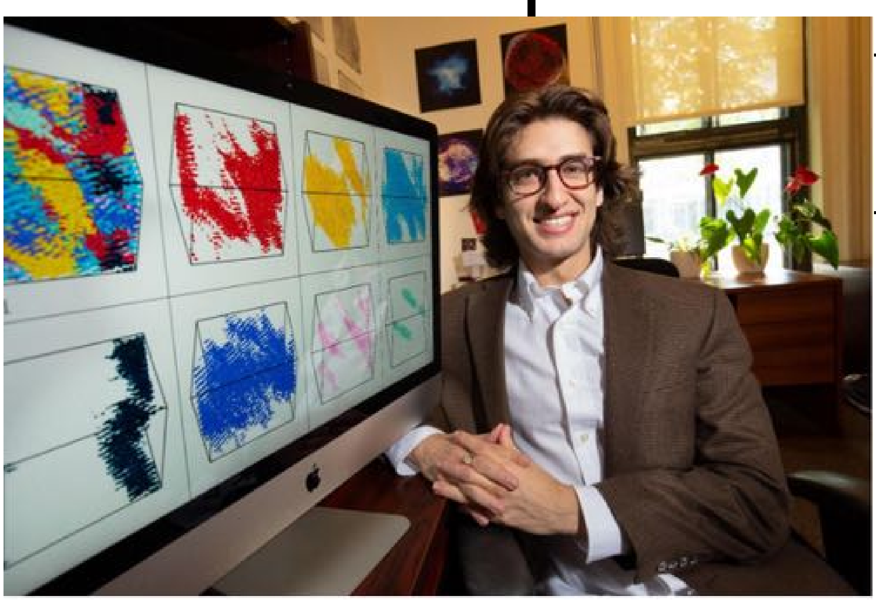
The strength of the neutron star crust is important for a variety of observed phe-nomena. Crust breaking is implicated in pulsar glitches and magnetar outbursts, and limits the size of continuous gravitational wave emission, potentially observable in the near future.

Neutron stars are the densest objects in the universe, and new research by MSI postdoc Matt Caplan now finds that they may contain the strongest material in the universe.

Formed when the core of a massive star implodes in a supernova, a neutron star is like a giant nucleus, with protons and neutrons squeezed so closely together that the mass of the sun fits in a space smaller than the island of Montreal.

But in many ways neutron stars are more like the Earth than a star. Their intense gravity creates enormous pressure which freezes their outer layers solid, giving them a solid crust over a liquid core. Since this crust is the part of the star astronomers can observe, it's essential to understand its properties to probe the interiors of these extreme objects.

On the Earth, the strength of rock can affect the magnitude of earth quakes and the heights of mountains, and neutron stars are no different. The strength of the materials in the neutron star crust may affect similar phe-nomena. Crust breaking on neutron stars may produce electromagnetic radiation and strong materials may support mountains which, if large enough, could radiate gravitational waves.



Caplan, M. E., Schneider, A. S., & Horowitz, C. J. (2018). Elasticity of Nuclear Pasta. Physical Review Letters, 121(13), 132701.

On left: Dr. Caplan in the MSI with his nuclear pasta simulations.

On opposite page: At the top of the figure are conventional nuclei, 'gnocchi', shown at high densities in a neutron star crust where they nearly touch. Under compression, at a slightly greater density, these nuclei fuse to form the range of shapes seen below such as the cylindrical 'spaghetti' and planar 'lasagna', each increasing with density. Toward the bottom, nearest the core, the density grows and the matter is squeezed together so that the pasta phases invert, with tunnels and round voids such as the 'antispaghetti' and 'antignocchi.'

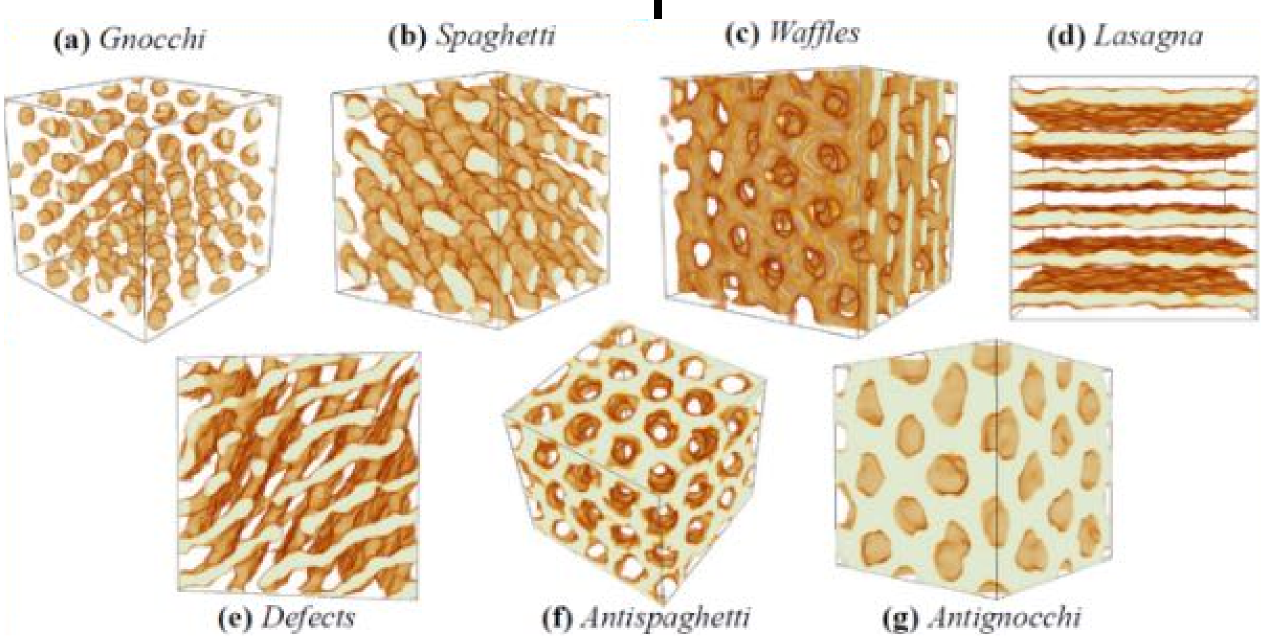
In 2018, Dr. Caplan published a paper in Physical Review Letters which includes the first ever calculations of the strength of the material at the base of the crust. A kilometer below the surface, the pressure is so great that nuclei get squeezed together and protons and neutrons rearrange into cylinders and sheets of nuclear material, named 'nuclear pasta' for its resemblance to spaghetti and lasagna.

Dr. Caplan and his collaborators performed the largest ever simulations of nuclear pasta, containing over three million protons and neutrons, which took nearly 2 million processor hours to run. These simulations stretched and squeezed the pasta to calculate its strength and study how it breaks. Found that nuclear pasta is the strongest material in the universe, which makes it possible for neutron star crusts to have crustal mountains that are tens of centimeters high. While that may not seem like much, the incredible density of the neutron star crust means that these mountains contain far more mass than the Himalayas. If any nearby neutron stars have mountains this large, they could be radiating gravitational waves which LIGO and other gravitational wave observatories may soon detect.

An Exciting Time to Study Neutron Stars

Prof. Andrew Cumming

We are learning more and more about the interiors of these dense stars, thanks to new kinds of observations, particularly those that reveal the response of the star to some kind of transient event. The detection of gravitational waves from merging neutron stars gives a brand new way to study their behaviour as they are ripped apart during the merger. Radio pulsar studies continue to find massive neutron stars that tell us about the maximum pressure nuclear matter can provide. Soon, the Neutron Star Interior Composition Explorer (NICER) experiment on the International Space Station should report accurate measurements of the size of neutron stars. We can now observe cooling of neutron stars for years after heating events which tells us about their heat capacity and whether they contain exotic particles other than neutrons and protons. Ever since their discovery more than 50 years ago, theorists have debated about what is happening inside neutron stars, we are living in an exciting time where these theories are being put to the test.



