2023 Annual Report

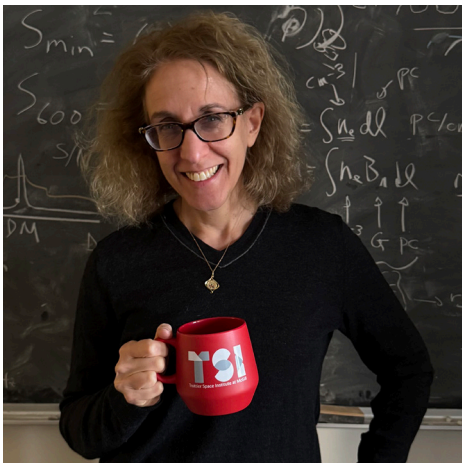
Trottier Space Institute at McGill

Institut spatial Trottier de McGill

TABLE OF CONTENTS

WELCOME

A Message from TSI Director, Prof. Vicky Kaspi



With the passage of our first year as the newly named Trottier Space Institute, it is worth taking a moment to reflect on our core mission: to provide an intellectual home for researchers in space-related areas and foster cross-fertilization and interdisciplinary interactions and collaborations between them; to support the development of technology and instrumentation for space-related research; to share our research goals, techniques, and results with students, educators, and the public.

TSI researchers are accomplishing these goals with style. With a brilliant cadre of faculty at the research helm, our undergraduate and graduate student researchers, as well as our postdoctoral scholars, are leading or playing leading roles in many of the most interesting astrophysical endeavours of today. Whether it's at the forefront of astrophysics and astrophysical instrumentation — studying the event horizons of supermassive black holes, the history of the Universe, cosmic dawn and the evolution of galaxies, compact objects and astrophysical transients — or understanding our planet's atmosphere and the now thousands of discovered extrasolar planets and what they can tell us about climate physics and the possibilities of extraterrestrial life, TSI research activities are among the most interesting in science today. And what's more, our interests couple easily with those of curious people, making outreach with educators, the press, and the public at large easy, and another great success of TSI.

The above accomplishments are thanks of course to the generous gift from the Trottier Family Foundation after which our Institute is named. But also, they are in no small way a result of the warm, friendly atmosphere we try to hard to foster at TSI, a place where students of all backgrounds, cultures, religions and identities can feel safe to pursue their passion: space-related science. As Director, I will continue to work hard to ensure all members feel welcome, respected, and safe, and have the intellectual and physical resources to reach their potential and, of course, to reach the stars.

A Message from TSI Associate Director, Prof. Ken Ragan

Welcome to the 2023 TSI Annual Report. Again, our goal has been to provide a brief overview of a very busy and active institute. In the bustle of our individual lives as students, staff, or faculty, it's sometimes easy to overlook the "big picture" story of an institute like ours. The Annual Report reminds us to do that - to remember that we have an incredible and devoted staff, an accomplished cohort of students, and a world-class team of faculty, and that together our activities span the gamut from cutting-edge research to large public outreach events.

Some of the notable highlights from this year include two new TSI staff members (Ms. Vincie Tang as our new Administrative Assistant, and Dr. Ste O'Brien as our new Computing Postdoctoral Fellow), continued planning for a new TSI building, which will provide modern spaces to complement the charming-but-quirky current building which houses the institute, and planning for the 2024 total solar eclipse (as you read these lines, that has occured and was a roaring success - but the full story will only be told in the 2024 Annual Report!).

Finally, this will be my last full year of being the TSI Associate Director. You'll be hearing from someone new in next year's report, so let me take this opportunity to thank you all for your contributions to the continued success of the TSI. That it is an enjoyable and exciting place to do science and outreach is a testament to you, the people that make it happen!

ABOUT TSI

The Trottier Space Institute at McGill (TSI) 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. TSI was established in 2015 thanks to a generous gift from the Trottier Family Foundation.

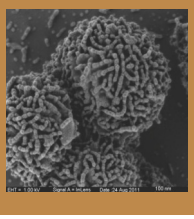
The main goals of the Institute are to:

- 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.

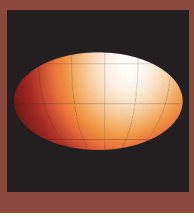
TSI RESEARCH AREAS

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



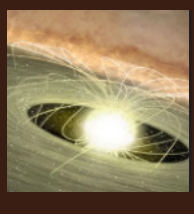
The Astrobiology and Extraterrestrial Biosignatures group examines microbial biodiversity and ecology in unique ecosystems like the Canadian High Arctic and the Antarctic dry valleys, studying microbial communities using classical microbiology and novel genomics-based molecular techniques. Understanding what types of microorganisms survive in these types of soils and detecting biosignatures provides insight into what to look for in near surface water ice on Mars or other cold, rocky places in the solar system. Members of the group also use cutting-edge telescopes 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*



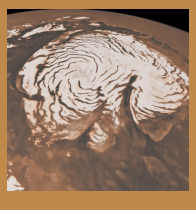
The extrasolar planet climate and atmosphere group characterizes exoplanets using observational evidence and climate modelling. Observational evidence for exoplanetary atmospheres comes from a variety of sources, including changes in brightness of the planet over time, spectroscopy, and upcoming next-generation 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).

