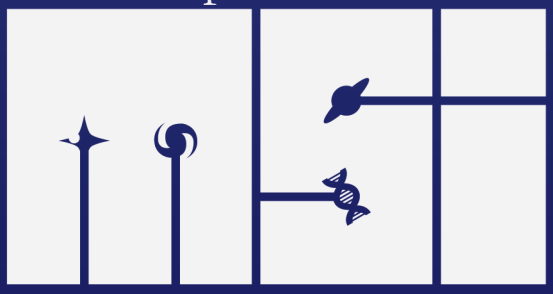
Institut Spatial de McGill



McGill Space Institute

Annual Report 2021

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About the MSI

A Message from the Director

Here at the McGill Space Institute, our core mission is to enable interdisciplinary interactions throughout the domain of space science, with topics ranging from very early Universe cosmology, through to the search for extraterrestrial life. Discussion and interaction are key activities, usually within our beloved "Space Shack" at 3550 University. With daily tea interaction time, weekly lunches, seminars and discussion groups, since its inception, the MSI has been an exciting, vibrant hub for all space related science on the McGill University campus. Though the COVID-19 pandemic affected MSI members as much as most others around the globe, our passion and commitment to understanding the cosmos continued to shine through this past year, in spite of lingering lockdowns. Thankfully, however, things are getting back to normal. Though it looks like zoom is here to stay, in-person meetings, at first small in number and heavily masked, have started re-appearing, and in early Summer 2022, regular daily teas returned to MSI, with participation growing daily. The coming year will surely be an exciting one, with those who recall pre-pandemic MSI dynamics set to re-create it, and those students, postdocs and staff who arrived in the interim about to enjoy the amazing research environment they so richly deserve. I look forward, as Director, to witnessing a 'stellar' recovery of MSI and the inevitable growth of synergistic research and outreach activities that is our hallmark.

About the MSI

The McGill Space Institute (MSI) is an interdisciplinary research centre that brings together researchers engaged in astrophysics, planetary science, atmospheric science, astrobiology and other space-related research at McGill University. We have a vibrant and interactive community of over 120 researchers at all levels, including faculty members, postdoctoral researchers, graduate students, and undergraduate students. The MSI was established in 2015 thanks to a generous gift from the Trottier Family Foundation.

The main goals of the Institute are to:

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

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

Institut Spatial de McGill

McGill Space Institute

MSI by the Numbers

20 Faculty Members

73 Graduate Students

41 Summer Undergraduates

25 Postdoctoral Fellows

4 Departments

13 Research Areas

149 Journal Articles

9 Weekly Discussions

28 Virtual Seminars

3
Virtual Trivia Night

9
Virtual Public Lectures

2
Livestreamed Panels

10^53
Hours on Zoom

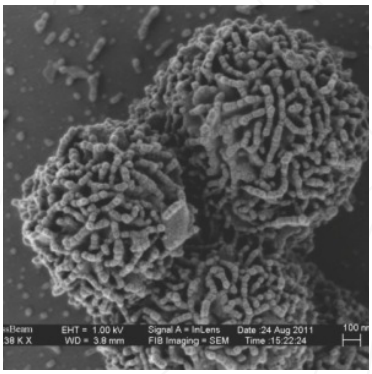
44
Gift bags distributed at the Halloween Party

14
Mini-pumpkins painted at the Halloween Party

61
Students supported by MSI funding

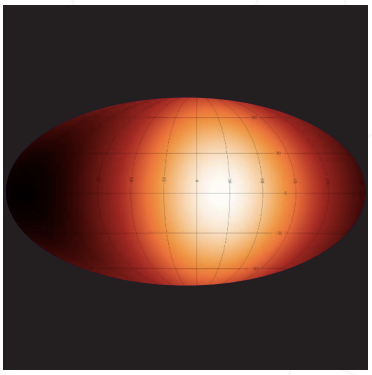
Research Areas

Astrobiology & Extraterrestrial Biosignatures *(Nicolas Cowan, Nagissa Mahmoudi, Lyle Whyte)*



The Astrobiology and Extraterrestrial Biosignatures group focuses 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 in these types of soils, as well as detecting biosignatures 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. In parallel with the search for life in habitable extraterrestrial environments within the Solar System, members of the group use cutting edge telescopes on the ground and in space to establish the habitability of nearby temperate terrestrial exoplanets and to search their atmospheres for signs of life.

Climates and Atmospheres of Exoplanets *(Nicolas Cowan, Andrew Cumming, Yi Huang, Tim Merlis)*

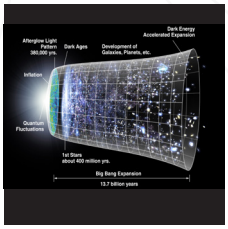


The extrasolar planet climate and atmosphere group works to characterize exoplanets using both observational evidence and climate modelling. Observational evidence for exoplanetary atmospheres comes from a variety of sources, including changes in brightness of the planet over time, spectroscopy, and 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 as part of the Institute for Research on Exoplanets (iREx).

Compact Objects *(Andrew Cumming, Daryl Haggard, Vicky Kaspi)*

The compact object group studies white dwarfs, pulsars and other highly magnetized neutron stars, and stellar-mass black holes. The observational pulsar group is involved in several projects including: searches for radio pulsars; pulsar timing, and X-ray observations of energetic pulsars and magnetars. Our multi-messenger group pursues intensive campaigns to identify and characterize kilonova and other electromagnetic counterparts to gravitational wave sources. 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 stars' spin and magnetism, interior structure, and the properties of neutron stars in close binary systems.

Early Universe and Theoretical Cosmology *(Robert Brandenberger, Jim Cline, Katelin Schutz)*

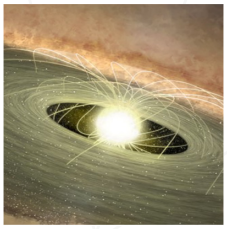


The theoretical cosmology group works to explain the history of the very early Universe and to provide an explanation of the large scale structure in the Universe. They create models using input from new fundamental physics such as superstring theory, dark matter particle theories, and particle physics 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.

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 instrumentations wherever the 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.

Formation and Evolution of Stars and Planets *(Andrew Cumming, Eve Lee)*



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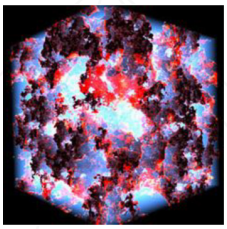
Galaxy Evolution and Active Galactic Nuclei (*Daryl Haggard, Tracy Webb)*

The galaxy evolution group is interested in understanding when galaxies form the bulk of their stellar mass; 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 their host galaxies and within galaxy clusters. We also study our own supermassive black hole, SgrA□, and its interactions with the Milky Way galaxy.

Gamma Ray Astrophysics *(David Hanna, Ken Ragan)*

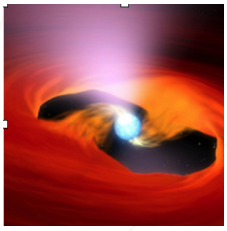
The Gamma Ray Astrophysics group is part of the VERITAS collaboration, which operates an array of four 12-m imaging atmospheric Cherenkov telescopes in southern Arizona. They carry out a program of very-high-energy (VHE) gamma-ray astronomy, observing photons with energy in the range from 50 GeV to 50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

Low Frequency Cosmology *(Cynthia Chiang, Adrian Liu, Jonathan Sievers)*



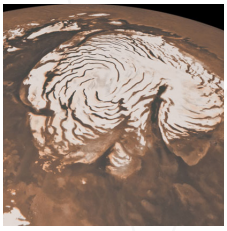
The low-frequency radio sky represents a new frontier in observational astrophysics and cosmology. This regime is a largely unobserved band of the electromagnetic spectrum, and holds the promise of revealing new astrophysical phenomenology. Our 21cm cosmology telescopes (ALBATROS, HERA, MIST, PRIZM)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

Nuclear Astrophysics *(Andrew Cumming)*



Nuclear astrophysics 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. We focus on developing connections between nuclear properties and astrophysical observations through the study of neutron stars, in particular by modelling the transient behaviour of accreting neutron stars on timescales of seconds to years. McGill is an Associate Member of the Joint Institute for Nuclear Astrophysics - Centre for Evolution of the Elements (JINA/CEE).

Planetary Surfaces *(Natalya Gomez)*

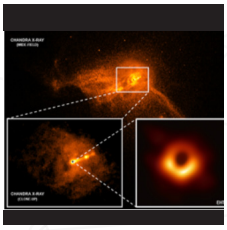


Members of the planetary surface group, led by Natalya Gomez, research models of the interactions between ice, water, climate and planetary interiors, and how these connections change planets' surfaces through time. These models are applicable to both the Earth and other rocky, icy planets and moons in the Solar System.

Radio Transients *(Matt Dobbs, Vicky Kaspi, Jonathan Sievers)*

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, particularly the CHIME telescope located in Penticton, British Columbia.

Supermassive Black Holes *(Daryl Haggard)*



Our studies of supermassive black holes span from their large scale environments to photons circling at the edge of the event horizon. The supermassive black hole group is a part of the Event Horizon Telescope Collaboration and the LISA Consortium, along with several international teams that coordinate multi-wavelength (and soon multi-messenger) programs to characterize these systems and probe fundamental questions including: is general relativity valid in the strong-gravity regime? How are jets launched? What physics governs accretion flows near the event horizon?

02
Research Highlights

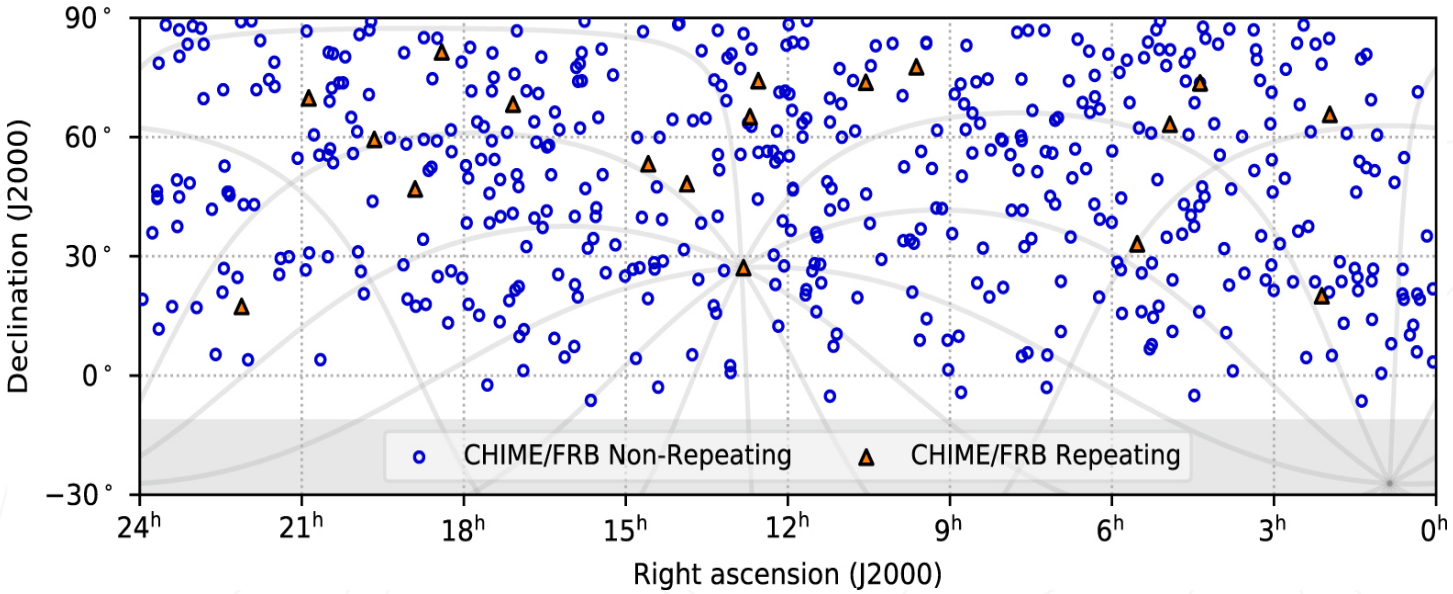
The First CHIME/FRB Fast Radio Burst Catalogue

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.

The CHIME telescope, located near Penticton, BC, consists of four cylindrical reflectors oriented North-South. They have no moving parts and observe the full Northern sky daily at radio frequencies between 400 and 800 MHz. CHIME's large collecting area, bandwidth, and field of view make it a superb transient detector, a capability made real by the CHIME/FRB Project.

The CHIME/FRB Project uses CHIME to detect Fast Radio Bursts in real time at a rate of roughly 3 per day -- orders of magnitude greater than any other telescope. The CHIME/FRB software pipeline, developed in large part thanks to MSI students and postdocs and first operational in mid 2018, allowed for the detection of over 500 FRBs by mid July 2019. This sample, by far the largest ever collected, constituted the First CHIME/FRB Catalog of Fast Radio Bursts. The sheer number of FRBs in this catalog has already enabled many detailed analyses of the FRB population by both the CHIME/FRB team, as well as by the FRB community worldwide.

Top: the CHIME telescope (Credit: the CHIME Collaboration).



Sky distribution of 18 repeating sources and 474 sources that have not been observed to repeat (Source: CHIME/FRB Collaboration, 2021).

In the Catalog paper itself, the team was able to do the first statistically meaningful comparison between repeating and apparently non-repeating FRB properties, showing their sky and dispersion-measure distributions appeared consistent with arising from the same underlying distribution, within the current uncertainties. The team also used the sample to determine the log N/log S distribution of FRBs, showing they are consistent with being from a non-evolving population distributed in Euclidean space, consistent with the CHIME/FRB sample originating mainly from redshifts less than 1.

Additional studies done by the CHIME/FRB team were enabled by the Catalog. For example, MSI PhD student Alex Josephy led an analysis using the Catalog to demonstrate the sky distribution of the CHIME/FRB sample is consistent with being isotropic, as expected from a cosmological population. MSI postdoc Masoud Rafiei-Ravandi further showed that the CHIME/FRB First Catalog sample locations show statistically significant correlations with Large Scale Structure Then MSI PhD student Pragya Chawla (now a postdoc at ASTRON in The Netherlands) studied the dispersion measure and scattering properties of the CHIME/FRB sample, showing that FRBs are likely found in local environments that have much more extreme properties than HII regions and supernova remnants like those known in our Milky Way galaxy. Finally, then MSI PhD student Ziggy Pleunis (now a Dunlap Postdoctoral Fellow at University of Toronto) used CHIME/FRB Catalog data to show there is a very significant difference between the morphologies and the spectra of repeating and apparently non-repeating FRBs, which may signal a difference in emission mechanism between the two populations. Ziggy was awarded the 2021 J. S. Plaskett Medal of the Canadian Astronomical Society for the top astronomy PhD thesis in Canada for this work, along with the Division D PhD Prize of the International Astronomical Union.

Citation: "The First CHIME/FRB Fast Radio Burst Catalog", CHIME/FRB Collaboration (2021), ApJ Supplement 257, 59.

Why this is important?