Research Highlight

The Fluid Case of Ancient Mars

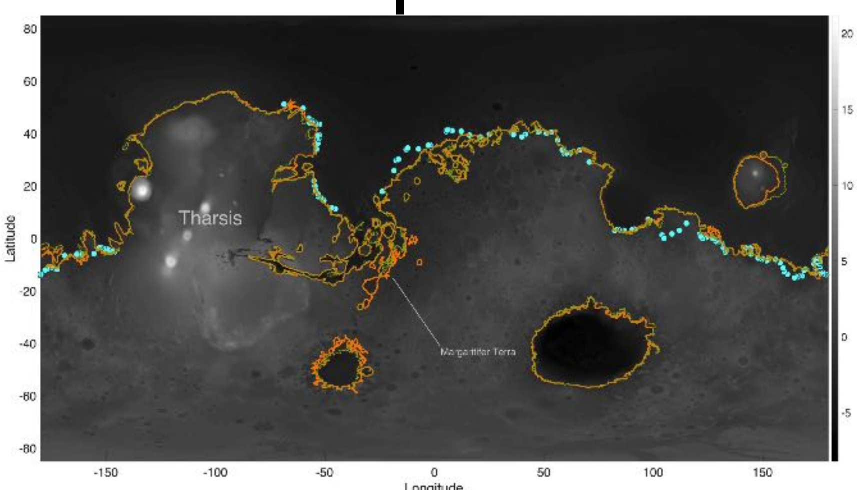
Dr. Erik Chan *is a postdoctoral fellow in* **Prof. Natalya Gomez's group.** *His research includes planetary structure, tidal deformation, mass loads, and rotational dynamics.*

Why this is important

Whether or not liquid water persisted on ancient Mars has important implications on its early climatic condi-tions. Was it ever as habitable as the Earth? If Earth and Mars were similar, what led to the stark differences ob-served today? The apparent conflict between a "cold and icy" and a "warm and wet" Mars is an important piece of the puzzle.

Was there an ancient ocean on Mars? Water exists on Mars today mostly as ice, either below the surface or in the polar ice caps. Billions of years ago, its liquid form also sculpted the Martian surface, producing features such as sediment deposits, valley networks, and even possible shorelines. Some of the possible sea-level markers trace out shorelines that vary greatly in elevation, which historically led to them being dismissed as evidence of an ancient ocean. However, a prior study showed that a wandering rotation pole which causes the equatorial bulge to readjust itself (a process called "true polar wander"), could lead to shoreline features becoming vertically deformed, resulting in the observed elevation differences. Subsequent analysis into deltaic deposits led to a contrasting conclusion: the deltas already lie along an ancient sea level, without any vertical deflection by true polar wander.

MSI postdoc Erik Chan and colleagues, including MSI Prof. Natalya Gomez, used multiple satellite-derived data sources to compile a dataset of valley networks that could have drained directly into an ocean in the northern plains of Mars. This set of valley networks serves as another independent marker of ancient sea level. The results of their analysis, now published in the Journal of Geophysical Research: Planets, favoured the true polar wander scenario. In fact, the true polar wander scenario also better explained the locations of the deltas, despite their not being included in the calculations. While their article was in peer review, however, a newly published study showed another scenario that could have deformed the ancient shorelines: the formation and growth of the massive volcanic province of Tharsis. Chan and colleagues quickly incorporated this new, "Tharsis-growth" scenario into their analysis and found it almost equally consistent with the data, albeit with unaccounted for telltale signs of true polar wander. The geological key to distinguishing between the true polar wander and the Tharsis-growth scenarios lies in a region called Margaritifer Terra. Future investigations into the relative ages of the fluvial features in that region could shed more light into this conundrum.



Topographic map of Mars (the gray scale colors reflect present-day topography in km. The cyan dots represent the valley network termini (VNT) that could have drained into a northern ocean. The orange contours show the reconstructed shoreline of an ancient Martian ocean in the true polar wander scenario. The light green dotted contour shows the shoreline under the Tharsis-growth scenario.

Despite abundant evidence that water once flowed on the Martian surface, most climate models indicated that early Mars wasn't warm enough to continuously sustain liquid water (let alone an ancient ocean). This led to suggestions of "episodic melting" events, which could have been caused by orbital variations, volcanic activities, or meteor impacts and could have lasted thousands to hundreds of thousands of years. To investigate the potential surface manifestation of these episodic events, Chan and Gomez are adapting and running simulations of ice-age sea level on various melting scenarios. The results could highlight which class of geological evidence could validate or constrain the duration and extent of possible episodic melting events.

Development of a microbial life detection system for space missions

The search for life in our solar system is among the highest priorities for space science, yet no modern instrument payload (on a rover/spacecraft) is able to definitively detect signs of life.

Prof. Lyle Whyte's lab is developing an instrument platform that could potentially be added to a rover payload that would be capable of definitive life detection. As life in our solar system is very likely to be microscopic in nature, this instrument would focus on the detection of microorganisms. To that end, the Whyte lab is testing and optimizing pre-existing, automated, and miniaturized robust instruments for life detection in our solar system.

Three different components of the platform are under development:

- An instrument capable of isolating and sequencing nucleic acids (DNA/RNA), based on the ultralight and ultraportable **MinION sequencer**. Nucleic acids are unambiguous signs of life.
- A **Microbial Activity MicroAssay (MAMA)**, which detects and characterizes living microbial communities, based on their metabolic activity.
- The **Cryo-iPlate**, a novel culturing method used to isolate microorganisms from the environment. It allows for culturing of microorganisms in their natural environment and isolation of previously inaccessible microorganisms.

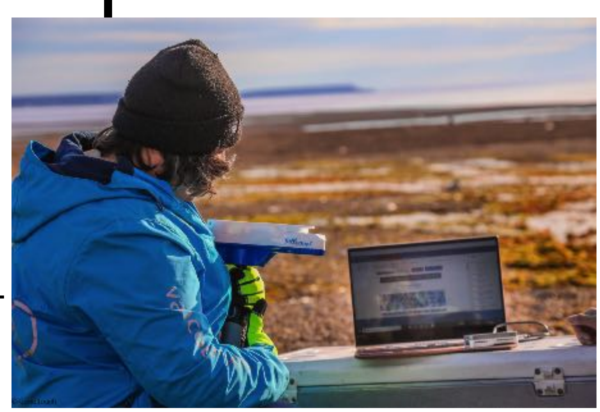
In the past year, the Whyte lab has successfully tested instruments capable of automatically extracting DNA from a variety of Arctic subzero environments similar to Mars, Enceladus, and Europa and sequencing this DNA using the MinION. The data showed diverse microbial communities containing extremophiles (microbes able to survive and thrive in extreme environments) and identified a detection limit of 100 cells/g. With the MAMA, microbial metabolic activity has also been detected with as low as a thousand yeast cells and with 4000 bacterial cells, similar to the number of cells we could find in extreme environments. Hundreds of diverse and unique Arctic bacterial strains have been cultured in situ using the Cryo-iPlate. Select novel strains are being characterized in the laboratory which will inform us on the traits required for life in extreme cryo-environments.

The Whyte lab's work over the past year has increased the robustness, sensitivity and detection limits of the instruments. Eventually, they hope to have a fully developed and optimized platform for microbial life detection system that could be robotized and integrated into future planetary exploration space missions attached to surface rovers.

Prof. Lyle Whyte *is a professor in the department of Natural Resource Sciences and in the McGill Space Institute. His research focuses on characterizing the microbial community and biodiversity of Canadian Arctic environments as analogues for Mars, Enceladus, and Europa.* **Dr. Isabelle Raymond-Bouchard** *is a MSI postdoctoral research fellow.* **Catherine Maggiori** *is a PhD student fellow at MSI.* **Olivia Blenner-Hassett and David Touchette** *are MSc student fellows at MSI. Their research focuses on life detection in astrobiology and characterizing the microbial community of extreme environments.*

Why this is important

As public and private space sector activity increases, with plans for additional landers, sample caches for return to Earth, and even plans for permanent settlements on Mars, it's important that we look for the presence of native microbial life in these environments before irreversible contamination occurs.



From top left:1) A Cryo-iPlate incubating in a pond for the isolation of novel microorganisms, in Resolute, NU; 2) a Microbial Activity MicroAssay showing metabolic activity from a cryoconite sample; 3) Dr. Isabelle Raymond-Bouchard using the MinION sequencer and the Fast Prep DNA extraction device in situ, in the Canadian high Arctic.

Education and Public Outreach

AstroMcGill serves as the education and public outreach (EPO) branch of the astrophysics group within the Physics Department at McGill University and the McGill Space Institute. It was founded in 2011 by an enthusiastic group of graduate students and post-doctoral fellows and its activities continue to be student-led. AstroMcGill has gained visibility in Montreal over the past few years and is often invited to participate in events organized by various organization in Montreal and its surroundings.

Public AstroNight

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 graduate student, post-doctoral fellow, or professor, aimed at a broad audience. After the lecture, student volunteers lead night sky observations with portable telescopes (weather permitting). These talks attract an average of about 250 people, with another 1000 people usually following via the live-stream on the event's Facebook page.