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



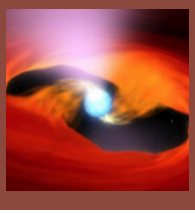
The quantity and diversity of known exoplanets provides an opportunity to learn about planetary formation, evolution, and the physical processes that operate in their atmosphere and interiors. The challenge is to connect observed properties of planets with theories of their formation, structure, and evolution. The group uses theoretical tools to identify the key physical processes behind the observed diversity of planetary systems, from super-Earths to gas giants. They study the earliest evolution of star-forming environments, protoplanetary disk evolution, disk-star-planet interaction, formation of planetary atmospheres, and dynamical interactions within planetary systems.

Planetary Surfaces • *Natalya Gomez*



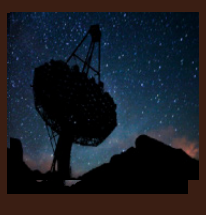
Members of the planetary surface group, led by Natalya Gomez, research models of the interactions between ice, water, climate and planetary interiors, and how these connections change planets' surfaces through time. These models are applicable to both the Earth and other rocky, icy planets and moons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

Nuclear Astrophysics • *Andrew Cumming*



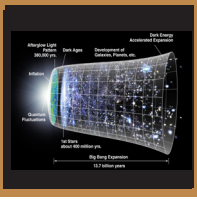
Nuclear astrophysics is the study of the origin of the chemical elements in stars and supernovae, explosive events such as supernovae, classical novae, and X-ray bursts, and the properties of matter at high densities as found in the interiors of neutron stars. We focus on developing connections between 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).

Experimental Particle Astrophysics • *Ken Ragan, David Hanna*



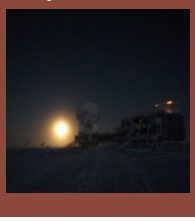
The Gamma Ray Astrophysics group is part of the VERITAS collaboration, which operates an array of four 12-m imaging atmospheric Cherenkov telescopes in southern Arizona. They carry out a program of very-high-energy (VHE) gamma-ray astronomy, observing photons with energy in the range from 50 GeV to 50 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.

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



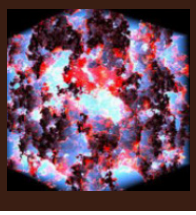
The theoretical cosmology group works to explain the history of the very early Universe and to provide an explanation of the large scale structure in the Universe. They create models using input from new fundamental physics such as superstring theory, dark matter particle theories, and particle physics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

Low Frequency Cosmology • *Cynthia Chiang, Adrian Liu, Jon Sievers*

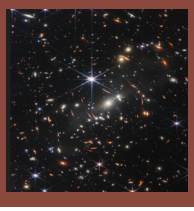


The low-frequency radio sky represents a new frontier in observational astrophysics and cosmology. This regime is a largely unobserved band of the electromagnetic spectrum, and holds the promise of revealing new astrophysical phenomenology. Our 21cm cosmology telescopes (ALBATROS, HERA, MIST, PRIZM) 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.

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's work includes searches for radio pulsars, pulsar timing, and X-ray observations of energetic pulsars and magnetars. The multi-messenger group identifies and characterize kilonova and other electromagnetic counterparts to gravitational wave sources. The theory group studies neutron stars' structure and how to use observations to constrain the physical processes operating in their interiors. They also investigate the origin and evolution of neutron stars' spin and magnetism and the properties of neutron stars in close binary systems.

Galaxy Evolution, Active Galactic Nuclei • *Tracy Webb, Daryl Haggard*

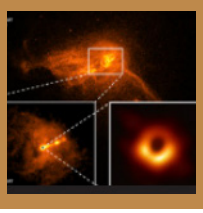


The galaxy evolution group is interested in understanding when galaxies form the bulk of their stellar mass; what drives and later shuts down this process; how the local environment of galaxies affect their evolution and growth; and how growing supermassive black holes (AGN) interact with their host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

Radio Transients • *Matt Dobbs, Vicky Kaspi, Jon 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 • *Tracy Webb, 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

- **Searching for Cosmic Dawn and Beyond from the Canadian High Arctic**
- **Unraveling The Formation Of Planets: The Influence Of Stellar Mass On Planetary Systems**
- **CHIME/FRB triples the sample of FRBs with Polarisation Information**
- **When Stars Collide: Searching For The Heaviest Elements Formed In Explosive Neutron Star Mergers**
- **Stars as a dark sector factory**
- **Preparing for Radio Astronomy in the CHORD Era**
- **Can Carbon Dioxide Increase Earth's Thermal Radiation?**
- **Cosmic String Loops May Explain The Origin Of High Redshift Galaxies Discovered In JWST Observations**
- **Is phosphorus a limiting nutrient for deep sea microorganisms?**

Searching for Cosmic Dawn and Beyond from the Canadian High Arctic

Prof. H. Cynthia Chiang is an associate professor of physics at McGill, and she specializes in instrumentation development for precision measurements of redshifted 21-cm emission of neutral hydrogen

Hydrogen, which pervades the universe as the most abundant element, naturally "glows" at radio wavelengths and is a powerful tool for illuminating the universe's distant past. Prof. Chiang's research focuses on developing novel radio instrumentation to elucidate periods of the universe's history that are poorly understood. Her team has established the first long-term radio astronomy observing program from the Canadian high Arctic, with experiments sited at the McGill Arctic Research Station (MARS) on Axel Heiberg Island, Nunavut.