Fast Radio Bursts (FRBs) are a relatively newly discovered astrophysical phenomenon. This first CHIME/FRB Catalog of Fast Radio Bursts contains over 500 FRBs detected during CHIME's first year of operations (mid 2018 to mid 2019). The sheer number of FRBs in this catalog has already enabled many detailed analyses of the FRB population by both the CHIME/FRB team, as well as by the FRB community worldwide.

Probing the Cores of Puffy Planets Using their Orbital Periods

Tim Hallatt is a PhD student working with Prof. Eve J. Lee, a William Dawson Scholar and Assistant Professor in the Department of Physics.

At its most basic level, a planet can be described as a solid rock enveloped by a gaseous atmosphere. The size of a planet is determined by how thick its atmosphere is, which in turn is determined by how massive the planet's rocky core is. The core mass plays a key role in whether the planet emerges as a small gas-poor planet or a large gas-rich planet. However, the core mass is not directly measurable.

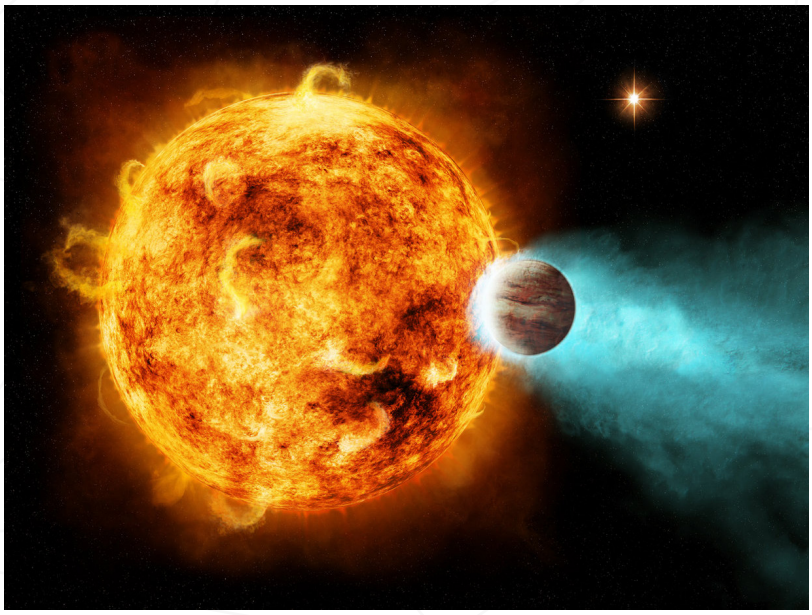
A new study led by PhD student Tim Hallatt and Prof. Eve Lee proposes a novel solution to the problem of measuring the core mass using orbital periods. Lee and Hallatt leveraged the distribution of planets' orbital periods to infer the overall core masses of a particular exoplanet population called Sub-Saturns. Sub-Saturns, planets that are about 4-8 Earth radii, are the failed Jupiters whose solid and gas masses are about equal. This makes them ideal targets for probing the origin of the boundary between gas-poor and gas-rich planets.

Lee and Hallatt demonstrate that the decrease in the prevalence of Sub-Saturns towards smaller orbital periods is a result of rapid atmospheric erosion, which shrinks their radii and transforms them into smaller worlds more efficiently at shorter orbital periods. Massive planets are able to hold on to their envelopes more tightly. Therefore, the relative rarity of Sub-Saturns at shorter periods can be translated directly into the likely distribution of core masses these planets inherited from planet formation, giving us an insight into the required conditions for the creation of gas-rich planets.

Additionally, the new study proposes that several super-puffs (a rare type of planets so "puffy" that their densities are equivalent to that of cotton candy) in our Galaxy are presently undergoing rapid mass loss. This prospect opens avenues for further theoretical and observational tests.

Citation: "Sculpting the Sub-Saturn Occurrence Rate via Atmospheric Mass Loss", Hallatt, T. & Lee, E.J. (2022) ApJ, Vol 924, Issue 1, 15 pp.

Left: Artistic conception of a hot Jupiter with an evaporating atmosphere (credit: NASA / Ames /



Why is this important?

Planetary core masses are a key parameter that determines whether a planet becomes gas-poor or gas-rich, but they cannot be measured directly. This study offers a simple yet novel way to infer the core masses of Sub-Saturns from their orbital periods, revealing the origin of these unique types of planets that had the potential to become gas giants but failed to do so.

Radio Observations from the Eye of Quebec

Prof. H. Cynthia Chiang is an Associate Professor of Physics at McGill University. She specializes in instrumentation development for precision measurements of redshifted 21-cm emission of neutral hydrogen.

Low-frequency observations of the radio sky have the potential to open a new window on the history of the universe: measurements at ~30 MHz and below can shed first light on the cosmic "dark ages," a period that is unexplored to date. The dark ages began about 400,000 years after the Big Bang, when the universe cooled sufficiently for neutral hydrogen to form for the first time, and lasted for about 100 million years until the first stars began to ignite. Without any stars to guide us in this period of darkness, our observations must rely solely upon redshifted 21-cm emission from the hydrogen that pervaded the universe during these early times.

Measurements of the dark ages correspond to observational frequencies of <30 MHz. Observations at these frequencies are exceptionally challenging because of contamination from human-generated radio-frequency interference (RFI) and the Earth's ionosphere. Prof. H. Cynthia Chiang is leading the Array of Long Baseline Antennas to Take Radio Observations from the Sub-Antarctic/Seventy-ninth parallel (ALBATROS), a new experiment that aims to provide improved maps of the low-frequency radio sky as a first step toward future observations of the dark ages.

ALBATROS will consist of antenna stations that observe in concert as an array. Each station will operate autonomously, thus allowing the array to span large distances (>10 km) to image the sky in sharp focus. ALBATROS stations will be installed at two exceptionally radio-quiet locations where Chiang's group has pioneered the first long-term radio astronomy programs: the McGill Arctic Research Station (MARS) on Axel Heiberg Island, Nunavut, and Marion Island in the sub-Antarctic. Because COVID-19 travel restrictions prevented access to these locations during 2020-2021, Chiang and her group began testing ALBATROS instrumentation at Uapishka Station, a radio-quiet site near the "Eye of Quebec." During July-August 2021, Chiang's team installed ALBATROS instrumentation at Uapishka and successfully demonstrated autonomous operation for the first time. With this milestone completed (and relaxed COVID-19 restrictions), the team is ready to continue ALBATROS build-out at MARS and Marion in the coming year. We gratefully acknowledge use of the traditional lands of the Pessamit Innu Band Tshinashkumitinan!

Why is this important?

One of the final frontiers in understanding the history of our universe is the cosmic "dark ages." With novel instrumentation and carefully chosen observing sites, we are taking the first steps toward understanding this early period of the universe's existence.

Understanding Neutron Stars Inflated by Extreme Explosions

Simon Guichandut is a PhD student working with Prof. Andrew Cumming at the McGill Space Institute.

Neutron stars are some of the most extreme objects in the Universe. These stars are trillions of times denser than anything that can be found on Earth; they have the same mass as the Sun, but compressed into the size of a city. They provide a unique opportunity to probe dense matter physics, even from thousands of light years away.

Type I X-ray bursts are extreme yet frequent explosions that occur on the surface of a neutron star after it has been "eating away" at the atmosphere of a nearby companion star for some time. Gas from the companion star builds up a disk, which slowly falls onto the surface of the neutron star. A Type I X-ray Burst is triggered when the new gas layer explodes by nuclear fusion. Some of these bursts are so bright that the atmosphere of the neutron star gets lifted up by the radiation force, generating winds that expel hot plasma into space at 1% the speed of light, and increasing a hundredfold the apparent size of the star itself.

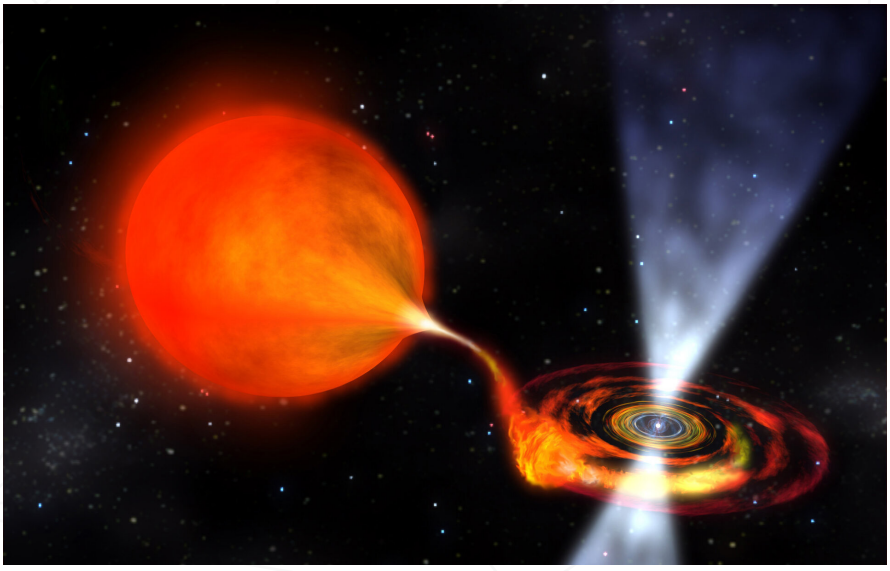
PhD student Simon Guichandut's work involves calculations of the structure of the atmosphere of the neutron star as it is being inflated during a burst. These calculations allow for extrapolating the limited information gathered by X-ray telescopes to the actual conditions of the star. Guichandut's calculations lend support to recent observations by the NICER telescope that suggest that metals such as iron and nickel, created by nuclear fusion during the burst and ejected by the wind, leave a gravitationally distorted imprint on the X-ray light that we receive. While previous studies have mostly focused on winds, this study shows that another type of expansion is possible, one in which the atmosphere is not outflowing as a wind but rather remains in equilibrium.

The existence of this regime cautions a more careful analysis of the properties of the neutron star. In particular, it makes determining a neutron star's radius using bursts a more challenging task than previously thought.

Citation: Guichandut et al. (2021). Expanded Atmospheres and Winds in Type I X-Ray Bursts from Accreting Neutron Stars.ApJ, Vol 914, Issue 1.

Why is this important?

Type I X-ray bursts encode a wealth of information about the physics of neutron stars. This study presents modern models that can be used to interpret observations of these bursts.



Right: Neutron star (the tiny white dot at the centre of the disk) "eating" its sun-like companion star. A Type I X-ray burst is triggered when the new gas layer explodes by nuclear fusion. Image Credits: ESA/NASA.

Sterile Neutrino Dark Matter Catalyzed by a Very Light Dark Photon

James Cline is a Professor of Physics at McGill University and is a member of MSI. Dr. Gonzalo Alonso Alvarez is a Trottier Chair Postdoctoral Fellow at MSI and McGill Physics.

Sterile neutrinos are hypothetical particles that have no interactions with standard model particles, apart from mixing with the usual neutrinos. They are widely believed to exist since they could explain neutrino masses. In the past, they were good candidates for the dark matter of the Universe. Recent astronomical X-ray observations have excluded them as dark matter, by looking for their decays into X-ray photons plus light neutrinos. Prof. Cline's team explored a novel way of reopening the possibility of sterile neutrino dark matter, involving another popular hypothetical particle, dark photons with very small masses.

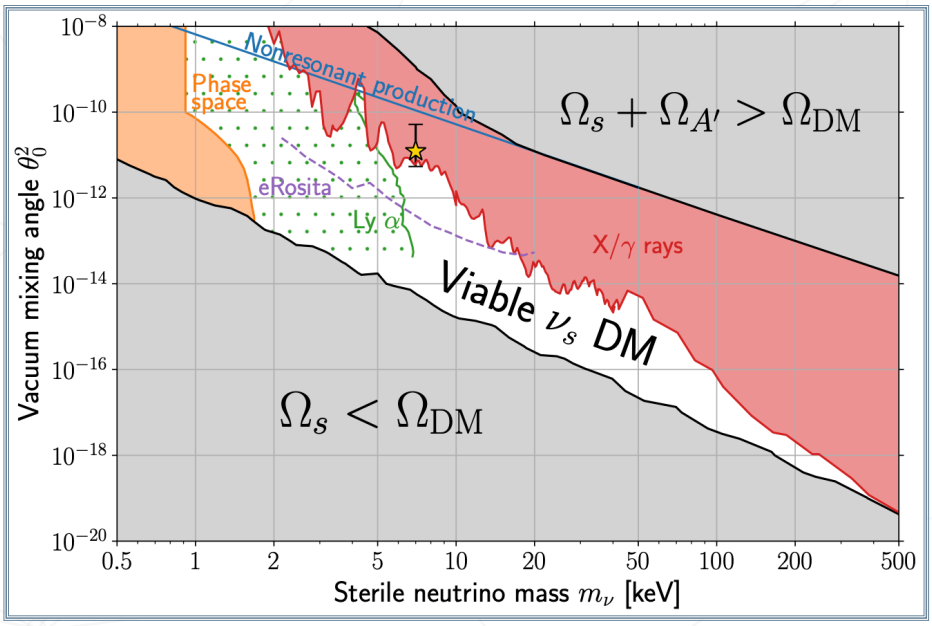
In this scenario, the interactions of dark photons with ordinary neutrinos give the latter an effective mass in the early universe, allowing them to more easily convert into sterile neutrinos through the famous neutrino oscillation mechanism. This lets the mixing angle, that controls how fast sterile neutrinos decay, to be much smaller than in the standard mechanism. In this way we were able to open a large region in the space of parameters (mixing angle versus sterile neutrino mass) that was previously excluded, shown in the figure (white region). This is important for understanding the true potential for sterile neutrinos to be the dark matter of the universe.

An interesting prediction of the model is that the neutrino-dark matter interactions could have a measurable effect on terrestrial neutrino oscillation experiments. We are investigating this with undergraduate student Katarina Bleau, in a forthcoming publication.

Citation: "Sterile neutrino dark matter catalyzed by a very light dark photon", James Cline and Gonzalo Alonso Alvarez,

Why is this important?

Sterile neutrinos are hypothetical particles that could explain neutrino masses. They were good candidates for dark matter in the Universe until recently, when astronomical observations excluded them as candidates. This study reopens the possibility of sterile neutrino dark matter using dark photons (another hypothetical particle).



Right: The white region shows newly reopened parameter space for sterile neutrino dark matter. The red region is ruled out by X-ray telescope observations. The grey region would have too much or too little dark matter.

Stratospheric Weather and the Importance of Longwave Radiation

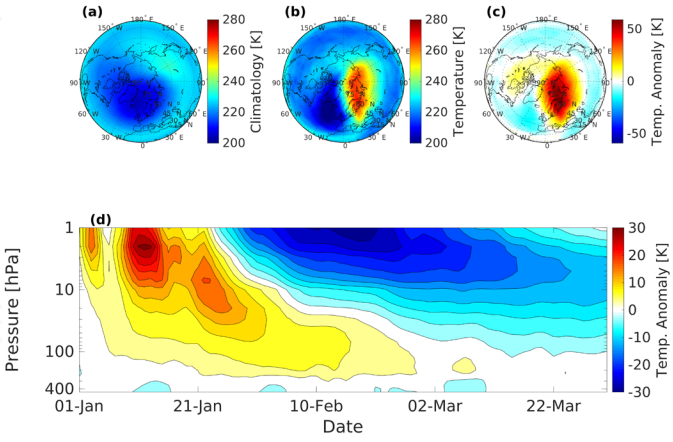
Kevin Bloxam is a PhD student under the supervision of Prof. Yi Huang, an Associate Professor in the Department of Atmospheric and Oceanic Sciences.