Astronomy on Tap MTL

Astronomy on Tap events feature accessible, engaging presentations on topics in astronomy and space science plus astronomy-themed trivia games and prizes. Events are held in local pubs on the last Tuesday of the month and alternate between English and French nights.

Social Media

AstroMcGill is very active on social media. Its Facebook following grew by 20% last year, and now totals over 4,300 followers. Additionally, AstroMcGill regularly has over 1000 people interested in its events. The AstroMcGill Twitter account (@AstroMcGill) has over 2000 followers. There are also 950 people subscribed to the AstroMcGill mailing list.

Perseide Techno

AstroMcGill was invited to participate in Perseide Techno, an activity organized by the city of Riviere-des-Prairies for the Perseid meteor shower. AstroMcGill volunteers facilitated telescope observation and demos, and shared their knowledge with event participants.

McGill Teacher Inquiry Institute

The McGill Teacher Inquiry Institute is a one-day program that targets primary school teachers from the English-language Lester B. Pearson school board who self-identified as uncomfortable with teaching science in their classrooms. The Inquiry Institute gives teachers a safe space to address anxieties related to teaching science topics, access to student volunteers who act as subject-matter experts, and appropriate hands-on, inquiry-based lesson plans to use in their classrooms. In 2018, AstroMcGill led the preparation of an inquiry-based activity on the phases of the moon that will be demonstrated at the Inquiry Institute later this year.

Eurêka! Festival

AstroMcGill contributed to the 12th edition of the Eurêka! Festival, Quebec's biggest science festival, alongside the Centre de Recherche en Astrophysique (CRAQ). Over the three days of the the festival, AstroMcGill volunteers ran space-themed games centred around the theme "Eyes on the sky", where visitors learned what different kinds of telescope measure, where they are found on the planet, and what goes into selecting their location. Volunteers also ran demos with an infrared camera and a solar telescope.

Explorations Summer Camp

AstroMcGill volunteers organized and ran a workshop for the McGill Explorations Summer Camp. MSI postdocs walked the high-school aged campers through a tutorial on how to estimate calculations using orders of magnitude, showing them how it can be useful both for astronomers and here on Earth.

Opposite page, from top: Student volunteers leading night-sky observations at Public Astronight; MSI PhD student Emilie Parent giving a public lecture at Astronight in March 2018.

From top: Volunteers running solar telescope observations at the a Eureka Festival; Saturn-inspire pancakes for Explorations Summer Camp participants; Trivia time at the Explorations Summer Camp; full house at Public Astronight for Dr. Lyman Page, from Princeton University, who gave a talk on observing the birth of the universe in February 2018.

Public AstroNights

CHIME: First Light For a Revolutionary New Telescope
21-Sep-2017
Dr. Matt Dobbs

Dark Matter Day: A Panel Discussion
27-Oct-2017
Dr. Jonathan Cornell, Dr. Ben Zitzer, Robert Keyes

Where, When, and Will It Ever End: A Muggle's Guide to Our Big Bang
16-Nov-2017
Dr. Oscar Hernandez

The Warped Road of Einstein's General Relativity
14-Dec-2017
Dr. Emmanuel Fonseca

Observing the Birth of the Universe
21-Feb-2018
Dr. Lyman Page

Pulsar Astronomy: 50 Years and Counting
22-Mar-2018
Emilie Parent

Where's E.T.? Searching for Life In Our Solar System
19-Apr-2018
Dr. Isabelle Raymond-Bouchard

Planetary Systems: Laboratories for Our Cosmic Origin
24-May-2018
Dr. Lauren Weiss

Voyage au coeur d'un amas de galaxies
21-Jun-2018
Marie-Lou Gendron-Marsolais

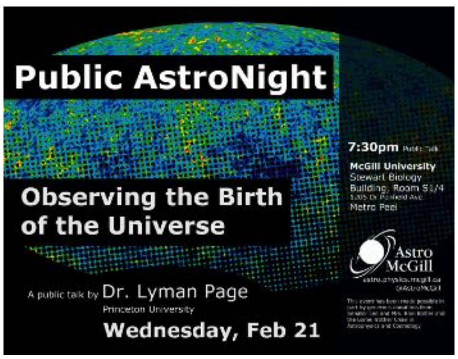
Astronaut Health: Risks and Reality
19-Jul-2018
Ksenia Kolosova

Watching Our Universe Grow Up: Radio Snapshots Through Cosmic Time
23-Aug-2018
Dr. Adrian Liu


Public AstroNight
PULSAR ASTRONOMY
50 Years and Counting
7:00pm Public Talk
McGill University
McIntyre Medical
Building, Room 522
3655 Promenade
Sir William Osler
Metro Peel
Astro McGill
A Public Talk by:
Émilie Parent
Thursday, Mar. 22
This event has been made possible in part by generous donations from Senator Leo and Mrs. Roni Kolber and the Lorne Trottier Chair in Astrophysics and Cosmology
Image credits: Amplitude Studios

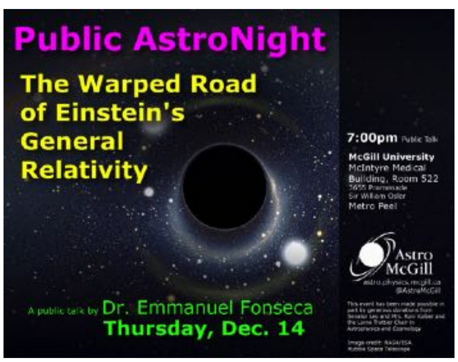

Public AstroNight
Astronaut Health:
Risks and Reality
7:00pm Public Talk
McGill University
Stewart Biology
Building, Room S1/4
Metro Peel
Astro McGill
Ksenia Kolosova
from McGill University
Thursday, July 19

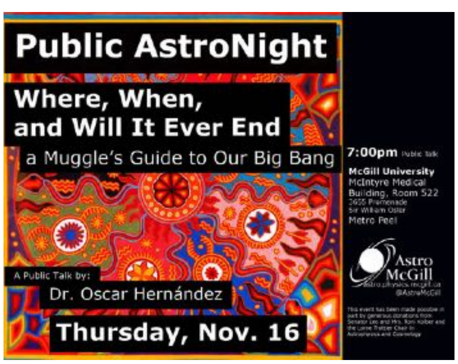

Public AstroNight
Voyage au coeur
d'un amas de galaxies
7:00pm
McGill University
Pavillon McIntyre des sciences médicales,
Salle 522
Métro Peel
Astro McGill
Marie-Lou Gendron-Marsolais
de l'Université de Montréal
Jeudi, 21 juin

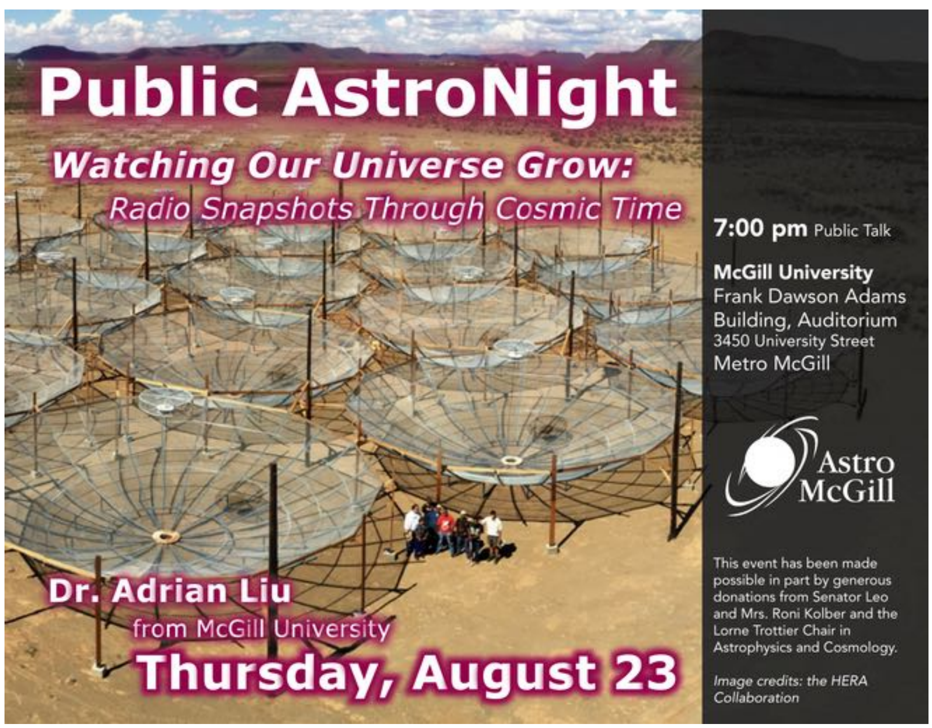

Public AstroNight
7:30pm Public Talk
McGill University
Stewart Biology
Building, Room S1/4
Metro Peel
Observing the Birth
of the Universe
Astro McGill
A public talk by Dr. Lyman Page
Princeton University
Wednesday, Feb 21