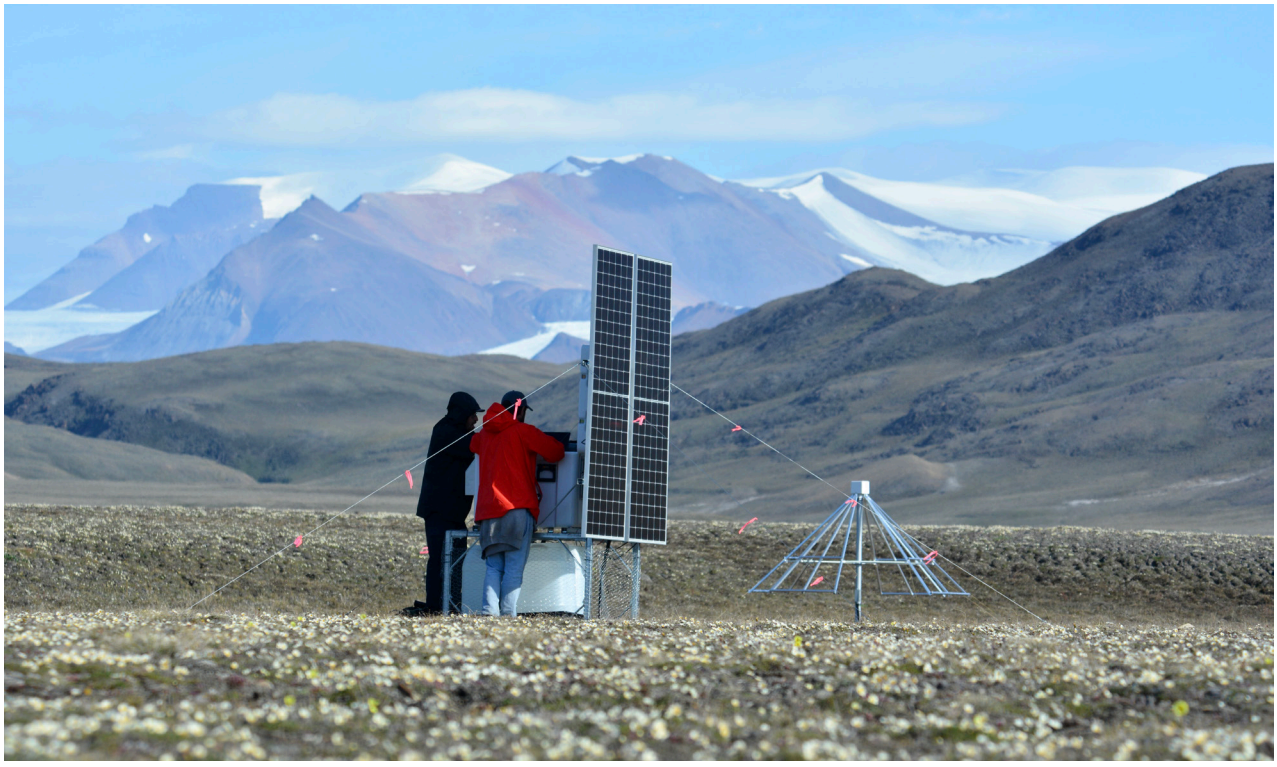
The Array of Long Baseline Antennas for taking Radio Observations from the Seventy-ninth parallel (ALBATROS) will image our Milky Way galaxy at low frequencies as a first step toward future observations of the cosmic "dark ages," the period in our universe's history before the first stars were born. ALBATROS consists of multiple antenna stations that operate autonomously and that are distributed over large distances to form an array, observing as a unified instrument. Our team successfully installed two new stations in 2023, bringing the total count up to four. Team members will return in 2024 to retrieve data and to continue expanding the array.

The Mapper of the IGM Spin Temperature (MIST) aims to observe both cosmic dawn and the dark ages, using a single antenna that "listens" to the sky at many wavelengths simultaneously. Our team travelled to MARS in April 2023 for MIST's first deployment during Arctic spring. Despite the challenging and chilly weather, the MIST observing campaign was a success, and data analysis is in progress.

Citations: (1) Monsalve, R. A., et al (2024). Mapper of the IGM spin temperature: instrument overview. MNRAS, 530(4), 4125-4147. (2) Monsalve, R. A., et al. (2024). Simulating the Detection of the Global 21 cm Signal with MIST for Different Models of the Soil and Beam Directivity. ApJ 961(1), 56.

Why this matters

The high Arctic is a beautifully radio-quiet site that provides a uniquely Canadian geographic advantage for radio astronomy. Our team is building instrumentation that aims to shed new light on the early history of the universe, leading up to and including the birth of the first stars during "cosmic dawn."



The newest ALBATROS antenna station, which is installed several kilometers away from MARS, significantly expands the footprint of the array. Our on-site team in July 2023 included TSI postdoctoral fellow Jack Orlowski-Scherer, PhD student Larry Herman, and undergraduates Marc-Olivier Lalonde and Chris Barbarie. Photo credit: Anthony Zerafa

Unraveling The Formation Of Planets: The Influence Of Stellar Mass On Planetary Systems

Yayaati Chachan is a CITA National and Trottier Space Institute Fellow at McGill University. Eve J. Lee is an Assistant Professor and William Dawson Scholar in the Department of Physics at McGill University and the Trottier Space Institute.

Super-Earths are planets that are a few times the mass of the Earth. They are the most common type of planet in our galaxy, and they tend to form more frequently around stars that are smaller and cooler than the Sun. On the other hand, Jupiter-like planets are hundreds of times the mass of the Earth are more often found orbiting stars that are like the Sun or larger. Intriguingly, when Jupiter-like planets do orbit Sun-like stars, they often have Super-Earths closer to the star. These observations raise an interesting question: how do these patterns emerge, especially considering that smaller stars have less material available for planet formation?