Disruptions in the stratosphere (the second layer of the Earth's atmosphere as you're going up) can lead to anomalous weather patterns in the troposphere (the lowest level of the atmosphere). Understanding the rate at which the stratosphere cools is important because it allows us to determine how quickly the stratosphere can revert to a more typical circulation pattern following an injection of thermal energy. In the face of climate change and a cooling stratosphere, it is even more important to understand how the stratosphere responds to perturbations that can impact not only surface level weather, but also millions of people.

On January 21, 2006 a large-scale stratospheric weather phenomenon developed over the Arctic leading the temperature of the upper stratosphere to increase up to +50 K above normal in a matter of days. Initiated by upward propagating waves from the troposphere, this form of stratospheric weather, commonly referred to as sudden stratospheric warmings (SSWs), can result in a near breakdown of polar stratospheric circulation. In some cases, this can alter the tropospheric jet stream below, leading to cold-air outbreaks that force bitterly cold Arctic air southward to lower latitudes.

The SSW of 2006 is of particular interest due to both its magnitude and its aftermath: a near complete shut-off of heat supplied by dynamics, the only source of heat in the stratosphere during the winter. The lack of dynamical heating provided the perfect opportunity to measure the radiative relaxation timescale of the stratosphere (the cooling of the stratosphere via the emission of longwave radiation to space). By measuring the longwave cooling rates, we determined that the upper stratosphere cools the fastest with a relaxation time of ~6 days, compared to ~14.5 days in the middle stratosphere. This tell us that the upper stratosphere can more easily remove excess heat and energy; at lower altitudes this process takes longer. Anomalies generally last longer in the lower stratosphere, which can impact tropospheric weather for extended periods of time.

Citation: *Bloxam, K., & Huang, Y. (2021). Radiative Relaxation Time Scales Quantified from Sudden Stratospheric Warmings. Journal of the Atmospheric Sciences, 78(1), 269-286.*



The SSW of 2006 captured at its starting date, shown at the upper stratosphere. (a) the 1979–2016 climatological temperature based on each calendar date, (b) the observed temperature, and (c) the resulting temperature anomaly. (d) The 60°– 90°N averaged temperature anomaly of the stratosphere and upper troposphere during the SSW. (Source: Bloxam & Huang, 2021)

Why is this important?

Disruptions in stratospheric circulation can lead to anomalous weather patterns in the troposphere. Measuring the stratosphere's radiative relaxation timescale reveals how quickly it removes excess energy and revert to a more typical configuration, and lead to better weather predictions.

EHT Releases Unprecedented Observations Of Famous Black Hole

Prof. Daryl Haggard is an Associate Professor in the Physics Department at McGill University and a Canada Research Chair in Multi-messenger Astrophysics. She is also a member of the Event Horizon Telescope Collaboration. MSI Prof. Ken Ragan (Professor, Physics Department), Dr. Stephan O'Brien, Dr. Sajan Kumar, and Mathew Lundy also contributed data to the observations as part of the VERITAS Collaboration.

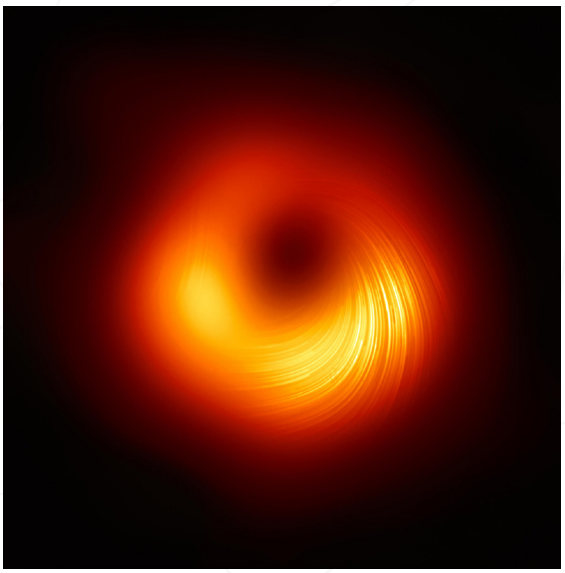
Two years ago, the Event Horizon Telescope (EHT) Collaboration (of which MSI Prof. Daryl Haggard is a member) unveiled the first direct image of a black hole. The image revealed the supermassive black hole at the centre of Messier 87 (M87), a galaxy in the nearby Virgo galaxy cluster. The shadow created by the gravitational bending and capture of light by the event horizon of the black hole allowed its enormous mass (6.5 million times that of our Sun) to be measured. The resulting image of a bright ring marking where light orbits the black hole, surrounding a dark region where light cannot escape the its gravitational pull, matched expectations from Einstein's theory of gravity.

That astonishing image was just the beginning. In April 2021, using data from 19 observatories, the EHT collaboration released images of how that same supermassive black hole at the centre of the M87 galaxy looks in polarised light. It's the first time that astronomers have been able to measure polarisation this close to the edge of a black hole. Polarisation lets astronomers map the magnetic field lines at the inner edge of a black hole. These new observations are key to explaining how M87 is able to launch powerful energetic jets from its core.

M87's jets produce light across the entire electromagnetic spectrum. This pattern of emission, which is different for each black hole, provides crucial insight into a black hole's properties. The pattern varies over time, posing an additional challenge. Scientists compensated for this variability by coordinating observations with many of the world's most powerful telescopes on the ground and in space, collecting light from across the spectrum. Each telescope delivers different information about the behaviour and impact of the black hole. The resulting multi-wavelength data set provides a "snapshot" of the black hole and its jet at the same moment in the time, allowing scientists to see how the energy and material are linked.

Why is this important?

The multtiwavelength observations of M87 by the 19 observatories that make up the Event Horizon Telescope collaborattion provide unparalleled insight into this black hole and the system it powers. The multiwavelentgh data will also be used to improve tests of Einstein's General Theory of Relativity.

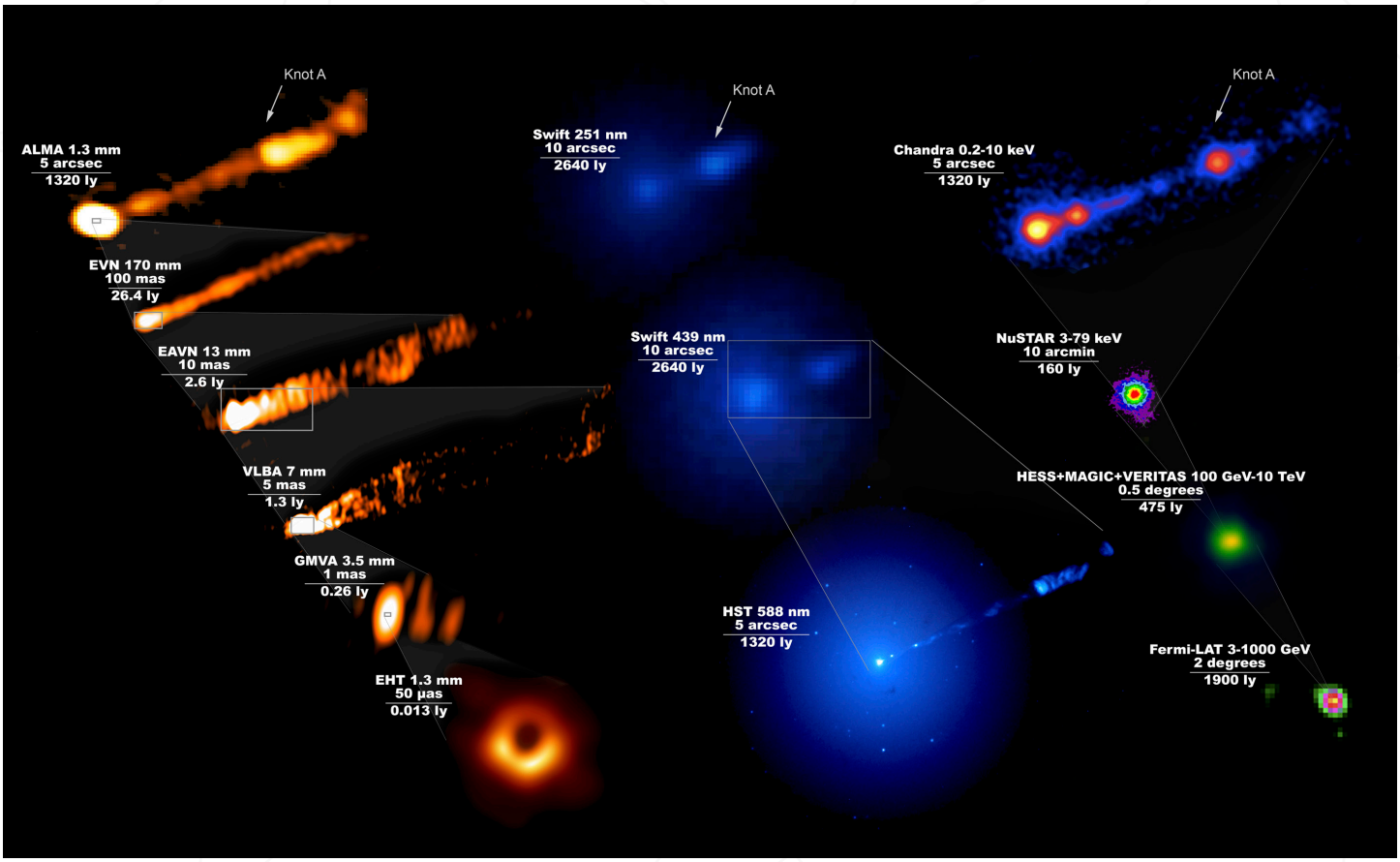


Right: A view of the M87 supermassive black hole in polarised light. The lines mark the orientation of polarisation, which is related to the magnetic field around the shadow of the black hole. Credit: EHT Collaboration

Prof. Haggard and MSI graduate student Hope Boyce helped lead the acquisition and analysis of X-ray data from the Chandra Telescope, and coordination of the multi-wavelength campaign. The X-ray data, in particular, are key for understanding the total energy output of the core (near the black hole) and the jet, and to figuring out whether the black hole is in the midst of an outburst or in a quiet state.

Current and future EHT observations will allow scientists to delve into some of astrophysics' most significant and challenging questions, including using the multi-wavelength data to improve tests of Einstein's Theory of General Relativity. More exciting science is on the horizon; EHT began another observing run in April 2021 targeting M87 again and several other black holes, including Sagittarius A*, the black hole at the centre of our galaxy.

Citation: Event Horizon Telescope Multi-Wavelength Science Working Group et al.: Broadband Multi-wavelength Properties of M87 During the 2017 Event Horizon Telescope Campaign, The Astrophysical Journal Letters, 911, L11, April 14, *2021*



Above: Composite image showing how the M87 system looked, across the entire electromagnetic spectrum, during the Event Horizon Telescope's April 2017 campaign to take the iconic first image of a black hole. Requiring 19 different facilities on the Earth and in space, this image reveals the enormous scales spanned by the black hole and it forward-pointing jet, launched just outside the event horizon and spanning the entire galaxy.

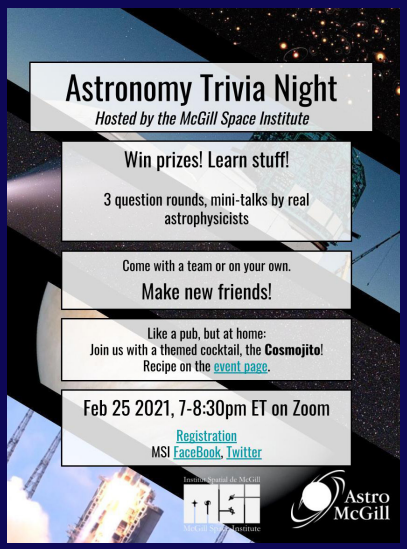
Image Credit: the EHT Multi-Wavelength Science Working Group; the EHT Collaboration; ALMA (ESO/NAOJ/NRAO); the EVN; the EAVN Collaboration; VLBA (NRAO); the GMVA; the Hubble Space Telescope, the Neil Gehrels Swift Observatory; the Chandra X-ray Observatory; the Nuclear Spectroscopic Telescope Array; the Fermi-LAT Collaboration; the H.E.S.S. Collaboration; the MAGIC collaboration; the VERITAS collaboration; NASA and ESA. Composition by J.C. Algaba.

03
Education & Public Engagement

MSI runs a variety of public outreach programs, from monthly events like public lectures to one-time events for smaller audiences both within and outside the McGill community. Many of our outreach events are run under the banner of **AstroMcGill**, which was founded in 2011 by an enthusiastic group of graduate students and post-doctoral fellows.

Over its almost decade of history, AstroMcGill has forged multiple partnerships with other outreach groups, both within and outside McGill, in order to offer a robust set of education and public engagement activities for the Montreal community. We regularly collaborate with outreach groups in the MSI's member departments (Physics Outreach, SMoRes), the Faculty of Science's outreach groups, the Institute for research on exoplanets (iREx), and the Centre de recherche en astrophysique du Québec (CRAQ). AstroMcGill has also made a name for itself in the broader Montreal community and is often invited to participate in events organized by various organizations in Montreal and its surroundings.

The ongoing COVID-19 pandemic meant that all of our public engagement remained virtual during 2021. **Public AstroPhysics Nights** (see page 20), our public lecture series run in collaboration with Physics Matters, moved to YouTube Live but kept its enthusiastic audience by experimenting with a mix of lectures and live-streamed panels. **Astronomy Trivia Night** (page 21) introduced in 2020 as a more pandemic-friendly replacement to Astronomy on Tap, became part of our regular roster of events, to the delight of our enthusiastic participants. Our **Special MSI Public Talk series** continued with "An Evening with Webb", a live virtual panel featuring 4 Canadian astronomers who were among the first to receive time on the James Webb Space Telescope (JWST).



On this page, from left: example of a bio card announcing a speaker for Public AstroNight; poster for Astro Trivia Night, Feb. 2021. Opposite page: an outreach volunteer using a home-made pinhole camera to view the partial solar eclipse; MSI grad student Nicholas Vieira presenting at our special eclipse event on June 2021.

MSI and AstroMcGill MSI also hosted a special event, **"2021 Eclipse: Chat & Trivia"**, in anticipation of the Annular Solar Eclipse that was visible from Canada on June 10th, 2021. MSI graduate student Nicholas Vieira walked participants through what a solar eclipse is and provided various tips and tricks for safely observing the eclipse. The Q&A session was followed by trivia, where participants tested their eclipse knowledge. We also participated in Discover the Universe's Eclipse Challenge; we showed our audience how to make pinhole cameras with which to view the eclipse and then send us pictures of their creations. We even included one of our own!

In addition to our regular outreach events, we regularly participate in one-time events organized by external partners. AstroMcGill collaborated with Physics Matters to offer programming for ***24 heures de science,*** a full day of science and technology themed activities that took place across Quebec in May 2021. "Craters on the Moon", an online interactive module aimed at children ages 8-12, was offered in both English and French as part of the event.