Public AstroNight
Where's E.T.?
Searching for life in our Solar System
7:30pm Public Talk
McGill University
McIntyre Medical
Building, Room 522
Metro Peel
Astro McGill
Isabelle Raymond
Thursday, Apr. 19


Public AstroNight
Planetary Systems:
Laboratories for Our Cosmic Origin
7:00pm Public Talk
McGill University
McIntyre Medical
Building, Room 522
Metro Peel
Astro McGill
Dr. Lauren Weiss
from Université de Montréal
Thursday, May 24


Public AstroNight
The Warped Road
of Einstein's
General
Relativity
7:00pm Public Talk
McGill University
McIntyre Medical
Building, Room 522
Metro Peel
Astro McGill
A public talk by Dr. Emmanuel Fonseca
Thursday, Dec. 14


Public AstroNight
Where, When,
and Will It Ever End
a Muggle's Guide to Our Big Bang
7:00pm Public Talk
McGill University
McIntyre Medical
Building, Room 522
Metro Peel
Astro McGill
A Public Talk by:
Dr. Oscar Hernández
Thursday, Nov. 16


Public AstroNight
Watching Our Universe Grow:
Radio Snapshots Through Cosmic Time
7:00 pm Public Talk
McGill University
Frank Dawson Adams
Building, Auditorium
3450 University Street
Metro McGill
Astro McGill
Dr. Adrian Liu
from McGill University
Thursday, August 23
This event has been made possible in part by generous donations from Senator Leo and Mrs. Roni Kolber and the Lorne Trottier Chair in Astrophysics and Cosmology.
Image credits: the HERA Collaboration

Astronomy on Tap

Starting in January 2017, Montreal became a “satellite” location of Astronomy on Tap, joining more than 50 cities around the world organizing these events. The Institute for research on exoplanets (iREx) and the Centre de recherche en astrophysique du Québec (CRAQ) joined AstroMcGill in the organisation of Astronomy on Tap MTL (Astronomie en Fut MTL). They consist of a popular series of free, monthly events that feature short presentations on topics in astronomy, plus astronomy-themed trivia games and prizes. These events alternate between English nights at McLean’s Pub and French nights at Pub l’Île Noire. Montreal is the first satellite location to have bilingual Astronomy on Tap, and has served as a model for other bilingual satellite locations, such as Budapest, Hungary (English + Hungarian) and Heidelberg, Germany (English + German).

Both venues are consistently near capacity (about 100 and 80 people, respectively) drawing praise from both the bar owners, who are happy to learn something while filling their venue on Tuesday nights, and patrons, who enjoy interacting with real astronomers in a casual setting.

Unlike more traditional astronomy outreach, which generally targets children or people who are interested enough in science to attend a lecture on a university campus, Astronomy on Tap reaches a more diverse audience of adults in a location where people already gather to socialize. Astronomy on Tap is also more informal and accessible than traditional hour-long lectures, which helps AstroMcGill reach a wider audience, including people that are new to astronomy and space sciences.

From top: 1) Coasters that are handed out for participants at Astronomy on Tap events; 2) A rapt audience at Astronomie en fut MTL at Pub l’Île Noire; 3) MSI postdoc Emmanuel Fonseca giving an Astronomy on Tap talk to a full house at McLean's Pub.

MSI In The News

Matthew Caplan

The Pasta in Our Stars ✳ The Atlantic ✳ *23 Oct. 2018*

Nuclear pasta' on a neutron star could support mountains centimetres tall ✳ CBC Radio Quirks & Quarks ✳ *28 Sep. 2018*

Nuclear Pasta: Strongest Material In Universe Discovered In Neutron Star Crust ✳ Newsweek ✳ *19 Sep. 2018*

Nicolas Cowan

La neuvième planète existe-t-elle? ✳ Québec Science ✳ *4 June 2018*

Natasha Hall Show, CJAD 800 AM ✳ *April 2018*

Distant 'hot Jupiter' Planet Corot-2b Has Strange Winds That Astronomers Can't Explain ✳ Newsweek ✳ *23 Jan. 2018*

Lisa Dang

Weird Winds Blow the 'Wrong Way' on Scorching Hot Exoplanet ✳ Space.com ✳ *23 Jan. 2018*

Des vents défient nos théories sur l'exoplanète CoRoT-2b ✳ Radio Canada ✳ *23 Jan. 2018*

Matt Dobbs

CHIME begins its cosmic search ✳ Astronomy Magazine✳*22 Mar.2018*

Emmanuel Fonseca

Científicos canadienses estudian las "voces" que llegan del espacio ✳ Radio Canada Internacional ✳ *8 August 2018*

Record-Breaking Signal May Help Solve the Mystery of Fast Radio Bursts ✳ Scientific American ✳ *13 Aug. 2018*

Natalya Gomez

Rising bedrock below West Antarctica could delay catastrophic ice sheet collapse ✳ Science ✳ *21 June 2018*

Rising ground under West Antarctica could prevent ice sheet collapse ✳ Axios ✳ *21 June 2018*

Daryl Haggard

X-ray glow keeps growing after recent neutron star collision ✳ Science News ✳ *24 Jan. 2018*

Coverage NS Merger Keeps Glowing Brighter and Scientists Can't Explain Why ✳ Newsweek ✳ *19 Jan. 2018*

La fusion de deux étoiles à neutrons observée et décortiquée ✳ Le Devoir ✳ *17 Oct. 2017*

When these neutron stars collided, the celestial explosion was a gold mine for astronomers ✳ Globe and Mail ✳ *16 Oct. 2017*

In a First, Gravitational Waves Linked to Neutron Star Crash ✳ National Geographic ✳ *16 Oct. 2017*

First Detection of X-rays from a GW Source: Interview with Daryl Haggard ✳ Chandra Release ✳ 13 *Oct. 2017*

Vicky Kaspi

The Storm Begins: Canadian Telescope Spots Its First Radio Burst ✳ Sky and Telescope ✳ *13 Aug. 2018*

Canadian radio telescope records mysterious low-frequency bursts from outside our galaxy ✳ Global News ✳ *3 Aug. 2018*

Weird Pulsar Is Emitting A Mysterious Unexplained Light And Scientists Aren't Sure Why ✳ Newsweek ✳ *18 Sep. 2018*

Astronomers Trace Radio Burst to Extreme Cosmic Neighborhood, ✳ Quantas Magazine ✳ *10 Jan. 2018*

Listening for the universe to chime in, ✳ The Globe and Mail ✳ *12 Sep. 2017*

De nouvelles oreilles canadiennes à l'écoute de l'Univers ✳ Radio-Canada * *7 Sep. 2017*

Kelly Lepo

Unveiling the mystery behind the "Super Blue Blood Moon" ✳ McGill Tribune ✳ *6 Feb 2018*

Montrealers catch glimpse of rare 'super blue blood moon' ✳ CBC News ✳ *31 Jan. 2018*

Richard Leveille

Décrocher la Lune avant Mars ✳ Le Devoir ✳ *23 Oct. 2017*

Shriharsh Tendulkar

Record-Breaking Signal May Help Solve the Mystery of Fast Radio Bursts ✳ Scientific American ✳ *13 Aug. 2018*

A repeating fast radio burst from an extreme environment ✳ McGill Newsroom ✳ *10 Jan. 2018*

Lyle Whyte

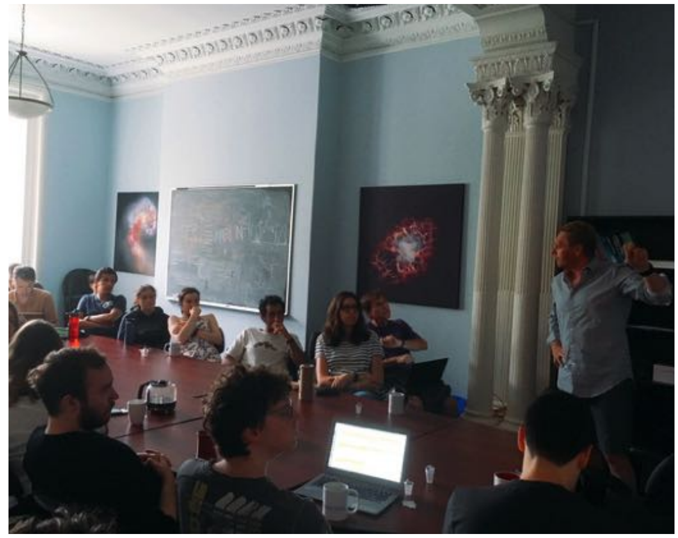
Unique salt lakes discovered under Nunavut glacier a 'jewel' for researchers ✳ The Globe and Mail ✳ *11 April 2018*