Chachan & Lee (2023) suggest that the key factor is the temperature ofthe protoplanetary disks—disks of gas and dust that surround young stars and give birth to planets. Planets initially form by the accumulation of dust into planetary cores. Cooler disks around smaller stars are more efficient at transforming dust into planetary cores. This increased efficiency means that even with less dust, these cooler disks can form Super-Earth cores more frequently. However, in the outer regions of these disks where Jupiter-like planets form, the increase in the efficiency of turning dust into planetary cores is lower. This smaller increase in efficiency does not make up for the lower amounts of available dust, making giant planets less common around lighter stars.

Why this matters

The relationship between the planet and stellar properties provides unique and important clues about how planets form. This work provides the first unifying formation framework that explains three seemingly contradictory observations about the three-way relationship between the central star, the inner planets,

Additionally, while these larger planetary cores are forming, dust in the disk drifts inward, providing ample material to form Super-Earths in the inner regions of the disk. Therefore, any star with enough material to form a Jupiter-like planet can also likely support the formation of Super-Earths closer to the star. The work of Chachan & Lee (2023) therefore provides, for the first time, a unified explanation for the observed distribution of planets around different types of stars.

Citation: Chachan, Y. & Lee, E. J. (2023), “Small Planets around Cool Dwarfs: Enhanced Formation Efficiency of Super-Earths around M Dwarfs”. ApJL, Volume 952, Issue 1, L20