We're thrilled that the ingenuity and dedication of our outreach volunteers allowed for a seamless transition, a broader variety of programming, and a wider reach that we intend to maintain going forward.

Spotlight: MSI on Social Media

Social media is more than ever a crucial tool for public engagement. We shifted our channels towards researcher focused outreach, highlighting not just the science but the researchers behind it. Both MSI and AstroMcGill saw significant growth in their followings across all platforms.

@astromcgill	*2,251 followers*	
@mcgillMSI	*1,195 followers*	
@astromcgill	*823 followers*	
@mcgillspacinstitute	*1,078 followers*	
AstroMcGill	*6,240 followers*	
McGillSpaceInstitute	*2,043 followers*	
AstroMcGill	*428 subscribers*	
McGill Space Institute	*170 subscribers*	

Public AstroNights

Public AstroNights (now Public AstroPhysics Nights) have been a mainstay of AstroMcGill's outreach efforts since 2011 and are now run in collaboration with Physics Matters. Every month, a professional astronomer or physicist gives a public talk aimed at a broad audience. Speakers are often MSI or McGill Physics professors, postdoctoral fellows, or graduate students, although we also welcome invited speakers from other institutions. Talks typically attracted a live audience of about 200 people, plus another 700 viewing the recording.

Our lectures moved online in March of 2020 and have taken place virtually for the duration of the COVID-19 pandemic. Virtual outreach allowed for a mix of different formats, from panels with multiple researchers in a field, Q&A sessions with experts, and more traditional talks. Our audience remains as enthusiastic as ever, with live viewership of up to 200 participants and post-event views that added 600 to 1900 viewers. All of our public talks are available on AstroMcGill's YouTube Channel.

21 Jan **Quantum Materials: How Quantum Mechanics Determine the Properties of Materials**
Prof. Tami Pereg-Barnea (McGill University, Physics Department)

18 Feb **Stephen Hawking - A Personal Perspective**
Prof. Robert Brandenberger (McGill University, Physics)

01 Apr **A Journey to the Infinitely Small**
Prof. Brigitte Vachon (McGill University, Physics)

22 Apr **Our Galactic Neighbourhood**
Tim Hallatt (MSI & McGill University, Physics)

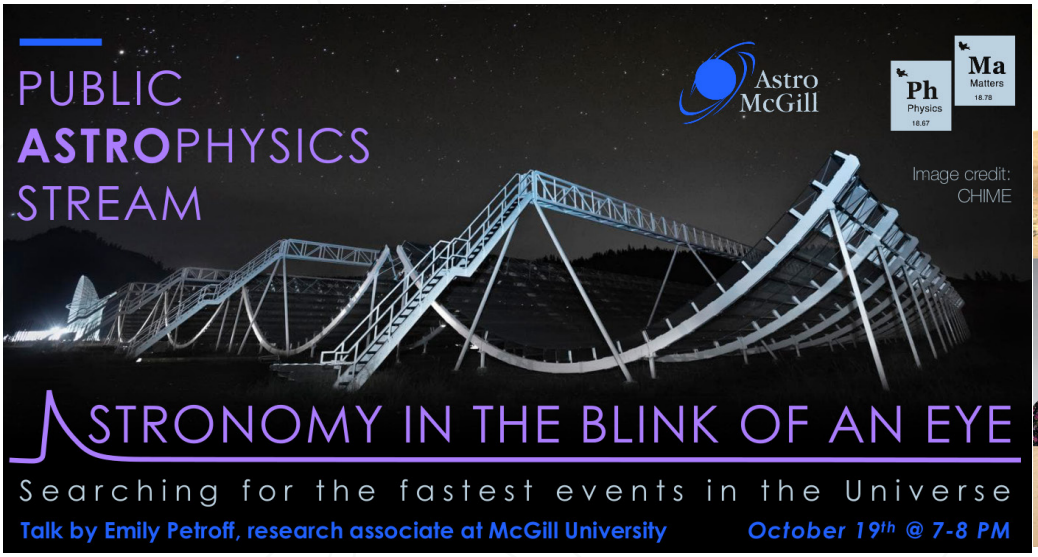
27 May **My Bacteria Teacher: What Extremophilic Microorganisms can Teach Us About Life in the Solar System**
Dr. Miguel Ángel Fernández (MSI & McGill University, Natural Resource Sciences)

08 Jun **Solar Eclipse Chat & Trivia!**
Nicholas Vieira (MSI & McGill University, Physics)

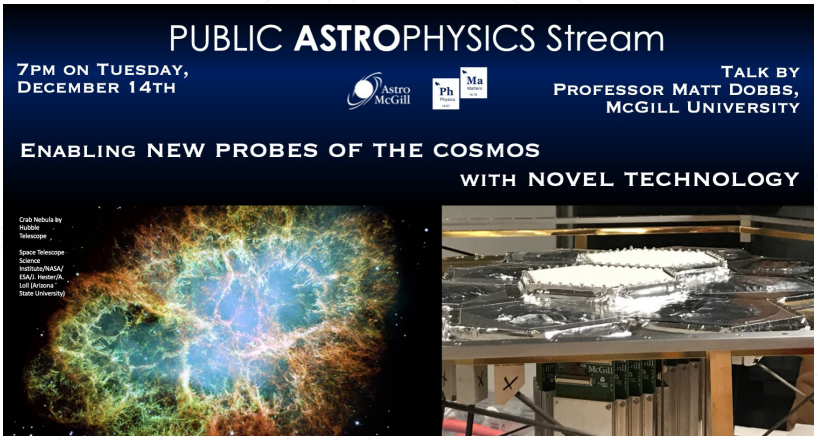
22 Sep **Talking with Martians: A Panel on Red-Planet Research**
Debarati Das, Erin Gibbons, Dr. Richard Léveillé (all: MSI & McGill University, Earth & Planetary Sciences)

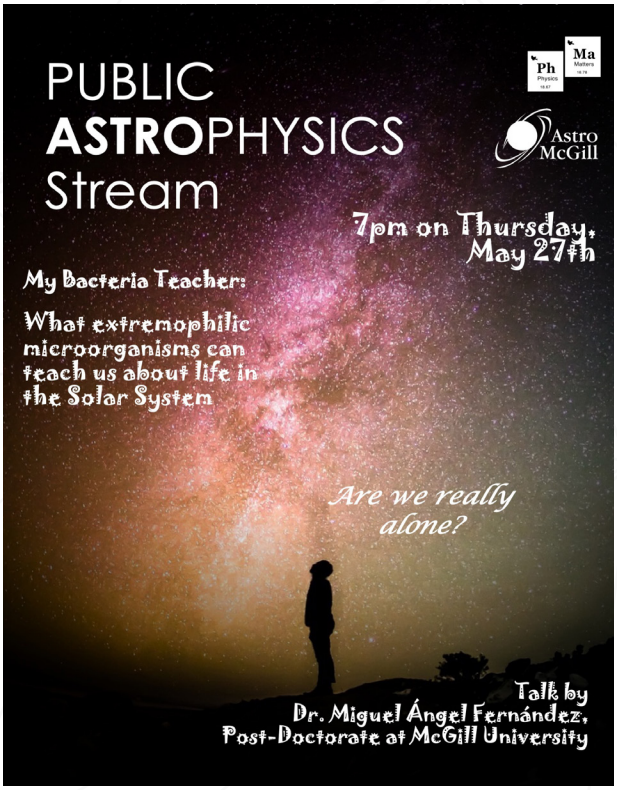
19 Oct **Astronomy in the Blink of an Eye**
Dr. Emily Petroff (MSI & McGill University, Physics)

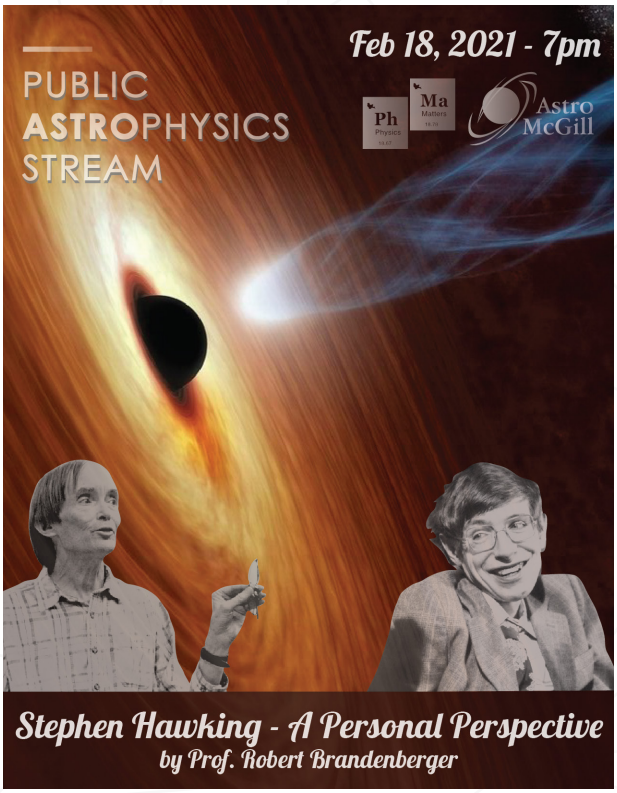
14 Dec **Enabling New Probes of the Cosmos with Novel Technology**
Prof. Matt Dobbs (MSI & McGill University, Physics)


PUBLIC
ASTROPHYSICS
STREAM
Astro McGill
Ph Physics
Ma Matters
Image credit: CHIME
ASTRONOMY IN THE BLINK OF AN EYE
Searching for the fastest events in the Universe
Talk by Emily Petroff, research associate at McGill University
October 19th @ 7-8 PM


Talking with Martians
A panel on red-planet research
September 22nd, 7 pm
PUBLIC
ASTROPHYSICS
Stream
Erin Gibbons
PhD Student
Debarati Das
PhD Student
Richard Léveillé
Professor


PUBLIC ASTROPHYSICS Stream
7PM ON TUESDAY, DECEMBER 14TH
TALK BY PROFESSOR MATT DOBBS, MCGILL UNIVERSITY
ENABLING NEW PROBES OF THE COSMOS
WITH NOVEL TECHNOLOGY


PUBLIC
ASTROPHYSICS
Stream
Astro McGill
7pm on Thursday, May 27th
My Bacteria Teacher:
What extremophilic microorganisms can teach us about life in the Solar System
Are we really alone?
Talk by
Dr. Miguel Ángel Fernández,
Post-Doctorate at McGill University


Feb 18, 2021 - 7pm
PUBLIC
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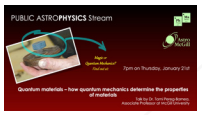
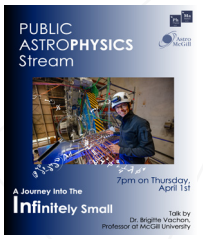
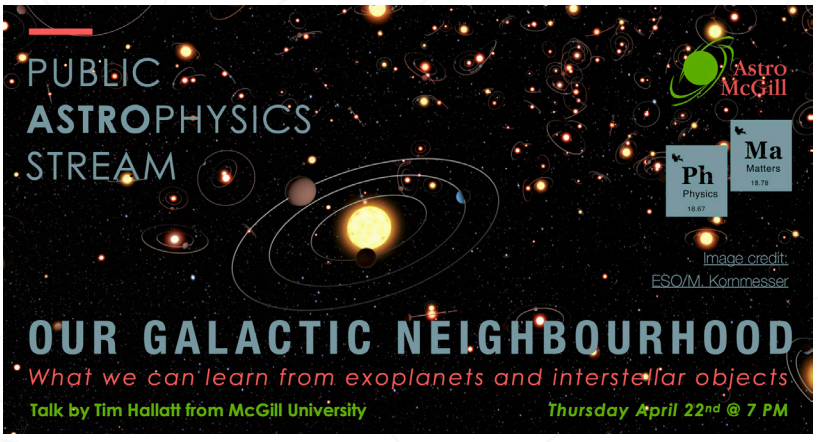
STREAM
Astro McGill
Stephen Hawking - A Personal Perspective
by Prof. Robert Brandenberger




PUBLIC
ASTROPHYSICS
Stream
7pm on Thursday, April 1st
A Journey Into The Infinitely Small


PUBLIC
ASTROPHYSICS
STREAM
Astro McGill
Ph Physics
Ma Matters
Image credit:
ESO/M. Kornmesser
OUR GALACTIC NEIGHBOURHOOD
What we can learn from exoplanets and interstellar objects
Talk by Tim Hallatt from McGill University
Thursday April 22nd @ 7 PM

Astro Trivia Night

Virtual Astronomy Trivia Nights began in November 2020, when we needed an alternative to Astronomy on Tap. It has since become a regular event, occurring at least once per semester. Much like its predecessor, the goal of Trivia Night is to make space-related research more accessible by combining trivia games and short science presentations.

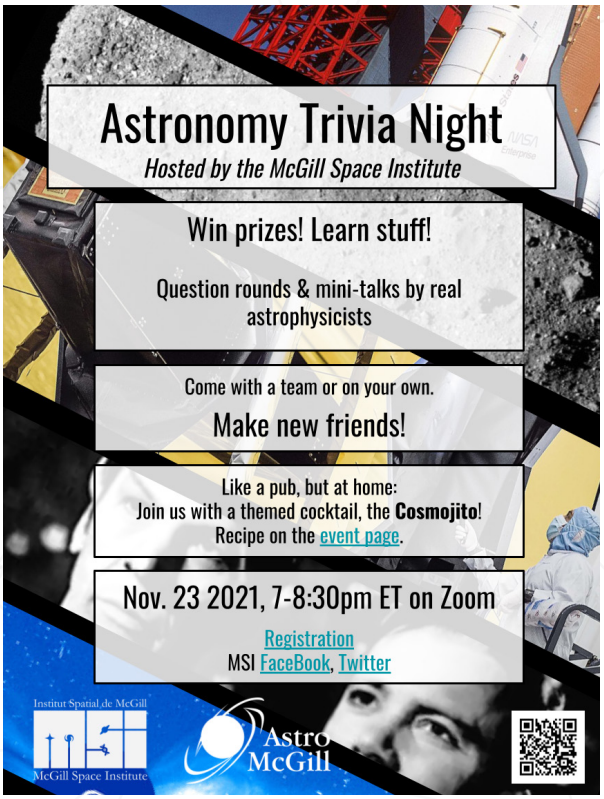
Three or four rounds of trivia test our participants' knowledge of the mysteries of the Cosmos in a variety of different ways. Rounds range from more traditional questions about the latest astronomical news to more off-beat rounds based on decoding strange astronomy acronyms and telling frying pans apart from Moons (a feat that proves much harder than it seems).

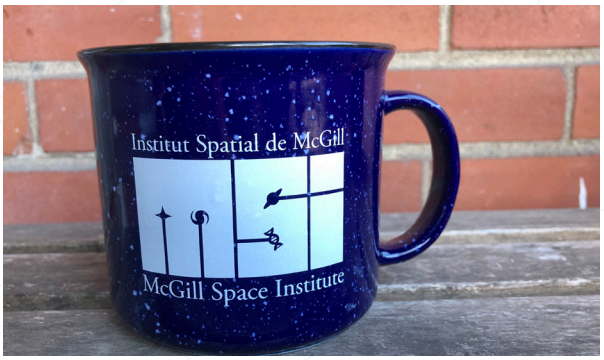
In between each round, an MSI graduate student or postdoc gives a 3-minute talk on the space-related topic of their choice. The highlights this year included how we can calculate whether an object on Earth is visible from space, a brief journey into string theory and cosmic strings, the mysteries of meteorites, and accidental space discoveries.