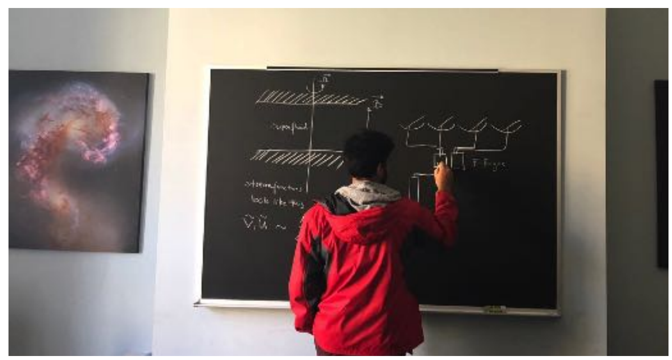
The search for life on Mars begins at McGill's Macdonald Campus ✳ CTV News ✳ *25 Feb. 2018*

How Canadian scientists are turning to the Arctic in the hope of finding life on Mars ✳ CBC News ✳ *25 Jan 2018*

Life at the MSI - Inreach

Fostering cross-fertilization and interdisciplinary interactions and collaborations among Institute members is one of the the main missions of MSI. We strive to provide as many opportunities as we can for students, postdoctoral fellows, faculty members, and visiting scholars to share their research and learn from each other. From seminar series to discussion groups to journal clubs, there's never a dull moment at the MSI!





MSI Seminars

MSI Seminar Series 2017-2018

MSI Faculty Jamboree
McGill University
12 September, 2017
Short presentations from all MSI faculty members about their research

John Ruan
McGill University
17 September, 2017
"Fade to Black: The Origin and Utility of Changing-Look Quasars"

Emily Rauscher
University of Washington
3 October, 2017
"Pushing Down and Out: Characterizing Hot Jupiters in Detail and Expanding Into New Regimes "

Christian Katlein
Alfred Wegener Institute
31 October, 2017
"Autonomous and Robotic Observations of the Arctic Sea Ice and the Associated Ecosystem"

John Moores
York University
7 November, 2017
"Doors Left Ajar in Storms: Insights Into Atmospheric Planetary Science"

Vassiliki Kalogera
Northwestern University
21 November, 2017
"Gravitational-Wave Discoveries Driving the Promise of Multi-Messenger Astronomy"

Matt Caplan
McGill University
9 January, 2018
"Astromaterials in Accreting Neutron Stars"

Yohai Kaspi
Weizmann Institute of Science
23 January, 2018
"Juno's first year at Jupiter"

Maikel Rheinstädter
McMaster University
6 February, 2018
"The Molecular Origins of Life"

Kaya Mori
Columbia University
20 February, 2018
"What Are the Thousands of X-Ray Emitting Point Sources in the Center of the Milky Way?"

Britney Schmidt
Georgia Tech
13 March, 2018
"Robots Under the Ice and One Day, In Space?"

Xi Zhang
UC Santa Cruz
27 March, 2018
"Hazes and Clouds in Cold and Hot Planetary Atmospheres"

Shijie Zhong
University of Colorado, Boulder
10 April, 2018
"Formation of the Lunar Fossil Bulges and Its Implication for the Early Earth and Moon"

Special Seminars

Anais Moller
Australian National University
8 May, 2018
"Update from Australia's SkyMapper, OzDES, and the DES Supernova Cosmology Analysis"

Torsten Bringmann
University of Oslo
26 June, 2018
"Would We Notice if Dark Matter Just Disappeared?"

Mariana Vargas-Magaña
Instituto de Física - UNAM
13 August, 2018
Decrypting the Large Scale Structures of the Universe With Spectroscopic Surveys: BOSS, eBOSS, and DESI"

Workshops

Northeast Cosmology Conference
March 16 - 18, 2018

The workshop sought to establish closer contacts between researchers in theoretical cosmology in the Northeast. The event was organized by MSI Prof. Robert Brandenberger and MSI alumnus Evan McDonough (Brown University).

LIBS in Earth & Planetary Science
November 2 - 3, 2017

A workshop organized by MSI Assoc. Member Richard Leveille, on laser-induced breakdown spectroscopy (LIBS) and its applications to geoscience. It attracted over 40 participants.

A WEEK AT MSI

Monday

12 pm : MSI Lunch Talk (every other Monday)
3:00 pm: Tea & Cookies

Tuesday

2:00 pm : Education, Public Outreach, and Diversity discussion group
3:00 pm: Tea & Cookies
3:30 pm: MSI or Astrophysics Seminar

Wednesday

2:00 pm : Planet Lunch
3:00 pm: Tea & Cookies

Thursday

9:30 am : iRex cafe (alternate weeks @ UdeM)
3:00 pm: Tea & Cookies
3:30 pm: Neutron Star Discussion

Friday

10:30 am : Astronomy Journal Club
2:00 pm: Cosmology Journal Club

Planet Lunch

The Planet Lunch series brings together about 20 researchers from the Departments of Earth and Planetary Sciences, Atmospheric and Oceanic Sciences, and Physics for a weekly lunch discussion. By bringing together this diverse group, the goal is to apply expertise on geology and planetary atmospheres as studied in our Solar System to exoplanets. In this way we can achieve a much better understanding of what we are learning from the observational data on exoplanets, which is much less detailed than for our Solar System planets. Experience derived from Solar System studies also guide the development of future astronomical facilities to study exoplanets. In the past year, topics discussed at Planet Lunch included: how solid material condenses in stellar nebulae; atmospheric loss in the Solar System and exoplanets; the history of Mars geology and water; the interstellar visitor 'Oumuamua; ultra-short period planets; and how JWST will be used to characterize exoplanets.

Black Hole Lunch

The Black Hole Lunch series is an informal gathering and discussion that centers on supermassive black hole (SMBH) research. The group derives mostly from the research teams of Daryl Haggard (McGill), Julie Hlavacek-Larrondo (UdeM), and Tracy Webb (McGill), but is open to all researchers with McGill/MSI and the University of Montreal. They meet bi-monthly, alternating between McGill and UdeM, and tackle core concepts including growth, feeding, and feedback from SMBHs. They also discuss observational and theoretical challenges and share new discoveries and research findings. This gathering of black hole enthusiasts led to a more formal research collaboration between Profs. Webb, Haggard, and Hlavacek-Larrondo, the "Montreal Black Hole Collaboration" (MCH CoLAB), funded by Fonds de recherche du Quebec - Nature et tecnologies (FRQNT).

MSI Lunch Seminars

The Monday lunch talk series showcases the diverse research that goes on at the McGill Space Institute by providing a forum for MSI grad students, postdoctoral fellows, and faculty members to give short presentations over lunch and then engage in an extended, informal discussion about said research. Speakers may use the opportunity to talk about their research, practice a conference presentation, or just discuss an interesting finding in their field. These lunch discussions are held every other Monday year-round, on weeks where there is no MSI seminar. Speakers are limited to three slides (with unlimited blackboard usage) and are asked to prepare 10 minutes of material for a 30 minute slot; the remaining 20 minutes filled by questions from the audience and discussion. MSI Lunch Talks are well-attended, drawing anywhere from 25 to 40 participants.

EPOD

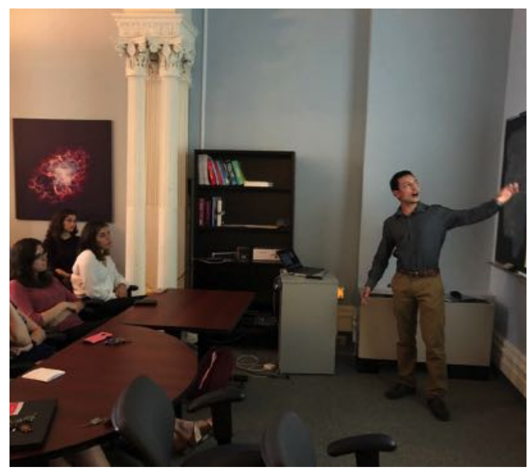
The Education, Public Outreach, and Diversity discussion group meets on Tuesday at the MSI. The discussion is fairly informal; topics vary from week to week and can include anything that fits within the umbrella of education, outreach, or diversity. MSI members are welcome to suggest topics, and seminar speakers are also welcome to participate or lead the discussion if they have a topic in mind. Past topics have included the American Physical Society's effective practices for recruiting and retaining women in physics, free expression, respect, and inclusion at McGill, and the challenges and trade-offs of urban astronomy for undergraduate education, among others.