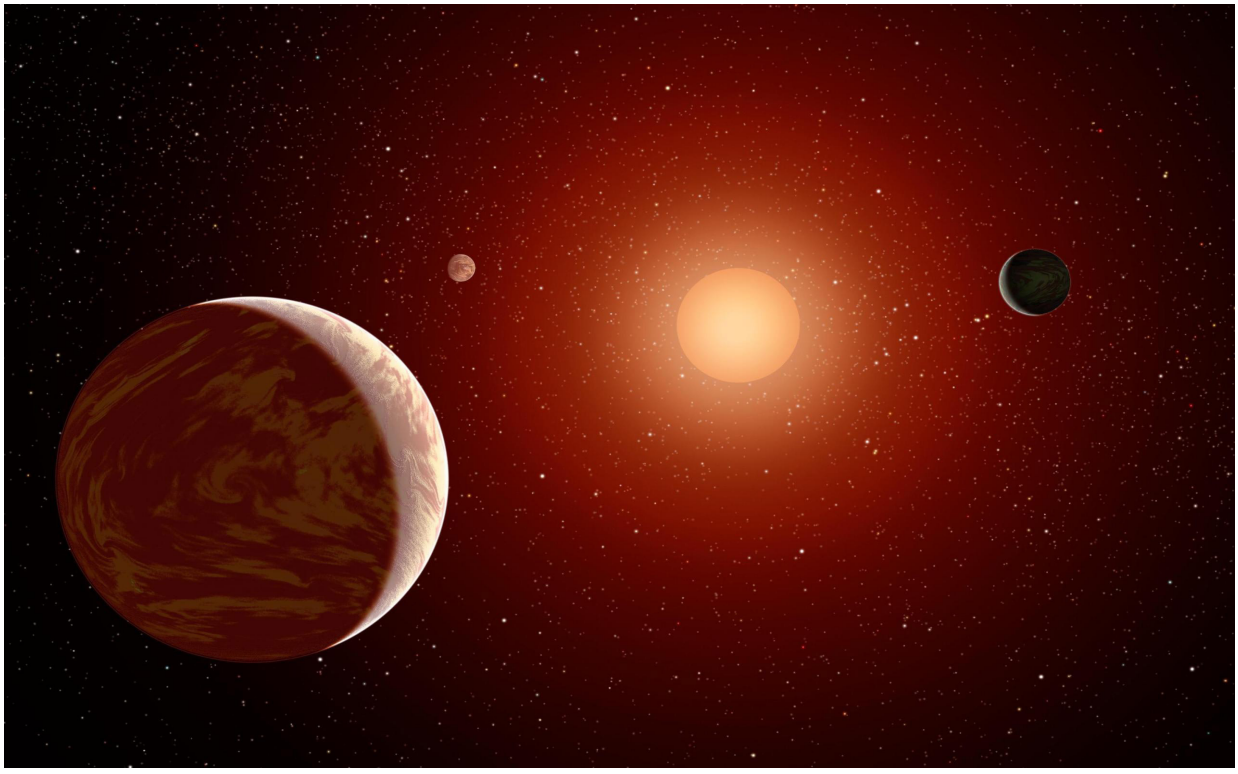


Image credit: NASA/Science Editorial Team

CHIME/FRB Triples the Sample of FRBs with Polarisation Information

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

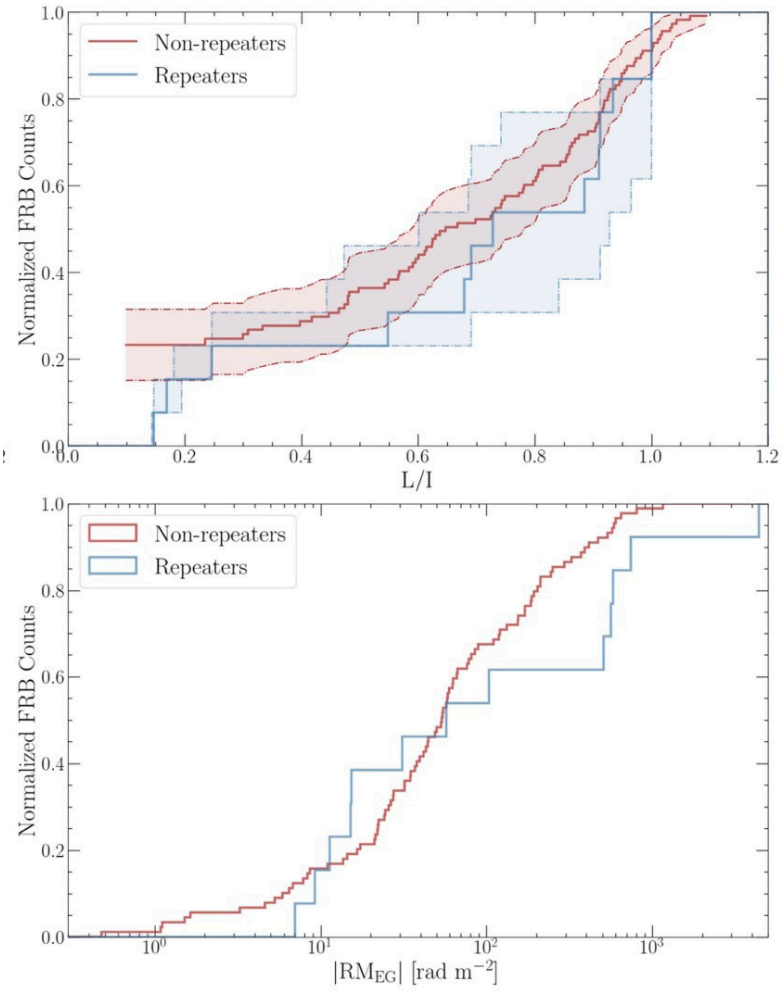
The CHIME telescope, located in Penticton, British Columbia consists of four cylindrical reflectors oriented along the North-South direction. They have no moving parts and observe the full Northern sky daily at radio frequencies between 400 and 800 MHz in dual polarization. The combination of CHIME's collecting area, bandwidth, and field of view make it an unrivaled radio transient detector, detecting FRBs at a cadence of a few per day. For a subset of these FRBs which are particularly bright, the full voltage data from CHIME are recorded. These data require ~1000 times more storage but provide much greater information about an FRB, including a burst's polarisation properties. This polarimetry provides insight into both the environment in which an FRB source is embedded, and the process by which it is emitted, making it a powerful tool for constraining the FRB emission mechanism.

Following the recent publication of the first CHIME/FRB baseband catalog, the collaboration reported the polarimetry of over 100 apparently non-repeating FRBs. Completing this catalog of FRB polarisation properties represents the culmination of several years of work across the CHIME/FRB collaboration, including many projects led or supported by TSI affiliated students and postdocs to develop automated polarisation analysis methods which build upon the processing of the initial baseband data.

Previous studies of population wide FRB polarisation properties were severely limited by a low sample size. The release of this sample therefore represents a significant contribution to the wider FRB community, tripling the number of sources with published polarisation information. From the distribution of extragalactic faraday rotation measures within this sample, the team concluded that most of the observed bursts likely originated from star forming regions in host galaxies similar to the Milky Way, as would be expected for a magnetar progenitor. Furthermore, comparison of non-repeater and repeater populations revealed no dichotomy in polarimetric behaviour, providing yet more evidence in favour of a unified origin for repeaters and non-repeaters, despite the observed morphological differences in their bursts. While the nature of FRB sources remains uncertain, this work serves as an important milestone in the evolution of FRB science, providing the first large sample study of FRB polarisation properties and defining the framework for future investigations.

Why this matters

Are repeating and non-repeating FRBs distinct populations? By recording the full voltage data for some bursts, CHIME/FRB leverages its unparalleled ability to detect FRBs to provide the largest available dataset for investigating this question in the domain on polarisation.



Caption: Comparison of the cumulative CHIME FRB counts as a function of fractional polarisation (top) and absolute faraday rotation measure (bottom)

Citation: Pandhi, A., et al. (2024). Polarization Properties of 128 Nonrepeating Fast Radio Bursts from the First CHIME/FRB Baseband Catalog. ApJ, 968(2), 50.

When Stars Collide: Searching For The Heaviest Elements Formed In Explosive Neutron Star Mergers

Nick Vieira is a third-year PhD student under Professor Daryl Haggard and John Ruan (Bishops University) who studies the explosions triggered by merging neutron stars and/or black holes, where the heaviest elements might be synthesized. Nicole Ford is a first-year PhD student who studies black holes with Professor Daryl Haggard, and is a member of the Event Horizon Telescope Collaboration. During her MSc, she also searched for the origins of the heaviest elements.

Why this matters

Neutron star mergers are a key site of rare element production in the Universe, and we apply various techniques to learn as much as we can about the physical conditions and elements formed during both the only confirmed merger to date, as well as a plethora of potential future mergers.

Citations: (1) Ford, N. M. et al. (2024). KilonovaAE: Exploring Kilonova Spectral Features with Autoencoders. The Astrophysical Journal, 961(1), 119. (2) Vieira, N. et al. (2024). Spectroscopic r-process Abundance Retrieval for Kilonovae. II. Lanthanides in the Inferred Abundance Patterns of Multicomponent Ejecta from the GW170817 Kilonova. The Astrophysical Journal, 962(1), 33.