Trivia Night is a popular event that regular draws between 70 and 100 people, playing alone or in teams. We give people the option to either have a preformed team or let us put them in a team; some of the teams that started out as strangers now regularly play together. Competition is fierce! The top 3 teams win space-themed prizes, including puzzles, rover socks, and even LEGO space shuttles.

The informal nature of the event and the focus on science education through games has allowed us to engage a different audience than our other events. The virtual format also broadens our reach beyond the city of Montreal to accept participants from all across North America. Our winners have hailed from Quebec City, Ottawa, Edmonton, and even NASA Goddard in Maryland!

Thanks to our audience's enthusiastic response, trivia nights are here to stay.





Spotlight: Webb Space Telescope

On December 25, 2021, the astronomy community received what could be considered a very timely gift: the successful launch of the James Webb Space Telescope (JWST). The much anticipated telescope, a collaboration between NASA, the European Space Agency, and the Canadian Space Agency (CSA), is the most complex and powerful telescope ever built. JWST is the result of over 20 years of planning and development, but the successful launch is only the beginning. The telescope's four scientific instruments capture infrared light, allowing it to see through cosmic dust to study colder and more distant objects. JWST will allow astronomers to see further back into the history of the Universe and to see more astronomical phenomena in greater detail than ever before.

Canada, through the CSA, contributed two key elements: a scientific instrument (Near-Infrared Imager and Slitless Spectrograph) and a guidance sensor (Fine Guidance Sensor). In exchange, Canadian researchers are guaranteed observation time on JWST and will be among the first to study data collected by the next-generation telescope. MSI PhD candidate Lisa Dang is the principal investigator on one of the very first projects to be granted time on JWST. Other MSI researchers will also get to use JWST in this first round, as co-investigators on various proposals.

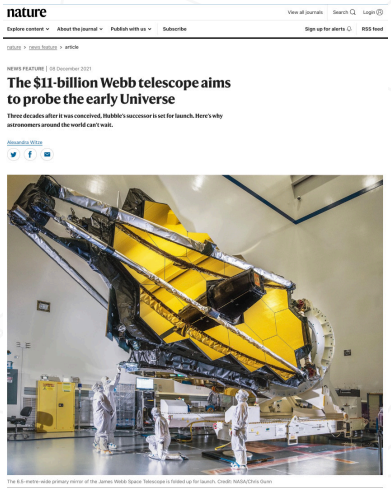
In anticipation of the launch and in recognition of its Canadian connection, MSI teamed up with iRex to co-host a special live-streamed panel event on Oct. 5, 2021. "An Evening with Webb" featured three Canadian scientists who received time on the next-generation telescope: Lisa Dang (McGill University), Olivia Lim (Université de Montréal), and Prof. Maria Drout (University of Toronto). The panel was moderated by Dr. Nathalie Oullete, JWST Outreach Scientist JWST and coordinator for iREx.

Over the course of the 1.5 hour-long event, our panelists explained their projects and fielded questions from an enthusiastic audience; we received such a high volume of questions that about half went unanswered! Over 250 people attended the live event, and the video, which is available on YouTube and Facebook, has received over 2000 views since. We're thrilled by the interest that the audience expressed in learning more about the telescope and the panelists' research, and we look forward to hosting more events in the coming year once the data starts becoming available!

MSI in the Media

- 'Astrónomos encuentran el 'magnetar' más joven hasta ahora; gira una vez cada 1.4 segundos', 24 Horas (Mexico), 19 Jan 2021 [Vicky Kaspi]
- 'Super-Puff Exoplanet WASP-107b is Even Stranger than Thought', SciNews, 21 Jan 2021 [Eve Lee]
- '"Puffed-up" planet unlike any other', Cosmos Magazine, 21 Jan 2021 [Eve Lee]
- 'A 'super-puff' planet like no other', McGill Reporter, 22 Jan 2021 [Eve Lee]
- 'Astronomers discover huge exoplanet has the density of cotton candy', CBC News, 25 Jan 2021 [Eve Lee]
- 'AAS Names 31 New Fellows for 2021', AAS Newsroom, 02 Feb 2021 [Vicky Kaspi]
- 'Astronomers uncover mysterious origins of 'Super-Earths'', McGill Newsroom, 10 Feb 2021 [Eve Lee]
- 'Puffy exoplanet challenges traditional notions of planet formation', McGill Tribune, 16 Feb 2021 [Eve Lee]
- 'À la conquête de la planète Mars', Le Journal de Montréal, 18 Feb 2021 [Richard Léveillé]
- 'Experts: Mars 2020's Perseverance landing in Jezero Crater', McGill Newsroom, 19 Feb 2021 [Richard Léveillé, Lyle Whyte, Erin Gibbons]
- 'À quoi ressemblait la vie sur Mars?', Le Devoir, 27 Feb 2021 [Richard Léveillé]
- 'Conheça 5 mulheres que revolucionaram a ciência nos últimos 5 anos', IG ÚLTIMO SEGUNDO, 07 Mar 2021 [Vicky Kaspi]
- 'Ziggy Pleunis receives the 2021 Plaskett Medal', CRAQ Newsroom, 11 Mar 2021 [Ziggy Pleunis]
- 'First images of magnetic fields at the edge of black hole in M87 Galaxy', McGill Newsroom, 25 Mar 2021 [Daryl Haggard]
- 'Abstract podcast Ep. 46: Cosmic Strings and the Early Universe ft. Bryce Cyr', Abstract Podcast, 11 Apr 2021 [Bryce Cyr]
- 'Telescopes unite in unprecedented observations of famous black hole', McGill Newsroom, 14 Apr 2021 [Daryl Haggard]
- 'Researchers examine how world-apart ice sheets influence each other', Yale Climate Connections , 14 Apr 2021 [Natalya Gomez]
- 'Fast radio bursts shown to include lower frequency radio waves than previously detected', McGill Newsroom, 15 Apr 2021 [Vicky Kaspi, Ziggy Pleunis]
- 'New black hole images contain clues to cosmic mysteries', National Geographic, 19 Apr 2021 [Daryl Haggard]
- 'Catastrophic Sea-Level Rise From Antarctic Melting Possible if Paris Climate Agreement Isn't Met', SciTech Daily, 11 May 2021 [Natalya Gomez]
- 'McGill students honoured by SWAAC', McGill Reporter, 20 May 2021 [Emilie Parent]
- 'Victoria M Kaspi and Chryssa Kouveliotou Receive the 2021 Shaw Prize in Astronomy', IAU Newsroom, 01 Jun 2021 [Vicky Kaspi]
- 'Victoria Kaspi named co-winner of the 2021 Shaw Prize in Astronomy', McGill Reporter, 01 Jun 2021 [Vicky Kaspi]
- 'Over 500 new FRBs detected in single year due to CHIME telescope', McGill Newsroom, 09 Jun 2021 [CHIME/FRB]
- 'Abstract Ep. 54: Exoplanets & Telescopes ft. Lisa Dang', Abstract Podcast, 13 Jun 2021 [Lisa Dang]
- 'Astronomers estimate 29 potentially habitable exoplanets may have received signals from Earth', CBC News, 25 Jun 2021 [Nicolas Cowan]

- 'June 25: The Quirks & Quarks listener question show', Quirks & Quarks (CBC Radio), 25 Jun 2021 [Daryl Haggard]
- 'Provost awards 27 McGill professors with distinguished rank', McGill Reporter, 12 Jul 2021 [Eve Lee]
- 'Life in Lava Caves Ignores Food from the Surface, Eats Rock Instead', Inside Science, 27 Jul 2021 [Richard Léveillé]
- 'NEW OBSERVATIONS CHALLENGE POPULAR RADIO BURST MODEL', Sky & Telescope, 21 Aug 2021 [Vicky Kaspi]
- 'Ten McGill researchers honoured by the Royal Society of Canada', McGill Reporter, 07 Sep 2021 [Daryl Haggard]
- 'The largest space telescope in history is about to blow our minds', Vox, 22 Sep 2021 [Lisa Dang]
- 'Vox's Unexplainable - The James Webb Space Telescope', Vox Media, Unexplainable Podcast, 22 Sep 2021 [Lisa Dang]
- 'Neutron stars: A cosmic gold mine', Astronomy Magazine, 21 Oct 2021 [Vicky Kaspi]
- 'Weird cosmic object keeps exploding over and over again, and scientists don't know why', Live Science, 01 Nov 2021 [Vicky Kaspi]
- 'Un objet mystérieux produit des explosions répétées dans le cosmos', Futura Science, 06 Nov 2021 [Vicky Kaspi]
- 'This tiny iron-rich world is extraordinarily metal', Nature - News, 02 Dec 2021 [Lisa Dang]
- 'The $11-billion Webb telescope aims to probe the early Universe', Nature - News, 08 Dec 2021 [Lisa Dang]
- 'Prof. Robert Brandenberger awarded 2021 CAP Medal for Lifetime Achievement in Physics', CAP Newsroom, 09 Dec 2021 [Robert Brandenberger]
- 'World's most powerful space telescope will let researchers look back in time. This Canadian astronomer will be among its first users', Toronto Star, 10 Dec 2021 [Lisa Dang]
- 'The only known pulsar duo sheds new light on general relativity and more', Science News, 13 Dec 2021 [Vicky Kaspi]
- ''Exceptional day': Canadian scientists rejoice successful launch of space telescope', Global News, 25 Dec 2021 [Daryl Haggard]



04
Inreach

Fostering cross-fertilization of ideas, interdisciplinary interactions, and collaborations among Institute members is one of 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 MSI!

The COVID-19 pandemic meant that our activities looked a little different this year, but we were able to keep up the sense of community that makes MSI unique. All of our discussion groups and seminars moved online, as did our celebration of the beginning of the academic year (the MSI Jamboree). Our annual Solstice Party went virtual once again, bringing together MSI members for an afternoon of crafts and games. We also hosted a virtual Halloween Party, complete with a costume contest, spooky astro trivia, and pumpkin painting!

Above: a screenshot of our Gather space, decorated for the holidays during the virtual MSI Solstice Party on Dec. 21, 2021. Right: a glimpse at our virtual Halloween Party, featuring pumpkins from the pumpkin painting and some of the entries in the costume contest.

A Week at MSI!

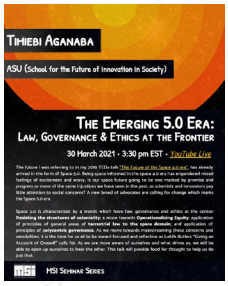
Monday	MSI Lunch Talks Random Papers Discussion
Tuesday	MSI & Astro Seminars Grad meeting w/ seminar speaker Summer Student discussion group
Wednesday	EPOD Discussion
Thursday	Neutron Star Discussion ML in Astrophysics Journal Club
Friday	Astro-PH Discussion Planet Lunch Cosmo-PH Discussion

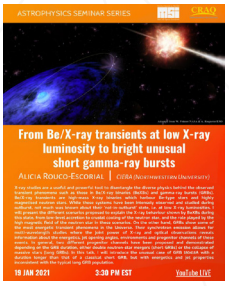
Seminars

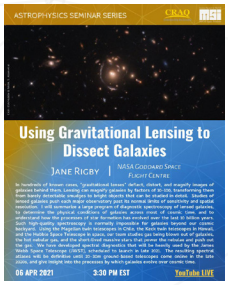
The MSI runs two regular seminar series, the MSI Seminar Series and the Joint Astrophysics Seminar Series. MSI Seminars are intended to be accessible to scientists from the entire breadth of backgrounds at MSI, including physics, planetary science, geology, atmospheric science, and astrobiology. Joint Astrophysics Seminars, which are organized in conjunction with the Centre de recherche en astrophysique du Québec (CRAQ), are aimed at astronomers and astrophysicists. Both continued to be virtual during 2021 due to pandemic travel restrictions. They can be viewed on the MSI's YouTube channel.

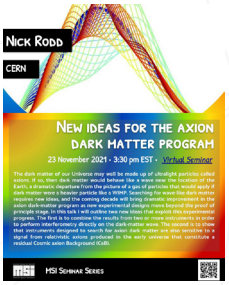
MSI Seminar Series

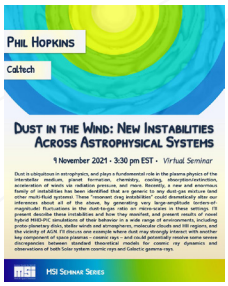
12 Jan	**Rosalba Perna** *(Stony Brook University)* 'Compact Object Mergers in the Gravitational Wave Era'
26 Jan	**Duo Xu** *(University of Texas at Austin)* 'Application of Machine Learning to Identify Stellar Feedback'
23 Feb	**Jerry X. Mitrovica** *(Harvard University)* 'Using Earth Rotation to Detect Climate Change'
30 Mar	**Timiebi Aganaba-Jeanty** *(Arizona State University)* 'The Emerging 5.0 Era: Law, Governance and Ethics at the Frontier'
13 Apr	**Blakesley Burkhart** *(Rutgers University)* 'A Predictive Theory of Star Formation and Turbulence Driving Across Cosmic Time'
07 Sep	**Smadar Naoz** *(UCLA)* 'Gravitational Wave Sources at the Hearts of Galaxies'
21 Sep	**David Martin** *(Ohio State University)* 'Small Circumbinary Planets - Do They Exist And How Do We Find Them?'
05 Oct	**Marta Reina-Campos** *(McMaster University)* 'Modelling stellar cluster populations alongside their host galaxies in a cosmic environment'
26 Oct	**James Owen** *(Imperial College London)* 'Tracing the building blocks of planet formation through protoplanetary discs'
09 Nov	**Phil Hopkins** *(Caltech)* 'Dust in the Wind: New Instabilities Across Astrophysical Systems'
23 Nov	**Nick Rodd** *(CERN)* 'New ideas for the axion dark matter program'
07 Dec	**Ryan Urquhart** *(Michigan State University)* 'Quasi periodic oscillations from a transient ULX in M 101'

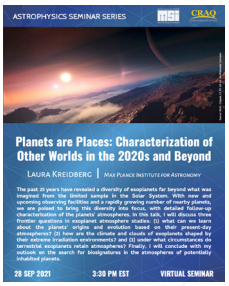












Astrophysics Seminar Series

05 Jan — **Yashar Hezaveh** *(Université de Montréal)*
'Probing the particle nature of dark matter with strong gravitational lensing'

19 Jan — **Alicia Rouco Escoria** *(Northwestern University)*
'From Be/X-Ray Transients At Low X-Ray Luminosity To Bright Unusual Short Gamma-Ray Bursts'

02 Feb — **Casey Law** *(Caltech)*
'Fast Transient Discoveries With Realfast At The Vla'

16 Feb — **Diana Powell** *(UC Santa Cruz)*
'Protoplanetary Disks and Clouds in Substellar Atmospheres: Insights from Microphysics '

09 Mar — **Amy Steele** *(University of Maryland)*
'Constraining The Composition Of Exoplanetary Material Using White Dwarf Stars '