MSI Undergraduate Summer Research Program

Every summer since its founding, MSI hosts undergraduate summer research students, both from McGill and universities across the country. In Summer 2018, the MSI hosted approximately 18 undergraduate summer researchers, the largest cohort that MSI has ever hosted, which resulted in a lively atmosphere at 3500 University all summer.

Although undergraduate researchers are hired to work in a particular professor's research group, they are encouraged to take part in all MSI activities, including seminars, journal clubs, and AstroMcGill outreach activities. Thanks to the friendly community and accessible environment of the MSI, summer undergraduates gain exposure to many different research groups beyond their own.

MSI Summer Undergraduate Research Showcase



At the end of the summer, the MSI organized a Summer Undergraduate Research Showcase, where each undergraduate summer researcher presented the results of their project to the entire MSI. The undergraduate research projects covered a wide range of topics that reflected the diverse and interdisciplinary nature of the MSI. For example, undergraduate students worked on developing Gaussian Process techniques to fit exoplanet transmission spectra, analyzing X-ray observations of a neutron star merger, modeling the gravitational response of melting ice sheets, and building data processing software for the Canadian Hydrogen Intensity Mapping Experiment. The presentations were extremely impressive and well-received by the audience.

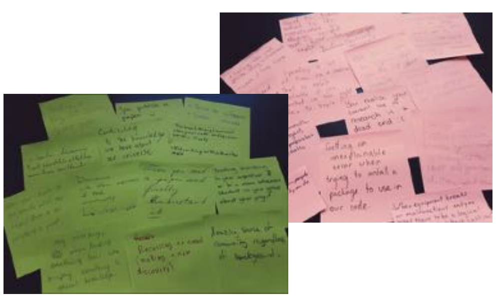
From top: 1) Summer undergraduate researchers Juliette Geoffrion (Cowan group) and Capucine Barfety (Webb group) volunteering at the Eureka! Festival booth; 2) Filipe Rodrigues (Kaspi group) presenting at the Undergraduate Research Showcase; 3) Linda Pan, an undergraduate researcher in Prof. Natalya Gomez's group presenting at the Undergraduate Research Showcase

Professional development discussions

A unique feature of the MSI summer undergraduate research program is a weekly seminar series for the undergraduate interns. The format of these weekly seminars is a casual discussion, organized by MSI Coordinator Carolina Cruz-Vinaccia and MSI Postdoc Fellow John Ruan, with immense help from various other MSI members. Discussion topics centre primarily around professional development, such as 'how to give effective talks', ‘dealing with imposter syndrome', 'applying to graduate school', and ‘pursuing non-academic careers’. McGill’s Women in Physics Committee co-led one of the sessions, running a workshop on diversity and inclusion.

The primary goal of this seminar series is to provide some guidance for students at the earliest stage of their research careers, when they often feel lost and isolated in their work. However, an important secondary benefit of these weekly lunch seminars is to build a sense of community for the undergraduate summer students, and ensure that they become familiar with their peers. The seminars were well attended (average of ~12 students per week, despite travel, vacation plans, etc.), and our end-of-summer survey evaluations showed unanimous support from the undergraduates for this effort.

The organizers are eager to build on the success of this MSI summer undergraduate research program next summer, and thank the MSI for funding the weekly lunch seminars!



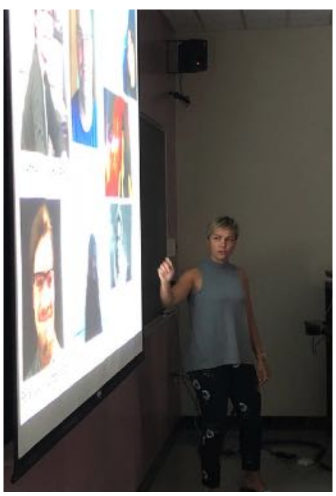
From top: 1) MSI Summer Undergraduates at a professional development lunch on how to apply to graduate school 2) A summer undergraduate researcher drawing a tribute to Richard Feynman on his 100th birthday on one of the MSI boards ; 3) Contributions to the discussion on The Highs and Lows of Research.

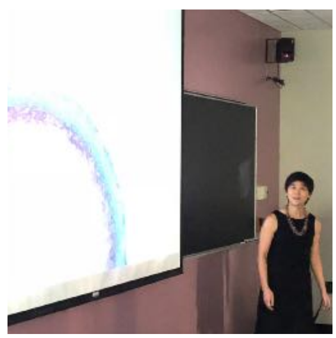
Right: A group of summer undergraduates at a professional development lunch in the MSI conference room.

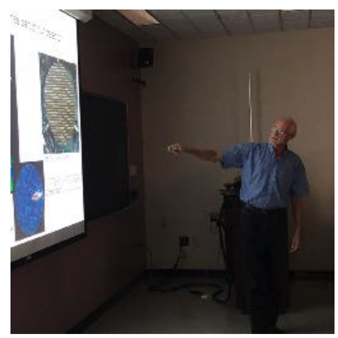
MSI Jamboree 2018

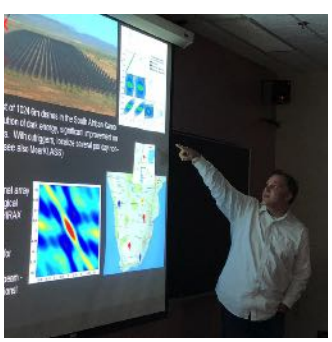
The MSI kicks off every school year with the MSI Jamboree, where we showcase who we are and the breadth of research that we do to new and returning students, postdoctoral fellows, and faculty members. This year's Jamboree took place on September 6, 2018 and was our largest and most ambitious yet; an impressive 17 MSI-affiliated faculty members from all 4 member departments gave quick overviews of their research groups and ongoing projects! We were especially happy to be able to introduce attendees to our three new faculty members, Profs. Adrian Liu, Cynthia Chiang, and Jonathan Sievers.

The Jamboree was well-attended, with over 60 attendees filling the Rutherford Physics Building's Bell Room to capacity. The research showcase was followed by a wine and cheese in the MSI Lounge. The Jamboree was an overall success and set the tone for what is sure to be an exciting year!









Awards

Faculty Members

Daryl Haggard
CIFAR Azrieli Global Scholar 2017

Adrian Liu
CIFAR Azrieli Global Scholar 2018

Jonathan Sievers
Canada 150 Research Chair

Natalya Gomez
2018 C. Gordon Winder Memorial SCUGOG Public Lecture
University of Western Ontario

Matt Dobbs
CIFAR Senior Fellow in the Gravity and the Extreme Universe Program

Vicky Kaspi
- Director, R. Howard Webster Foundation Fellow, CIFAR Gravity & Extreme Universe Program
- 2018 Doctor of Science, Honoris Causa, U. British Columbia (Okanagan)
- 2018 Columbia University Bishop Lecturer

Graduate Students (current)

Taylor Bell
NSERC PGS-D (*starting Fall 2018)*

Mohit Bhardwaj
MITACS Globalink Award

Olivia Blenner-Hasset
- FRQNT Master's Scholarship (*starting Summer 2018)*
- Walter M Stewart Postgraduate Scholarship, McGill University
- Graduate Excellence Award, McGill University
- Northern Scientific Training Program

Paula Boubel
NSERC CGS-M (Canada Graduate Scholarship, Masters)

Élie Bouffard
FRQNT Master's Scholarship

Hope Boyce
- Mary Louise Taylor Award, McGill Physics
- NSERC PGS-D (*starting Fall 2018*)

Pragya Chawla
FQRNT Doctoral Scholarship (*starting Summer 2018)*

Lisa Dang
Prix Relève étoile Louis-Berlinguet, Fonds de Recherche de Quebec

Catherine Maggiori
McGill Graduate Excellence Award

Emilie Parent
- Schulich Fellowship, McGill Physics
- Vanier Canada Graduate Scholarship 2018, NSERC

Ziggy Pleunis
Schulich Fellowship, McGill Physics *(starting Fall 2018)*

David Touchette
NSERC CGS-M (Canada Graduate Scholarship, Masters)