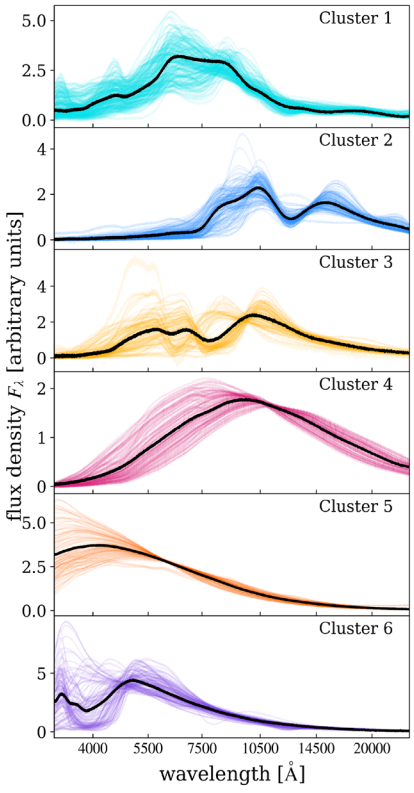
In 2017, GW170817, the first detection of a merger between two neutron stars in both gravitational waves and light, thrilled astronomers across the world. As they spiral inwards, the neutron stars produce gravitational waves---ripples in spacetime itself---which are detected by specially designed detectors such as LIGO and Virgo. At the same time, the neutron stars are shredded into neutrons that combine into the heaviest elements in the Universe, including silver and gold. These elements shine as a days-long 'kilonova', and astronomers with conventional telescopes can then join in!

PhD students Nick Vieira and Nicole Ford study these kilonovae's spectra — their brightness as a function of colour — to understand exactly which elements are present.

Vieira fit the GW170817 spectra at several points following the merger to understand what elements must be present to produce the bumps and wiggles where different elements are absorbing or emitting light. He found that the early spectra show strong evidence of the element strontium, which we use to make things glow in the dark. At later times, a new component emerges with even rarer elements, including the rare Earth metals, such as cerium. These rare Earth metals are used by humans to light things up ranging from fireworks to phone screens.

To understand the diversity of future kilonovae beyond GW170817, Ford simulated thousands of spectra spanning a wide range of kilonova physical properties. Nicole then used machine learning techniques to sort the spectra based on their shapes. The simulated kilonovae often showed strong absorption by strontium and rare Earth metals. When a new kilonova is observed, her new machine-learning framework will help identify the dominant spectral features and key physical properties, allowing us to place them in the "zoo" of kilonovae.

Gravitational wave detectors recently turned back on in 2023, and the team is eagerly awaiting future mergers, with approved programs on JWST and other telescopes ready to point at them!



Left: Groupings of simulated kilonova spectra identified by our machine learning algorithm as belonging to distinct "types" of kilonova, based on their unique absorption dips and emission bumps. Some of the most prominent features come from rare Earth elements (N. M. Ford et al, 2024) Right: An artist's rendition of neutron star merger, capturing the moment the two stars collide and spit out neutron-rich material (Image credit: NASA-JPL/Caltech).

Stars as a Dark Sector Factory

Katelin Schutz is an Assistant Professor in the McGill Department of Physics and a Canada Research Chair in Astrophysics Beyond the Standard Model. She received her PhD from UC Berkeley in 2019, where her thesis won the American Physical Society's Sakurai Dissertation Award in theoretical particle physics. Prior to starting her appointment at McGill, she was a NASA Einstein Fellow at MIT.

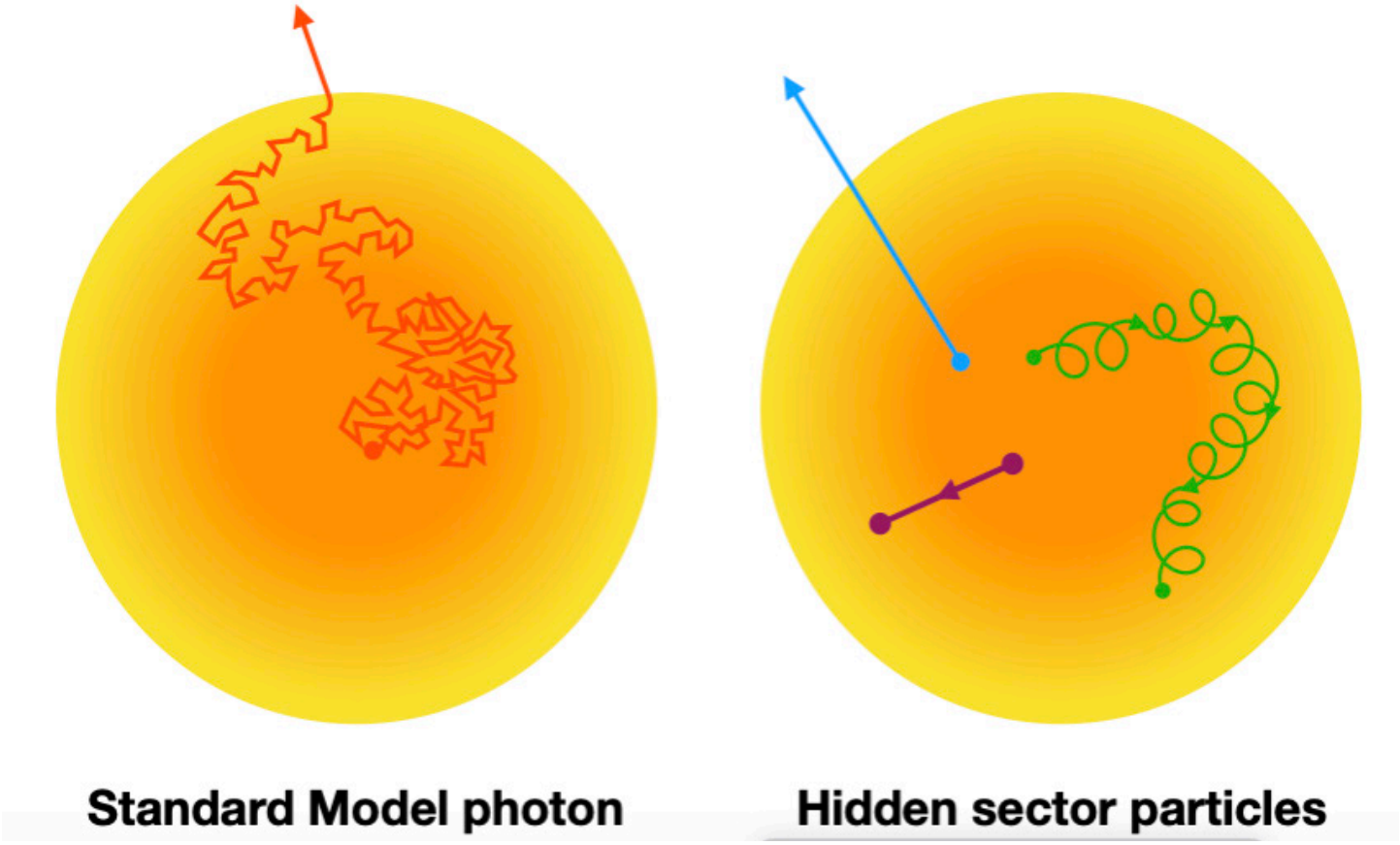
Physics beyond the Standard Model of particle physics is necessary to explain the universe we live in, as we currently lack an understanding of dark matter and other puzzles. One possibility is that our universe contains "hidden sectors" with new particles that barely interact with the particles we know about.