23 Mar — **Allison Noble** *(Arizona State University)*
'Dissecting Galaxies in High-redshift Galaxy Clusters'

06 Apr — **Jane Rigby** *(NASA Goddard Space Flight Center)*
'Using Gravitational Lensing to Dissect Galaxies'

16 Sep — **Natasha Hurley-Walker** *(Curtin University)*
'An Ultra-Long Period Magnetar With Periodic Radio Emission'

28 Sep — **Laura Kreidberg** *(Max Planck Institute for Astronomy)*
'Planets are Places: Characterization of Other Worlds in the 2020s and Beyond'

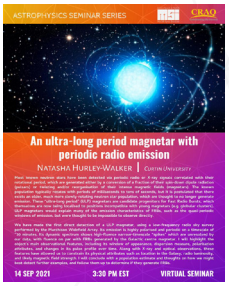
19 Oct — **Laura Keating** *(Leibniz Institute for Astrophysics Potsdam)*
'Constraining the history of reionization with quasar absorption lines'

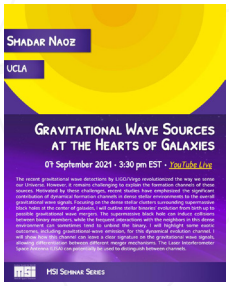
02 Nov — **Nissim Kanekar** *(NCRA - Tata Institute of Fundamental Research)*
'The atomic gas mass of galaxies during the epoch of galaxy assembly'

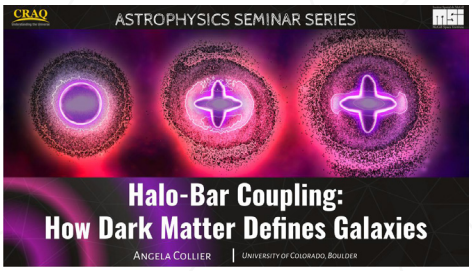
16 Nov — **Christina Williams** *(University of Arizona)*
'The Dark Side Of Distant Massive Galaxies, And New Light With JWST '

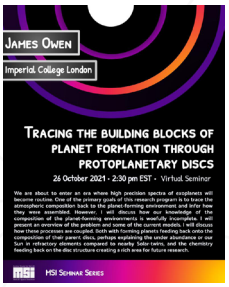
30 Nov — **Johanna Nagy** *(Washington University)*
'Cosmology with the Next Generation of Cosmic Microwave Background Experiments

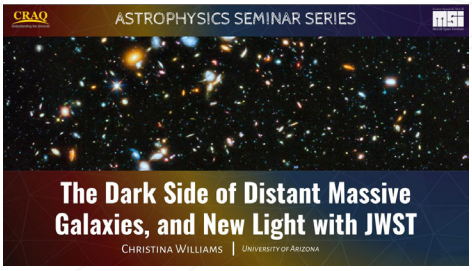
14 Dec — **Angela Collier** *(University of Colorado, Boulder)*
'Halo-Bar Coupling: How Dark Matter Defines Galaxies'

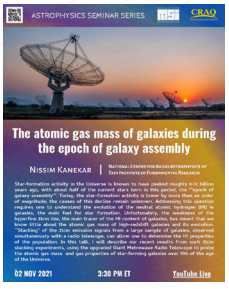


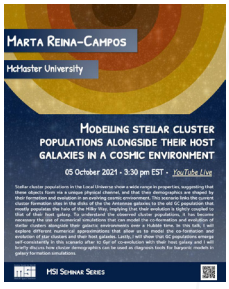








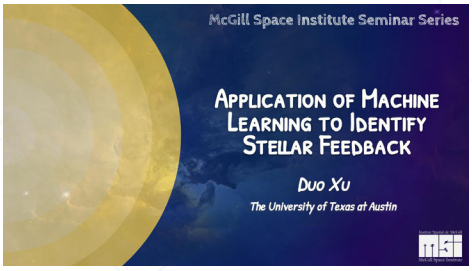




Special Seminars

30 Nov — **Allison Gonsalves** *(McGill University)*
'Social networks as identity supports for minoritized students in physics'

14 Dec — **Jason Sun** *(Caltech)*
'Understanding the Cosmological Evolution of Galaxies with Intensity Mapping'



Discussion Groups

MSI Lunch Talks

The Monday Lunch Talk series provides 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. These lunch discussions are held every other Monday year-round, on weeks where there is no MSI seminar. Like most of our events, Lunch Talks moved online in April 2020 and have remained virtual since. Speakers are limited to five slides (with unlimited blackboard usage) and are asked to prepare 15 minutes of material for a 30 minute slot; the remaining 15 minutes are filled by questions from the audience and discussion. Speakers may use the opportunity to talk about their research, practice a conference presentation, discuss an interesting finding in their field, or dive deeper into a subject outside their expertise that they'd like to learn more about. MSI Lunch Talks are well- attended, regularly drawing anywhere from 25 to 45 participants.

EPOD Discussion

EPOD (Education, Public Outreach, Equity, Diversity and Inclusion) Discussion is a weekly discussion group that deals with topics at the intersection of education, equity, and inclusion. EPOD discussions are paper-based, but the paper is usually meant to be a way of framing the discussion of a broader issue. The discussion is targeted at MSI members at all levels but we regularly welcome participants from the Physics department. More information about EPOD, including a list of topics discussed in 2020, can be found on page 34.

Astro-ph Discussion

Astro-ph is a weekly journal discussion that takes place every Friday morning at MSI over donuts and coffee. This year, it moved to an online format while we were all working from home. It is an open and intellectual discussion where people can feel free to share something they've learned from an interesting paper without criticism, and where the astronomy community at McGill can learn from one another. It lasts around 30 minutes and is named so because of the arXiv tag from where nearly all our papers come: astro-ph!

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. Each term, the group chooses a theme or particular area of planetary science that they want to learn more about, and each week someone leads a discussion about a paper or a topic related to that theme.

Neutron Star Discussion

Each week, researchers from across MSI come together in an informal setting to discuss the latest papers involving neutron stars. Neutron stars are a common thread that unites multiple research groups at MSI: they are a possible source of at least some Fast Radio Bursts being detected by CHIME (Prof. Kaspi & Prof. Dobbs); the discovery of a neutron star merger by LIGO has opened up a new way of studying these exotic objects (Prof. Haggard), and they are associated with emission at all astronomical wavelengths, including the highest energy photons (Profs. Hanna and Ragan). These new observational discoveries are challenging theories of how neutron stars form and evolve, and what matter is like in their dense interiors (Prof. Cumming).

Random Papers Discussion

The goal of Random Papers is to gain a broad view of current astrophysics research. Each week, a script chooses 5 random papers published in the last month in refereed astrophysics journals. This gives a different slice of the literature than the typical astro-ph discussion, with papers that might not otherwise be chosen for discussion. Rather than reading each paper in depth, the goal is to focus on the big picture, with questions such as: How would we summarize the paper in a few sentences? What are the key figures in the paper? What analysis methods are used? Why is this paper being written, and why now?

Black Hole Lunch

The Black Hole Lunch series is an informal gathering and discussion that centres 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 within McGill/MSI and the University of Montreal. Meetings alternate between McGill and UdeM, where attendees 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" (MBH CoLAB).

Cosmo-ph Discussion

Cosmo-ph is a weekly journal club at MSI focused on keeping up with recent results in observational and theoretical cosmology. Discussions are generally led by graduate students and postdocs, and feature papers that have appeared on the arxiv in the last few weeks. Attendees include researchers at all career stages, with expertise spanning a broad range, from instrumentation, to observations and data analysis, to high-energy particle theory.

Machine Learning in Astrophysics Journal Club

The Machine Learning in Astrophysics Journal Club is new to the roster of weekly events for 2021. It was co-founded by graduate students at MSI and Universite de Montreal and takes place every other week. Discussions are generally led by graduate students and focus on, as the name implies, the growing variety of applications of machine learning in astrophysics. So far, the group has had discussions about ML applications in pulsars, exoplanets, and cosmology.

Equity, Diversity & Inclusion

MSI is committed to equity, diversity, and inclusion (EDI) within the community. Fostering and sustaining an equitable and inclusive environment —one which recognizes the diversity of backgrounds, identities, and expectations— strengthens our community and our research. We aim to build EDI into our activities as we develop them, taking advantage of the fact that we are still a young research institute. So far, we have focused on creating space for discussion of EDI and workplace climate issues, primarily through our weekly EDI discussion group (see below). We have also prioritized identifying and addressing areas of underrepresentation in the immediate MSI community.

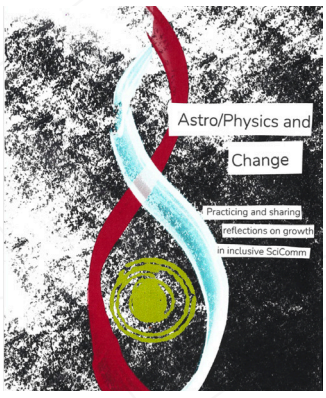
MSI collaborates on EDI related issues with similar groups both within and outside McGill. MSI works closely with the EDI Committee in the Physics Department and collaborates with the EDI Committee in Earth & Planetary Sciences. As of 2020, MSI has a seat on the Faculty of Science's Equity and Climate Committee (SECC), currently occupied by the MSI Coordinator. We also collaborate with the newly formed EDI Committee of the Center for research in astrophysics of Quebec (CRAQ).

EPOD Discussion & Hack Sessions

EPOD (Education, Public Outreach, Equity, Diversity and Inclusion) Discussion is a weekly discussion group run by the MSI coordinator. EPOD has been a mainstay of the MSI's activities since its founding, and the mandate of the group has evolved and changed to meet the needs and interests of the MSI's members. EPOD discussions explore issues at the intersection of education, equity, and inclusion. Discussions are paper-based (usually on either a journal article or occasionally a best practices report), but the paper is usually meant to be a way of framing the discussion of a broader issue.

EPOD is meant to be both a learning space and a place to think about the changes we can implement to become a more inclusive and welcoming space. The discussion is targeted at MSI members at all levels but we regularly welcome participants from the Physics department. Topic selection is a collective effort; at the beginning of each term, we run a brainstorming session where everyone is encouraged to suggest topics. MSI members are encouraged to suggest topics and lead the discussion if they so choose!

In January 2019, we introduced EPOD Hack Sessions, where we pick a topic we've discussed at EPOD and try to tackle a specific project that relates to it. Hack sessions are meant to help EPOD participants use the knowledge they've gained to produce something concrete and actionable, even if it's small. EPOD hack projects include a quantitative study of the gender breakdown of the department (2019), a set of guidelines for thinking about the ethical impact of physics/astronomy research (2020), and a zine collecting reflections about inclusive science communication (2021). The Zine project in particular was met with a lot of enthusiasm by the students, postdocs, faculty, and staff who participated. We ran writing and peer editing sessions for people to work on their pieces. The informal, do-it-yourself style of zines let us be personal, creative and share something physical made with love and care, in a format different to how we usually communicate about learning and science.



Climate Survey

MSI teamed up with the Physics department to develop a climate survey. The intention was to have a baseline of where we stand, to inform the changes needed to create a more inclusive environment. The survey was deployed in September 2020. The results were analysed over the Fall of 2020, with the final report published in May 2021. A copy of the full report is available upon request.

The main take-away was that different groups in the department have very different experiences across a variety of settings. While the tone of responses generally skewed positive, gender minorities, racial minorities, and LGBTQIA+ community members report a higher level of dissatisfaction across a variety of questions.

The results point to specific areas that are actionable, and we have already started implementing changes to address them. Concrete actions include highlighting the achievements of junior department members, both via our internal listservs and on our social media pages. Mental health emerged as a significant concern from the survey, so MSI and Physics established a joint task force on Mental Health in October 2021 to begin tackling the challenges faced by our members.

MSI will continue to be involved in future iterations of the climate survey, which we plan to run on a bi-yearly basis.

Addressing Areas of Under-representation

Despite improvements in the past decade, minority groups (including but not limited to racial and gender minorities) continue to be underrepresented in the field of astronomy. Our institute is not exempt. We have made a particular effort to address under-representation at the post-doctoral level, implementing best practices during the application and evaluation process. The changes we implemented yielded results; for the past two years, over 50% of our incoming MSI postdoctoral fellows have been women. For the 2022 cycle, we are looking at how to do the same for racial diversity, particularly to address the lack of Black and Indigenous postdocs. There is still more work to be done and we are committed to continuing our efforts and ensuring that the environment we are recruiting into is inclusive.

A Glimpse into EPOD Discussion Topics: 2021

- *'Introduction to science and technology studies (of Physics)'*
- *'Cultural and environmental impact of physics/astro activities: case studies'*
- *'Where do values belong in science?'*
- *'The masculine construction of physics'*
- *'Who gets to do physics/science and who gets to watch (scientific publics)'*
- *'Indigenous epistemologies in physics/astro'*
- *'Physics identity'*
- *'Supervision structures and EDI'*
- *'How to talk about EDI in the classroom'*
- *'Critical science pedagogy'*
- *'The role of qualitative research methods and intro to qualitative methods'*
- *'Lit review - inclusive science communication'*
- *'Inclusive Science Communication"*
- *'Problematizing science communication'*
- *'Approaches to inclusive science communication going forward'*
- *Zine planning & brainstorming of prompts*
- *Zine project: writing & editing sessions*
- *'Physics and capitalism'*
- *'Physics/Astro research funding structures'*
- *'Does organising have a role in departments and labs?'*
- *'Climate change and physics/astro'*
- *'Research, communications, and land relations*
- *Strategic communication & audience*
- *Barriers to doing science : white supremacy*
- *Barriers to doing science : classism*

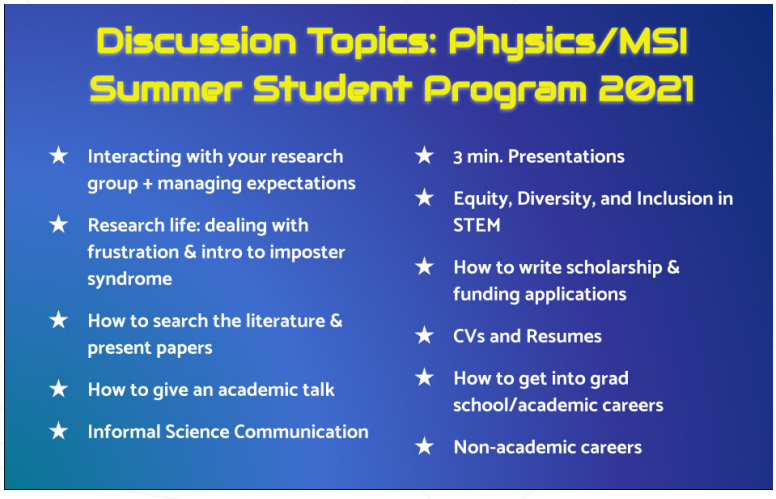
MSI Undergrad Summer Program

Every summer since its inception, MSI hosts undergraduate summer research students from McGill and universities across the world. An integral part of the summer research experience at MSI is the MSI Summer Undergraduate Researcher Program, which consists of weekly Professional Development Discussion and an end-of-the-summer Undergraduate Research Showcase. Due to the popularity of the program, in 2019 MSI was asked to expand the program to the entire Department of Physics, and we've hosted a joint summer program ever since. The program is open to all undergraduates conducting summer research with MSI-affiliated or Physics-affiliated professors. This year's edition of the program hosted over 60 undergraduate summer researchers, of which approximately 40 were working with MSI researchers. Due to the COVID-19 pandemic, the program was once again hosted entirely virtually. Weekly Zoom meetings and a Slack workspace helped us build a sense of community while working remotely.