Incoming Grad. Students

Omar Al Aryani
McGill-UAE Fellowship in Science and Engineering

Soud Al Kharusi
Hydro Quebec Fellowship

Simon Guichandut
FRQNT Master's Scholarship (*starting Fall 2018)*

Marcus Merryfield
NSERC Canada Graduate Scholarship, Masters (*starting Fall 2018)*

Nathalie Thibert
NSERC CGS - Doctoral (*starting Fall 2018)*

MSI Members 2017-2018

Faculty Members

Robert Brandenberger	Phys
Cynthia Chiang (*Aug. 2018*)	Phys
Jim Cline	Phys
Nicolas Cowan	Phys & EPS
Andrew Cumming *MSI Associate Director*	Phys
Matt Dobbs	Phys
René Doyon	Phys
Natalya Gomez	EPS
Victoria Kaspi *MSI Director*	Phys
Daryl Haggard	Phys
David Hanna	Phys
Yi Huang	AOS
Adrian Liu (*Aug. 2018*)	Phys
Timothy Merlis	AOS
Ken Ragan	Phys
Jonathan Sievers (*Aug. 2018*)	Phys
Tracy Webb	Phys
Lyle Whyte	NRS

Postdoctoral Fellows

Matthew Caplan	Phys
Eric Chan	EPS
Jonathan Cornell	Phys
Qi Feng	Phys
Elisa Ferreira	Phys
Emmanuel Fonseca	Phys
Vanessa Graber	Phys
Arun Naidu	Phys
Ryo Namba	Phys
Melania Nynka	Phys
Isabelle Raymond-Bouchard	NRS
John Ruan	Phys
Holly Sheets	Phys
Seth Siegel	Phys
Shriharsh Tendulkar	Phys
Ben Zitzer	Phys

Associate Members

Oscar Hernández	Phys
Richard Léveille	EPS

Graduate Students

Taylor Bell	Phys
Mohit Bhardwaj	Phys
Olivia Blenner-Hassett	NRS
Paula Boubel	Phys
Élie Bouffard	Phys
Hope Boyce	Phys
Paul Charlton	Phys
Pragya Chawla	Phys
Gabriel Chernitsky	Phys
Jeremie Choquette	Phys
Peter Crockford	EPS
Disrael Cunha	Phys
Bryce Cyr	Phys
Lisa Dang	Phys
Anna Delahaye	Phys
Sreela Das	Phys
Guilherme Franzmann	Phys
Erin Gibbons	EPS
Claire Guimond	EPS
Alexander Josephy	Phys
Dylan Keating	Phys
Marie-Pier Labonté	AOS
Tony Lin	Phys
Catherine Maggiori	NRS
Juan Mena	Phys
Joshua Montgomery	Phys
Matthew Muscat	Phys
Jenny Ni	EPS
Gavin Noble	Phys
Yuuki Omori	Phys
Brady O'Connor	NRS
Emilie Parent	Phys
Chitrang Patel	Phys
Ziggy Pleunis	Phys
David Purnell	EPS
Jerome Quintin	Phys
Thomas Rosin	Phys
Gabrielle Simard	Phys
David Touchette	NRS
Jonathan Tyler	Phys

Undergraduate Students

Capucine Barfety	Phys
Claudia Bielecki	Phys
Daniela Breitman	Phys
Marion Burnichon	Phys
Athias Clement	AOS
Nick Delnour	Phys
Hannah Dykaar	Phys
Shereen Elaidi	EPS
Emma Ellingwood	Phys
Anne-Sophie Fortin	AOS
Juliette Geoffrion	EPS
David Ittah	Phys
Alexandre Khoury	Phys
Matthew Lundy	Phys
Evelyn MacDonald	EPS
Marcus Merryfield	Phys
Charles Moatti	Phys
Linda Pan	EPS
Emily Pass	Phys
Andy Ramirez-Cote	Phys
Filipe Rodrigues	Phys
Maclean Rouble	Phys
Felix Valin	Phys

Staff

Carolina Cruz-Vinaccia
MSI Coordinator (as of Apr. 2018)
Kelly Lepo
MSI Coordinator (*up to Mar. 2018*)
Patrick Boyle
CHIME/FRB Project Manager
Adam Gilbert
Lab Manager Cosmology Lab

Key

Phys: Physics
EPS: Earth and Planetary Sciences *AOS*: Atmospheric and Oceanic Sciences
NRS: Natural Resource Sciences

Former MSI Members

Postdoctoral Fellows

Dan Capellupo
Currently a Data Scientist at Aston Capital Management in Tel Aviv, Israel.

Sean Griffin
Currently a Postdoctoral Associate at University of Maryland College Park / CRESST II, NASA Goddard Space Flight Center.

Graduate Students

Robert Archibald
Postdoctoral Fellow at the University of Toronto.

Hossein Basrafshan
Assistant Professor of Physics at Ferdowsi University of Mashhad, Iran.

David Berardo
A second year graduate student at the Massachusetts Institute of Technology (MIT) Kavli Institute for Astrophysics and Space Research.

Nina Bonaventura
JWST/NIRSpec post-doctoral researcher at the Cosmic Dawn Center (DAWN) at the Niels Bohr Institute of the University of Copenhagen.

Étienne Bourbeau
Pursuing a PhD in neutrino physics with IceCube at the Niels Bohr Institute, University of Copenhagen.

Grace Dupuis
Data Scientist at Goldspot Discoveries Inc in Montreal, QC.

Evan McDonough
Postdoctoral Researcher at Brown University.

Yuuki Omori
Postdoctoral Research Fellow at Stanford University, California (USA).

Elinore Roebber
Postdoctoral research fellow in the gravitational wave group at the University of Birmingham, UK.

Gabrielle Simard
Scientific Attachée at the Quebec Government Office in Munich, Germany.

MSI Board 2017-2018

External Members

Lorne Trottier
Co-founder · Matrox

Marc Guilbert
Director · Power Corporation of Canada

Vassiliki Kalogera
Director · CIERA Institute at Northwestern University

Internal McGill Members

Chris Manfredi
Provost

Martha Crago
Vice Principal - Research & Innovation

Bruce Lennox
Dean · Faculty of Science

MSI Internal Members

Vicky Kaspi
Director · McGill Space Institute
Professor of Physics

Andrew Cumming
Associate Director · McGill Space Institute
Associate Professor of Physics

Matt Dobbs
Professor of Physics

Robert Brandenberger
Professor of Physics

Timothy Merlis
Assistant Professor of Atmospheric & Oceanic Sciences

Isabelle Raymond-Bouchard
Postdoctoral Fellow

Emilie Parent
PhD Student

Facilities Used by MSI Members

Laboratory and Computing Facilities

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

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

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)
(Whyte)
Supports field research activities consisting of sample acquisition, some limited laboratory microbial and molecular analyses, and in situ analyses for microbial activity.

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

Ground-based Telescopes

Observatoire du Mont-Mégantic
(Cowan, Haggard)

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

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

W.M. Keck Observatory
(Webb)

Canada-France-Hawaii Telescope
(Cowan, Haggard, Webb)

VERITAS Gamma-ray Telescope
(Hanna, Ragan)

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

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

Atacama Large Millimeter Array
(Webb)

Arecibo Observatory, Radio wavelengths
(Kaspi)

Green Bank Telescope, Radio wavelengths
(Kaspi)

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

Large Millimeter Telescope Alfonso Serrano
(Webb)

Anglo-Australian Telescope
(Webb)

Probing Radio Intensity at high-Z from Marion (PRIZM)
(Chiang, Sievers)

The Hydrogen and Intensity Real-time Analysis eXperiment (HIRAX)
(Chiang, Dobbs, Sievers)

C-Band All Sky Survey (C-BASS)
(Chiang, Sievers)

The Hydrogen Epoch of Reionization Array (HERA)
(Liu)

Gemini Observatory
(Haggard, Webb, Kaspi)

Space-based Telescope Facilities

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

NASA/Hubble Space Telescope
(Cowan, Webb, Kaspi)

NASA/Kepler Mission
(Cowan)

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

NASA/Neutron Star Interior Composition Explorer, NICER
(Kaspi)

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

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

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

NASA Spitzer Space Telescope
(Haggard, Cowan, Webb)

NASA/Fermi mission
(Ragan)

MSI Faculty Collaborations

C-BASS:

C-Band All Sky Survey

(Chiang, Sievers)

Other participating institutions:

✴ University of Oxford ✴ King Abdulaziz City for Science and Technology ✴ University of Manchester ✴ University of KwaZulu-Natal ✴ Rhodes University ✴ SKA-South Africa ✴ Caltech

CASE

Contribution to ARIEL Spectroscopy of Exoplanets

(Cowan)

Other participating institutions:

✴ Jet Propulsion Laboratory ✴ Arizona State University ✴ University of Arizona ✴ UC Santa Cruz, University of Chicago ✴ Smithsonian Astrophysical Observatory ✴ Penn State University, Space Science Institute ✴ Grinnell College ✴ INAF Osservatorio Astronomico di Palermo ✴ Space Telescope Science Institute

CASTOR

Cosmological Advanced Survey Telescope for Optical and Ultraviolet Research

(Haggard, Cowan)

Other participating institutions:

✴ ABB ✴ Athabasca University ✴ Bishop's University ✴ Caltech ✴ Drexel University ✴ Dunlap Institute ✴ Honeywell ✴ The Infrared Processing and Analysis Center ✴ Jet Propulsion Laboratory ✴ McMaster University ✴ NRC-Herzberg ✴ Queen's University Belfast ✴ Royal Military College ✴ The Royal Observatory, Edinburgh ✴ St. Mary's University ✴ Subaru-NAOJ ✴ UC Riverside ✴ University of Alberta ✴ University of Arizona ✴ Universite de Laval ✴ University of British Columbia ✴ University of Calgary ✴University of Manitoba ✴ University of Montreal ✴ University of Paris ✴ University of Potsdam ✴ University of Toronto ✴ University of Victoria ✴ University of Waterloo ✴ University of Victoria ✴ University of Washington ✴ University of Waterloo ✴ Western University ✴ York University

Colibri

Canadian High-Resolution X-ray Telescope

(Haggard, Cumming)

Other participating institutions:

✴ St. Mary's University ✴ Western University ✴ Queen's University ✴ TRIUMF ✴ Bishop's University ✴ University of British Columbia ✴ University of Alberta ✴ University of Manitoba

CHIME

The Canadian Hydrogen Intensity Mapping Experiment:

Cosmology (Dobbs) and Fast Radio Burst (Kaspi, Dobbs)

Other participating institutions:

✴ Dominion Radio Astrophysical Observatory ✴ University of British Columbia ✴ University of Toronto ✴ U.S. National Radio Astronomy Observatory ✴Perimeter Institute ✴ West Virginia university ✴ Yale ✴ MIT

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

Event Horizon Telescope: Multiwavelength Coordination Team

(Haggard)

Other participating institutions:

✴ Academia Sinica Institute of Astronomy and Astrophysics ✴ Barnard College ✴ Boston University ✴ Caltech Directory ✴ Chinese Academy of Sciences ✴ Columbia University ✴ Goethe University of Frankfurt ✴ Harvard University ✴ Harvard-Smithsonian Center for Astrophysics ✴Instituto de Astrofísica de Andalucía ✴ Jagiellonian University ✴ Jet Propulsion Laboratory ✴ Kavli Institute for Astronomy and Astrophysics at Peking University ✴ Korea Astronomy and Space Science Institute ✴ Max Planck Institute for Extraterrestrial Physics ✴ Max Planck Institute for Radio Astronomy ✴ McGill University ✴ MIT ✴ MIT Haystack Observatory ✴ National Astronomical Observatory of Japan ✴ National Institute of Astrophysics, Rome ✴ National Radio Astronomy Observatory ✴ National Taiwan University ✴ Peking University ✴ Perimeter Institute ✴ Purdue University ✴ Purple Mountain Observatory ✴ Radboud University ✴ Shanghai Astronomical Observatory ✴ Steward Observatory ✴ The Pennsylvania State University ✴ Universidad de Concepción ✴ University of Amsterdam ✴ University of Arizona ✴ University of California, Los Angeles ✳ University of Heidelberg ✳ University of Köln ✳ University of Manchester ✳ University of Maryland ✳ University of Massachusetts ✳ University of Michigan ✳ University of Padova ✳ University of Tokyo ✳ University of Waterloo ✳ Villanova University ✳ Würzburg University

HERA

The Hydrogen Epoch of Reionization Array

(Liu)

Other participating institutions:

Arizona State University ✳ Brown University ✳ University of California Berkeley ✳ University of California Los Angeles ✳ University of Cambridge ✳ Massachusetts Institute of Technology ✳ National Radio Astronomy Observatory ✳ University of Pennsylvania ✳ Scuola Normale Superiore di Pisa ✳ SKA-South Africa ✳ University of Washington

iREx

Institut de recherche sur les exoplanètes

(Cowan, Cumming, Doyon)

Other participating institutions:

✳ Université de Montréal

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

MBH CoLAB

Montréal Black Hole Collaboration

(Haggard, Webb)

Other participating institutions:

✳ Université de Montréal

MSE

Maunakea Spectroscopic Explorer

(Haggard)

Other participating institutions:

✳ National Research Council (Canada) ✳ CNRS ✳ University of Hawaii ✳ AAO Macquarie ✳ Indian Institute of Astrophysics (IIA) ✳ NAOC ✳ NOAO ✳ Texas A&M

NANOGrav

The search for gravitational waves using pulsars

(Kaspi)

Other participating institutions:

✳ Caltech ✳ 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

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

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

PRIZM

Probing Radio Intensity at high-Z from Marion

(Chiang, Sievers)

Other participating institutions:
✳ University of KwaZulu-Natal ✳ Carnegie Mellon ✳ University of California at Berkeley ✳ Square Kilometre Array South Africa ✳ South African National Space Agency

SpARCS

The Spitzer Adaptation of the Red-Sequence Cluster Method

(Webb)

Other participating institutions:
University of California Riverside Irvine ✳ University of Toronto ✳ York University ✳ MIT ✳ University of Montreal ✳ Australian Astronomical Observatory ✳ University of Concepcion, Chile ✳ University of Waterloo ✳ Argelander-Instiut fur Astronomie, Bonn, Germany ✳ National Radio Astronomy Observatory ✳ Universidad Andrés Bello, Chile ✳ Spitzer Science Centre, Caltech, ✳ CEA Saclay, France ✳ University Innsbruk, Austria

SPT

The South Pole Telescope

(Dobbs)

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 Observatory

(Dobbs, Sievers)

Other participating institutions:
✳ Lawrence Berkeley National Laboratory ✳ Princeton University ✳ University of California, San Diego ✳ University of California, Berkeley ✳ University of Pennsylvania ✳ (among others)

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 ✳ 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

Thirty Meter Telescope

International Science Development Team for Supermassive Black Holes

(Haggard)

Other participating institutions:
✳ Caltech ✳ Institute of High Energy Physics ✳ IPAC ✳ Kavli Institute for Astronomy and Astrophysics, at Peking University ✳ Kyoto University ✳ National Astronomy Observatory of China ✳ National Astronomical Observatory of Japan ✳ National Optical Astronomy Observatory ✳ Shanghai Astronomical Observatory ✳ SOFIA Science Center ✳ Tata Institute of Fundamental Research ✳ Tohoku University ✳ Tokyo University of Science ✳ University of California, Irvine ✳ University of California, Riverside ✳ UC Santa Cruz ✳ University of California, Las Angeles ✳ University of Alaska, Anchorage ✳ University of Colorado, Boulder ✳ University of Illinois, UrbanaChampagne ✳ University of Manitoba ✳ University of Pennsylvania ✳ University of Science and Technology of China ✳ University of Waterloo ✳ University of Texas at San Antonio ✳ Virginia Tech ✳ Western University

VERITAS

(Hanna, Ragan)

Other participating institutions:
✳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

HIRAX

The Hydrogen and Intensity Real-time Analysis eXperiment

(Chiang, Dobbs, Sievers)

Other participating institutions:
✳University of KwaZulu-Natal ✳ NRF-SARAO South African Radio Astronomy Observatory ✳ Durban University of Technology ✳ University of Cape Town ✳ Rhodes University ✳ Universiteit Stellenbosch University ✳ University of the Western Cape ✳ Botswana International University of Science and Technology ✳ African Institute for Mathematical Sciences ✳ APC Laboratoire As troparticule & Cosmologie ✳ UBC ✳ Carnegie Mellon University ✳CITA ✳ ETH Zürich ✳ Université de Géneve ✳ IUCAA Inter-University Centre for Astronomy and Astrophysics ✳ NASA JPL Caltech ✳ University of Oxford ✳ Perimeter Institute ✳ University of Toronto ✳ West Virginia University ✳ University of Wisconsin Madison ✳ Yale University

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