Stars turn out to be among the best places to look for evidence of these hidden sectors, primarily because of their high density, temperature, and volume.. For instance, it takes light tens of thousands of years to emerge from a star because the density is so high that the light is continually being trapped by interactions with electrons. In contrast, hidden sector particles carry away energy efficiently, crossing the star in a matter of seconds because they barely interact with the stellar plasma. Energy loss affects the evolution of stars and the rates of nuclear reactions in their dense interior. We used the state-of-the-art code package MESA to simulate how hidden sector particles would be produced inside of the star and to track the effects of the resulting energy loss on stellar evolution. Notably, we found that there is a big impact on helium ignition, which corresponds to the tip of the "Red Giant branch." We compared these simulations with observations of stellar populations made with the Hubble Space Telescope, Gaia, and other observatories. Since the observations were consistent with the Standard Model prediction, we were able to set a world-leading bound on the existence of new particles

Citation: Fung, A., Heeba, S., Liu, Q., Muralidharan, V., Schutz, K., & Vincent, A. C. (2024). New bounds on light millicharged particles from the tip of the red-giant branch. Physical Review D, 109(8), 083011.

Why this matters

This work used stellar evolution to set the strongest limits ever on the existence of particles from a hidden sector



Preparing for Radio Astronomy in the CHORD Era

Faculty members H. Cynthia Chiang, Matt Dobbs, Daryl Haggard, Vicky Kaspi, Adrian Liu, and Jonathan Sievers lead research on next-generation radio telescope.

2023 was an exciting and productive time for CHORD, the Canadian Hydrogen Observatory and Radio-transient Detector. CHORD is a new radio telescope facility currently under construction at the Dominion Radio Astrophysical Observatory near Penticton, BC. Incorporating the latest advances in dish fabrication, low-noise electronics, and digital signal processing, CHORD is poised to further strengthen Canada's position as a world leader in radio astronomy over the next decade. CHORD will provide unmatched capabilities in several areas of research, including Fast Radio Bursts, pulsars, the distribution of gas in nearby galaxies, and the large-scale distribution of matter in the Universe. The collaboration has grown to include 77 members representing 13 institutions from 3 countries, and membership continues to grow. The TSI represents a significant fraction of the collaboration, with over two dozen members working across all areas of the experiment.

Construction is well underway, with a new 12,600 square-foot facility completed in 2023 to house CHORD's antenna manufacturing activities. Technical design reviews for all the major instrument sub-systems were also completed in 2023, and prototypes of the antenna, analog, and digital systems are currently being evaluated (Figure 1). In parallel with the efforts on hardware and infrastructure, science teams are meeting regularly to make forecasts and simulations, compile observation targets and strategies, and develop the sophisticated algorithms and software pipelines needed to handle the massive volume of data that CHORD will generate. To support these efforts, the CHORD collaboration was awarded 696 core years of computing resources in 2023 by the Digital Research Alliance of Canada (equivalent to one computer running continuously for 696 years!). 2024 is poised to be every bit as exciting, as construction continues to ramp up and we prepare for CHORD to make its first observations of the cosmos.

Top: TSI PhD candidate Ian Hendricksen installs prototype digital systems for testing at the CHORD site. Bottom: CHORD dishes (source: CHORD Collaboration).

Citation: (1) MacKay, V., Lai, M., Shmerko, P., Wulf, D., Belostotski, L., & Vanderlinde, K. (2022). Low-cost, Low-loss, Ultra-wideband Compact Feed for Interferometric Radio Telescopes. arXiv preprint arXiv:2210.07477.
(2) Lai, M., Mackay, V., Wulf, D., Shmerko, P., & Belostotski, L. (2023). 0.3–1.5-GHz LNA With Wideband Noise and Power Matching for Radio Astronomy. IEEE Microwave and Wireless Technology Letters, 33(8), 1163-1166.
(3) www.chord-observatory.ca

Can Carbon Dioxide Increase Earth's Thermal Radiation?