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 informal discussions. Thanks to the friendly community and welcoming environment of the MSI, summer undergraduate researchers gain exposure to many different research areas well beyond their own group.

Professional Development Discussions

A unique feature of the MSI summer undergraduate research program is a weekly seminar series for the undergraduate students. The format of these weekly seminars is a casual discussion, organized by MSI Coordinator Carolina Cruz-Vinaccia and Physics Undergraduate Advisor Kim Metera, with immense help from various other MSI members. The primary goal of this weekly seminar series is to provide guidance and mentorship 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 seminars is to foster a sense of community amongst the undergraduate summer researchers, and ensure that they become familiar with their peers.



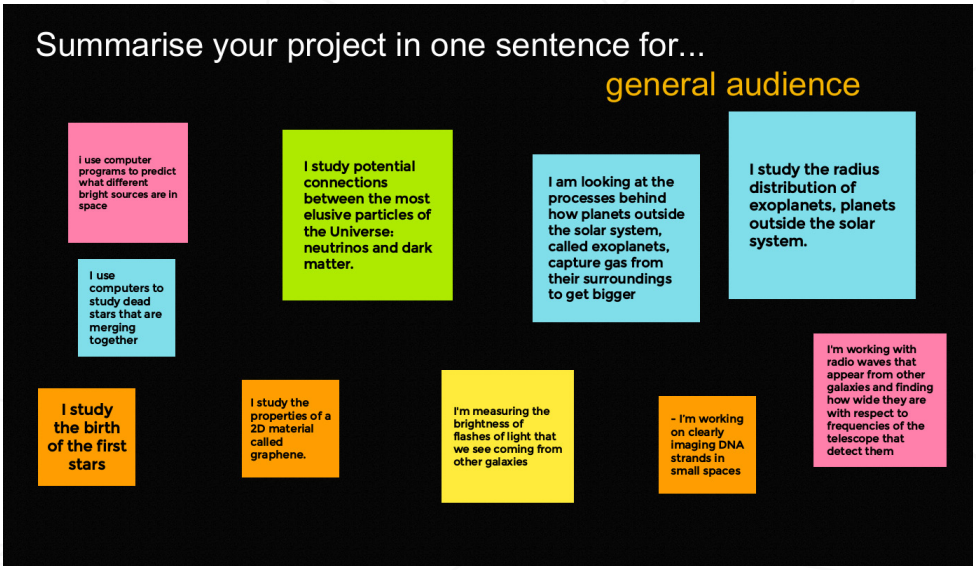
Discussion topics centre primarily around professional development, such as "how to give effective talks", "how to write scientific papers", "applying to graduate school", and "pursuing non-academic careers". The program also emphasized non-academic topics that impact researchers, such as dealing with frustration, how to tackle impostor syndrome, and a workshop on diversity and inclusion in STEM. This year's program emphasized science communication, both to other scientists and to the public. Students had multiple opportunities to practice their communication skills, from informal 3 minute talks about their research, to workshops on distilling the essence of their research to non-scientists, to a 10-minute scientific talk about their research project.

These weekly sessions took place entirely on Zoom due to COVID-19 restrictions. The online format let us experiment with multiple forms of participation. Our undergraduates adapted incredible well, engaging enthusiastically with everything from Jamboards to communal slide making to Impostor Syndrome Bingo! Feedback reflected that though they missed in-person interactions, they appreciated the sense of community and break from isolation that the program provided.

Undergraduate Research Showcase

Each year, we cap off the Summer Program with a Research Showcase, where undergraduate summer researchers were given the opportunity to present the results of their project to the entire MSI and Physics Department. This year's showcase took place entirely on Zoom, but the virtual format did not impact participation; we had over 30 presenters! The showcase took place over an entire afternoon, from 1pm to 5pm. There were four blocks of presentations, with 8 presenters giving 5-min talks back to back and then breakout rooms for the audience to interact with the presenters.

The undergraduate research projects covered a wide range of topics that reflected the diverse and interdisciplinary nature of the MSI. The presentations were evaluated by a panel of judges, who then handed out awards for the four best presentations (two of whom were MSI summer students). The quality was so high that we also recognized 3 presenters with honourable mentions.



Best Presentation

Jade Ducharme
Yuliya Shpunarska
Mikka Stasiuk
Elvira Vazquez-Avila

Honourable Mentions

Thomas Abbott
Sarah Christensen
Martin Gallois

05 People

Awards

Faculty Members

Robert Brandenberger
2021 CAP Medal For Lifetime Achievement In Physics

Daryl Haggard
Member of the Royal Society of Canada's College of New Scholars, Artists, and Scientists

Vicky Kaspi
- *2021 Shaw Prize In Astronomy*
- *Fellow of the American Astronomical Society*

Eve Lee
William Dawson Scholar

Graduate Students

Lea Baumser
David Stewart Memorial Fellowship

Sabrina Berger
NSERC-CREATE NTCO

Simon Guichandut
NSERC PGS-D

Tim Hallatt
NSERC CGS-D Alexander Graham Bell

Mahesh Herath
David Stewart Memorial Fellowship

Samuel Laliberte
FRQNT Doctoral Scholarship

Brady O'Connor
- *NSERC PGS-D*
- *FRQNT BX2 Doctoral Award*

Emily Parent
Graduate Student Award of Merit from the Senior Women Academic Administrators of Canada (SWAAC)

Ziggy Pleunis
2021 J.S Plaskett Medalfor the best doctoral thesis in astrophysics in Canada

Jeremy Roffman
David Stewart Memorial Fellowship

Vishwangi Shah
MITACS Globalink Graduate Fellowship

MSI Members

Faculty

Robert Brandenberger
Cynthia Chiang
Jim Cline
Nicolas Cowan
Andrew Cumming
Matt Dobbs
René Doyon
Natalya Gomez
Daryl Haggard
David Hanna
Yi Huang
Vicky Kaspi
Eve Lee
Adrian Liu
Nagissa Mahmoudi
Timothy Merlis
Ken Ragan
Katelin Schutz
Jonathan Sievers
Tracy Webb
Lyle Whyte

Associate Members

Oscar Hernandez
Richard Léveillé

Staff

Carolina Cruz-Vinaccia

Postdoctoral Researchers

Gonzalo Alonso-Alvarez
Suddhasattwa Brahma
Arnab Chakraborty
Cherie Day
Kristen Dage
Miguel Angel Fernandez
Emmanuel Fonseca
Adélie Gorce
Saniya Heeba
Mona Jalilvand
Ronniy Joseph
Adam Lanman
Ryan McKinven
Daniele Michilli
Jordan Mirocha
Raul Monsalve
Thomas Navarro
Stephan O'Brien
Aaron Pearlman
Emily Petroff
Masoud Rafiei-Ravandi
Peter Sims
Amy Steele
Chia Min Tan
Dallas Wulf
Maryam Yousefi
Fernando Zago

Graduate Students

Mohan Agrawal
Soud Al Karusi
Bridget Andersen
Lea Baumser
Taylor Bell
Sabrina Berger
Mohit Bhardwaj
Vadym Bidula
Olivia Blenner-Hasset
Hope Boyce
Nirmalya Brahma
Margaret Bruna
Pragya Chawla
Paul Chouha
Vincent Comeau
João Corrêa Buschinelli
Alice Curtin
Bryce Cyr
Lisa Dang
Amanda Di Nitto
Constanza Echiburu
Aline Gramacho Favero
Kelly Foran
Nicole Ford
Hannah Fronenberg
Rafael Fuentes
Guillermo Gambini
Samskruthi Ganjam
Erin Gibbons
Simon Guichandot
Timothy Hallatt
Ian Hendriksen
Mahesh Herath
Ian Hendricksen
Lawrence Herman
Hao Jiao
Xiangyu Jin
Alexandre Josephy
Zarif Kader
Zoe Kearney
Dylan Keating
Marie-Pier Labonte
Samuel Laliberte
Julia Lascar
Benoit Laurent
Anan Lu
Matthew Lundy
Catherin Maggiori
Lisa McBride
Melissa Mendes Silva
Marcus Merryfield
Gabrielle Mitchell
Keavin Moore
Karishma Moorthy
Brady O'Connor
Michael Pagano
Xinyu Pan
Emilie Parent
Robert Pascua
Matheus Pessoa
Elizabeth Pieters
Matteo Puel
David Purnell
Jeremy Roffman
Maclean Rouble
Ketan Sand
Vishwangi Shah
Jared Splinter
Andrew Sikora
Nicolas Vieira
Jeannette Wan
Huiyi (Cheryl) Wang

Undergraduate Students

Thomas Abbott
Sina Babaeizadeh
Emma Barbisan
Joelle-Marie Begin Miolan
Katarina Bleau
Alexandra Bojanich
Eitan Buffaz
Jonathan Colaco-Carr
Dhvani Doshi
Jade Ducharme
Taj Dyson
Stephen Fay
Charlotte Garcia
Alex Gass
Christian Hellum Bye
Ian Hendricksen
Hans Hopkins
Jeff Huang
Amalia Karalis
Jacob Kennedy
Marc-Olivier Lalonde
Kathryn Landry
Alexander Laroche
Mattias Lazda
Xueying Li
Olivia Locke
Samson Mercier
Camryn Mullin
Cedrick Perron
Michael Poon
Isabella Ricci
Phoebe Richman-Taylor
Katie Savard
Yuliya Shpunarska
Simon Tartakovsky
Sarah Thiele
Thomas Villeneuve
Qui Shi Wang
Lan Xi Zhu
Jasmine Zhang

MSI Fellowships

MSI Postdoctoral Fellows

McGill Space Institute Postdoctoral Fellowships are awarded by a committee of faculty members who span different fields of the MSI and recognize excellence in research. McGill Space Institute Fellowships are made possible by a generous donation from the Trottier Family Foundation to support MSI postdoctoral researchers and graduate students.

Arnab Chakraborty
Physics • Prof. Matt Dobbs's Group
Dr. Chakraborty has been an MSI postdoctoral fellow since Fall 2021. He works on observational cosmology and trying to understand the distribution of baryons at large scales using the redshifted 21-cm signal of atomic hydrogen. He is also interested in radio instrumentation and data analysis of CHIME and the upcoming CHORD telescope.

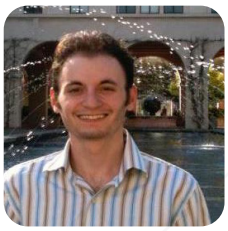
Kristen Dage
Physics • Prof. Daryl Haggard's Group
Dr. Dage joined MSI as a MSI postdoctoral fellow in Fall 2020. She studies the population of X-ray binaries in globular clusters, with a focus on ultraluminous X-ray sources, which provide observational evidence of the extent of black holes in extragalactic globular clusters and the nature of the clusters that host them.

Mona Jalilvand
Physics • Prof. Jonathan Slevers's Group
Dr. Jalilvand has been an MSI Postdoctoral Fellow since Winter 2021. She works with Prof. Jon Sievers.

Saniya Heeba
Physics • Prof. Katelin Schutz's Group
Dr. Saniya Heeba has been an MSI Postdoctoral Fellow since Fall 2021. She studies dark matter at the intersection of particle physics and cosmology. Broadly, that includes how dark matter is produced in the early universe, how it evolves, and how it can be probed using terrestrial and cosmological search strategies.

Ronniy Joseph
Physics • Prof. Jonathan Slevers's Group
Dr. Joseph joined Prof. Slevers's as an MSI Postdoctoral Fellow in Fall 2021. He works on the detection of faint ancient radio signals from the most distant parts of the Universe to understand formation of very first stars and the Universe itself.

Thomas Navarro
EPS • Prof. Natalya Gomez, Prof. Nicolas Cowan, Prof. Tim Merlis
Dr. Navarro has been an MSI postdoctoral fellow since Fall 2019. Dr Navarro explores the meteorology and climate of terrestrial planets with general circulation models and observations. His research interests are the Martian dust and water cycles, Venus' atmospheric circulation, and the possible climates of tidally locked exoplanets.



Aaron Pearlman
Physics • Prof. Vicky Kaspi's Group
Dr. Pearlman joined MSI in as an MSI postdoctoral fellow in Fall 2020. Dr. Pearlman is currently working on precisely localizing FRBs on the sky using the CHIME/FRB radio telescope and several outrigger radio telescopes that are under rapid development as part of the CHIME/FRB Outrigger project.

Peter Sims
Physics • Prof. Jonathan Slevers's Group
Dr. Sims has been an MSI postdoctoral fellow since Fall 2020. He works on data analysis techniques to enable observational probes of the redshifted 21 cm hyperfine line of neutral hydrogen gas during Cosmic Dawn and the Epoch of Reionization, and the extraction of astrophysical and cosmological information encoded in observations of said periods.

Amy Steele
Physics • Prof. Eve Lee, Prof Nicolas Cowan
Dr. Steele has been an MSI Postdoctoral Fellow since Summer 2021. She studies circumstellar gas and dust, with a focus on using dead planetary systems to probe the composition of exoplanets.

Dallas Wulf
Physics • Prof. Matt Dobbs's Group
Dr. Wulf has been an MSI postdoctoral fellow since January 2019. His research interests include instrumentation for radio interferometry, with applications in 21cm cosmology, the interstellar medium, and radio transients. He is also interested in physics education research.

Fernando Zago
Physics • Prof. Jonathan Slevers's Group
Dr. Zago has been an MSI postdoctoral fellow since Fall 2019. His research interests range from theoretical early-universe cosmology to the analysis of astrophysical data. His works on the development of computational tools geared towards the extraction of cosmological signals from radio and microwave observations of the sky.

MSI Graduate Fellows

As of 2018, every new MSc or PhD student supervised by an MSI faculty member receives a fellowship and the title of MSI Graduate Fellow. As a result, all MSI graduate students receive a portion of their funding from the Trottier Family Foundation's gift. Our incoming 2021 MSI Graduate Fellows are featured below*.

Mohan Agrawal
Supervisor: Jon Sievers
Department of Physics

Lea Baumser
Supervisor: Nagissa Mahhmoudi
Earth & Planetary Sciences

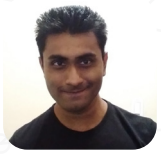
Vadym Bidula
Supervisor: Jon Sievers
Department of Physics

Nirmalya Brahma
Supervisor: Katelin Schutz
Department of Physics

Nicole Ford
Supervisor: Daryl Haggard
Department of Physics

Noah Goldman
Supervisor: Eve J. Lee
Department of Physics

Ian Hendricksen
Supervisor: Cynthia Chiang
Department of Physics



Mahesh Herath
Supervisor: Nicolas Cowan
Earth & Planetary Sciences

Zoe Kearney
Supervisor: Tracy Webb
Department of Physics

Samuel McNichol
Supervisor: Nagissa Mahhmoudi
Earth & Planetary Sciences

Jeremy Roffman
Supervisor: Natalya Gomez
Earth & Planetary Sciences

Vishwangi Shah
Supervisor: Vicky Kaspi
Department of Physics

Jared Splinter
Supervisor: Nicolas Cowan
Earth & Planetary Sciences

Huiyi (Cheryl) Wang
Supervisor: Eve J. Lee
Department of Physics

Qing Hao Xu
Supervisor: Vicky Kaspi
Department of Physics

** Not pictured: Louis-Jacques Bourdage (Natural resource Sciences), Aryana Hagjoo (Physics)*

MSI Summer Undergraduate Research Awards

2021 marked the first year of our MSI Summer Undergraduate Research Awards (MSI SURAs), a fellowship program aimed at funding undergraduate students interested in pursuing research with MSI faculty members. MSI Summer Undergraduate Research Awards are a unique opportunity for undergraduate students to join the MSI's interdisciplinary, vibrant community, while engaging in cutting-edge research in astrophysics, planetary science, atmospheric science, or astrobiology. MSI SURA recipients also participate in our MSI Undergraduate Summer Program (see page 34).

The program acts as a financial complement to our existing Summer Undergraduate Research Programme, and also complements existing McGill summer undergraduate fellowship programs (NSERC USRA & McGill SURA). MSI Summer Undergraduate Research Awards are valued at $3500, which is supplemented by the supervisor's funds to provide a stipend of approximately $7000 for the whole summer. Applications are open to students pursuing an undergraduate degree in relevant fields at any Canadian university, at any point in their programs. In recognition of the growing importance of having access to research opportunities, we actively encourage applications from students in the early stages of their program.

The evaluation process was designed with MSI's commitment to equity, diversity, and inclusion in mind. Applications are evaluated by the MSI Summer Undergraduate Award Committee, which is composed of postdoctoral researchers and the MSI Coordinator (see page xx). The evaluation rubric developed by the committee was made publicly available on our website during the application process. During the deliberation process, the committee took care to ensure that there was a diversity of interests, research fields, and background represented on the short list of candidates.

Overall, the pilot project proved to be a success! We received over 80 applicants from universities across Canada. The quality of the applicant pool was impressive, making the committee's job quite difficult! In the end we awarded 6 MSI SURAs, with an additional 7 applicants receiving Honourable Mentions. Our inaugural cohort of awardees spans the breadth of research areas at MSI, with students working on everything from fast radio bursts to white dwarfs to microbial assays. You can learn more about our inaugural cohort and their experiences with the program, in their own words, on the next two pages.

MSI SURA Recipients
Sina Babaei Zaideh
Jonathan Colaco-Carr
Charlotte Garcia
Marc-Olivier Lalonde
Kathryn Landry
Yuliya Shpunarska

Honourable Mentions
Davin Baal
Joelle-Marie Begin Miolan
Shereen Elaidi
Amalia Karalis
Zixuan Lan
Niharika Namulla
Elvira Vazquez Avila

Sina Babaei Zadeh

University of Toronto • Prof. Andrew Cumming

About your project: I analyzed existing models to look for patterns based on the key properties of white dwarfs. I ended my project by building my own model to mimic the behaviour of such stars using python!

Favourite part: The highlight of my summer was attending group meetings and general MSI workshops. As a person coming from a marginalized background, these events allowed me to network with field experts and truly learned about the scientific method and how scientific collaboration is done. A few of the other things that I learned are programming skills and complex problem-solving skills which are not taught in most classrooms!

Jonathan Colaco-Carr

McGill University • Prof. Adrian Liu

About your project: My project was "Decontaminating 21cm Cosmology Observations with Deep Learning". The goal of this project was to determine whether machine learning could be used to restore contaminated 21cm cosmology data.

Favourite part: I had a lot of fun working Dr. Liu's cosmology group. It hosts a broad range of smart people asking some very hard questions about the universe. I really enjoyed learning from all of them about how to communicate complex problems to fellow researchers.

Charlotte Garcia

McGill University • Prof. Tracy Webb

About your project: We used the software FAST, developed by Mariska Kriek, to fit stellar population to broadband photometry, which then outputs information about the population such as redshift, age, dust content and star formation rate. With such data, we were able to compute the luminosity distance and emitted luminosity for each galaxy, and from this we were able to compute their stellar mass. We then plotted stellar masses against each other with different parameters to try to explain any unexpected result.

Favourite part: I particularly liked the weekly meetings we had where everyone described their ongoing project!

Marc-Olivier Lalonde

McGill University • Prof. Cynthia Chiang

About your project: My project, "Autonomous antenna station development for ALBATROS", was mainly building and testing the backend electronics for our antennas as well as doing antenna simulations for further improvements. I also had the chance to set up our experiment at Uapishka Station in northern Quebec.

Favourite part: "I loved being able to do more hands-on work as there are fewer opportunities to do so in class. Working with an amazing group and supervisor is also a bonus."

Kathryn Landry

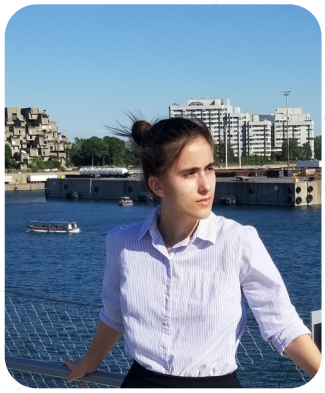
McGill University • Prof.Lyle Whyte

About your project: I worked on the optimization of uMAMA (microfluidics microbial activity microassay) to detect living microbes in extreme environments. Each well in the assay contains a dye and inorganic substrate, chosen due to their potential presence on Mars. We load a sample into the assay and if its color visibly changes, we can conclude that microbes are actively metabolizing the substrate. This will allow us to determine if there are live microbes on Mars.

Favourite part: I enjoyed exploring a new area of microbiology that I hadn't done research in. I was able to design experiments and work with mentors to discover solutions to assay issues, deepening my understanding of microbiology and assay development.

Yuliya Shpunarska

McGill University • Prof. Vicky Kaspi



About your project: My project aimed to provide the CHIME collaboration with several Python scripts to obtain flux and fluence measurements of Fast Radio Bursts (FRBs) for the first time using this telescope. When coupled with precise distance measurements, these results will pave the way to obtaining reliable luminosity estimates of FRBs.

Favourite part: I particularly enjoyed having tons of opportunities to talk about my project and present it either in front of other undergrads at the MSI weekly meetings, at the WVU symposium, or even just in CHIME team meetings. Having to put my progress into words several times a week was an important sanity check and gave me no choice but to have a deep understanding of what I was working on.

MSI Board & Committees

MSI Board 2021

External Members

Lorne Trottier
Co-founder · Matrox

Marc Guilbert
Chief Financial Officer · Kelvin Zero Inc.

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 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

Nagissa Mahmoudi
Assistant Professor of Earth & Planetary Sciences

Dallas Wulf
Postdoctoral Fellow, Physics

Catherine Maggiori
PhD Student, Natural Resource Science

MSI Committees

Fellowships Committee

Adrian Liu [Co-Chair]
Assistant Professor, Physics

Robert Brandenberger
Professor, Physics

Nagissa Mahmoudi
Assistant Professor of Earth & Planetary Sciences

Kenneth Ragan
Professor, Physics

Jonathan Sievers
Associate Professor, Physics

MSI Seminar Committee

Eve Lee [Co-Chair]
Assistant Professor, Physics

Katelin Schutz [Co-Chair]
Assistant Professor, Physics

Kristen Dage
Postdoctoral Fellow, Physics

Miguel Angel Fernandez
Postdoctoral Fellow, Natural Resource Science

Jordan Mirocha
Postdoctoral Fellow, Physics

Amy Steele
Postdoctoral Fellow, Physics

Carolina Cruz-Vinaccia
MSI Coordinator

Undergraduate Summer Awards Committee

Carolina Cruz-Vinaccia
MSI Coordinator

Kristen Dage
Postdoctoral Fellow, Physics

Jordan Mirocha
Postdoctoral Fellow, Physics

Thomas Navarro
Postdoctoral Fellow, Earth & Planetary Sciences

Stephan O'Brien
Postdoctoral Fellow, Physics

Dallas Wulf
Postdoctoral Fellow, Physics

AstroMcGill Steering Committee

Daryl Haggard
Associate Professor, Physics

Bridget Andersen
PhD Student, Physics

Taylor Bell
PhD Student, Physics

Lisa Dang
PhD Student, Physics

Simon Guichandut
PhD Student, Physics

Carolina Cruz-Vinaccia
MSI Coordinator

06 Impact

Facilities Used by MSI Members

Laboratory & 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, Chiang)
Supports field research activities consisting of sample acquisition, some limited laboratory microbial and molecular analyses, and in situ analyses for microbial activity. Also used for low-frequency radio astronomy observations.

McGill Radio Lab
(Chiang)
Develops radio instrumentation for observational cosmology experiments.

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

Béluga supercomputer
(Lee, Liu, Kaspi)
Owned and administered by Compute Canada and Calcul Quebec

Cedar supercomputer
(Haggard, Liu)
Owned and administered by Compute Canada

Graham supercomputer
(Lee, Brandenberger)
Owned and administered by Compute Canada

Narval supercomputer
(Haggard)
Owned and administered by Compute Canada and Calcul Quebec

Ground-based Telescopes

Anglo-Australian Telescope
(Webb)

Atacama Large Millimeter Array
(Haggard, Webb)

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

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

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

Event Horizon Telescope Array
(Haggard)

Gemini Observatory
(Haggard, Webb)

Green Bank Telescope, Radio wavelengths
(Kaspi)

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

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

James Clerk Maxwell Telescope
(Haggard)

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

Large Millimeter Telescope Alfonso Serrano
(Webb)

Observatoire du Mont-Mégantic
(Cowan, Haggard)

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

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

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

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

W.M. Keck Observatory
(Webb)

VERITAS Gamma-ray Telescope
(Hanna, Ragan)

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, Haggard, Lee, Webb)

NASA/Kepler Mission
(Cowan)

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

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

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

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

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

NASA Spitzer Space Telescope
(Cowan, Haggard, Webb)

NASA/Fermi Mission
(Ragan)

NASA/Transiting Exoplanet Survey Satellite
(Lee)

MSI Faculty Collaborations

ARIEL Atmospheric Remote-sensing Infrared Exoplanet Large-survey
(Cowan)
Other participating countries:
◦ UK ◦ France ◦ Italy ◦ Poland ◦ Belgium ◦ Spain ◦ the Netherlands ◦ Austria ◦ Denmark ◦ Ireland ◦ Norway ◦ Sweden ◦ Czech Republic ◦ Hungary ◦ Portugal ◦ Germany ◦ Estonia

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

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 University ◦ MIT

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 ◦ UBC ◦ University of Alberta ◦ University of Manitoba

D3A - Deep Dish Development Array
(Chiang, Dobbs, Sievers)
Other participating institutions:
◦ National Research Council ◦ Dominion Radio Astrophysical Observatory ◦ University of Toronto

EPPE Extrasolar Planet Polarimetry Explorer
(Cowan)
Other participating institutions:
◦Western Ontario ◦ Magellan Aerospace ◦ NRC Hertzberg

Event Horizon Telescope Collaboration
(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

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 ◦ Western Michigan University

HELIX - High Energy Light Ion eXperiment
(Hanna)
Other participating institutions:
◦ University of Chicago ◦ Penn State University ◦ Ohio State University ◦ University of Michigan ◦ Indiana University ◦ Northern Kentucky University

HERA - The Hydrogen Epoch of Reionization Array
(Liu, Sievers)
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 ◦ Queen Mary University of London ◦ University of Pennsylvania ◦ Scuola Normale Superiore di Pisa ◦ SKA-South Africa ◦ University of Washington ◦ University of Western Cape ◦ Winona State University

HIRAX
(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 Astroparticule & 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

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

LISA Consortium
(Haggard)
Participating countries:
Germany ◦ Italy ◦ France ◦ UK ◦ Switzerland ◦ Spain ◦ Denmark ◦ The Netherlands ◦ Belgium ◦ Portugal ◦ Sweden ◦ Hungary ◦ Romania ◦ Canada ◦ USA

Maunakea Spectroscopic Explorer
(Haggard, Webb)
Other participating institutions:
◦ National Research Council (Canada) ◦ CNRS (France) ◦ University of Hawaii (United States) ◦ AAO Macquarie (Australia) ◦ Indian Institute of Astrophysics (IIA) ◦ NAOC (China) ◦ NOAO (United States) ◦ Texas A&M (United States)

MBH CoLAB Montréal Black Hole Collaboration
(Haggard, Webb)
Other participating institutions:
Université de Montréal

MIST - Mapper of the IGM Spin Temperature
(Chiang, Sievers)
Other participating institutions:
◦ Universidad Católica de la Santísima Concepción ◦ Universidad de Chile ◦ National Radio Astronomy Observatory

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

NICER NASA's Neutron Star Interior Composition Explorer
(Kaspi)
Other participating institutions:
MIT Kavli Institute for Astrophysics and Space Research ◦ NASA Goddard Space Flight Center ◦ Noqsi Aerospace

NIRISS Near-InfraRed Imager and Slitless Spectrograph, James Webb Space Telescope
(Cowan)
Other participating institutions:
Cornell University ◦ COM DEV ◦ National Research Council Canada ◦ Saint Mary's University ◦ Space Telescope Science Institute (STScI) ◦ Swiss Federal Institute of Technology Zurich ◦ Université de

Montréal ◦ University of Rochester ◦ University of Toronto ◦ York University

NIRPS Near Infrared Planet Spectrograph
(Cowan)
Other participating countries:
◦Switzerland ◦ France ◦ Brazil ◦ Portugal ◦ Spain

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

PITCH BLACK - JCMT Large Program
(Haggard)
Other participating institutions:
East Asian Observatory ◦ University of Oxford ◦ Curtin University ◦ Nihon University ◦ New York University Abu Dhabi ◦ University of Amsterdam ◦ University of Alberta ◦ Chinese Institute of High Energy Physics ◦ Shanghai Astronomical Observatory ◦ Academia Sinica Institute of Astronomy and Astrophysics ◦ INAF-Rome Observatory ◦ Chalmers University ◦ University of Durham ◦ University of Southampton ◦ McGill University ◦ Institut Teknologi Bandung ◦ Tokyo Tech University ◦ National Tsing Hua University ◦ Shibaura Institute of Technology ◦ Texas Tech University ◦ Ehime University ◦ University of the Chinese Academy of Sciences ◦ Kyoto University

PRIZM/ALBATROS
(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

The Simons Observatory
(Dobbs, Sievers)
Other participating institutions:
◦ Lawrence Berkeley National Laboratory ◦ Princeton University ◦ Universityvof California, San Diego ◦ University of California, Berkeley ◦ University of Pennsylvania

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

SPIRou Spectro-Polarimetre Infra-Rouge Science Legacy Survey
(Cowan, Lee)
Other participating countries:
◦France ◦ Brazil ◦ Taiwan ◦ Switzerland ◦ Portugal

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 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

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 ◦ UCLA ◦ UC Santa Cruz ◦ University of Chicago ◦University of Delaware ◦ University of Iowa ◦ University of Minnesota ◦University of Utah ◦ Washington University, St. Louis

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