Yan-Ting Chen is a PhD candidate in the Department of Atmospheric and Oceanic Sciences at McGill University, supervised by Prof. Yi Huang. His research delves into the intersection of radiation and climate change

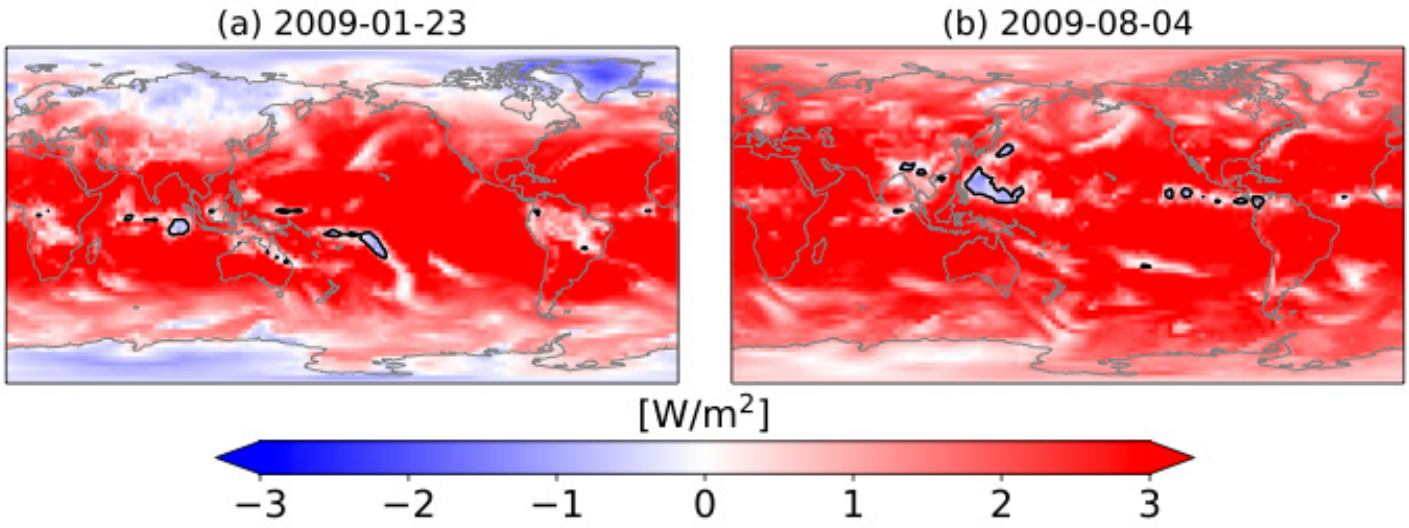
An increasing concentration of carbon dioxide (CO2), a greenhouse gas, traps the Earth's infrared emission and increases the Earth's overall energy budget. This interception in radiation is called radiative forcing, which is positive when a greenhouse gas reduces Earth's cooling to space. Counter-intuitively, under specific conditions, particularly in the Antarctic and occasionally in the Arctic and tropics, CO2 can also increase infrared emission in a way that reduces this energy budget, resulting in a negative forcing. Conventional explanations of this phenomenon focus on the importance of a unique troposphere temperature structure, where the temperature increases with altitude. However, these explanations lack quantitative assessment and do not account for negative forcing outside of Antarctica.

In this study, we use a radiative transfer model – a model that calculates energy transfer in the form of electromagnetic radiation through a planetary atmosphere – to break down the CO2 forcing into contributions from different atmosphere layers: the stratosphere, troposphere, and the surface. Our findings reveal that the stratosphere can contribute negatively to the forcing, while the troposphere's contribution is consistently positive. The results are supported by idealized experiments, where we altered the temperature structure in either the stratosphere or the troposphere. Contrary to conventional wisdom, we found that the forcing is not affected by the changes in the tropospheric temperature structure. It is important to note that while negative CO2 cools the stratosphere efficiently, it does not necessarily imply cooling for the troposphere and the surface. Nevertheless, this study underscores the value of resolving the radiative sensitivity over the whole atmosphere, instead of the emission around a simple characteristic level of temperature as some simplified models do.

Citation: Chen, Y.-T., Merlis, T. M., & Huang, Y. (2024). The cause of negative CO2 forcing at the top-of-atmosphere: The role of stratospheric versus tropospheric temperature inversions. Geophysical Research Letters, 51, e2023GL106433. https://doi.org/10.1029/2023GL106433

Why this matters

By elucidating the physical cause of a counter-intuitive negative greenhouse effect where CO2 increases the Earth's infrared emission, we highlight the role of the stratosphere in affecting the Earth's infrared emission.



Cosmic String Loops May Explain The Origin Of High Redshift Galaxies Discovered In JWST Observations

Robert Brandenberger is a Professor in the McGill Department of Physics and a Canada Research Chair (Ter 1) in Theoretical Cosmology. Jiao Hao is a PhD student in Prof. Brandenberger's research group.

The James Webb Space Telescope is providing astronomers with a first view of the structure of matter in the early universe. Preliminary results provide indications that the number of high mass galaxies at high redshifts is significantly larger than what the standard paradigm of early universe cosmology predicts. In recent work, McGill PhD student Hao Jiao, Professor Robert Brandenberger and Professor Alexandre Refregier (from the ETH in Zurich, Switzerland) have shown that the data could easily be explained if the seeds of the high redshift galaxies are cosmic string loops.

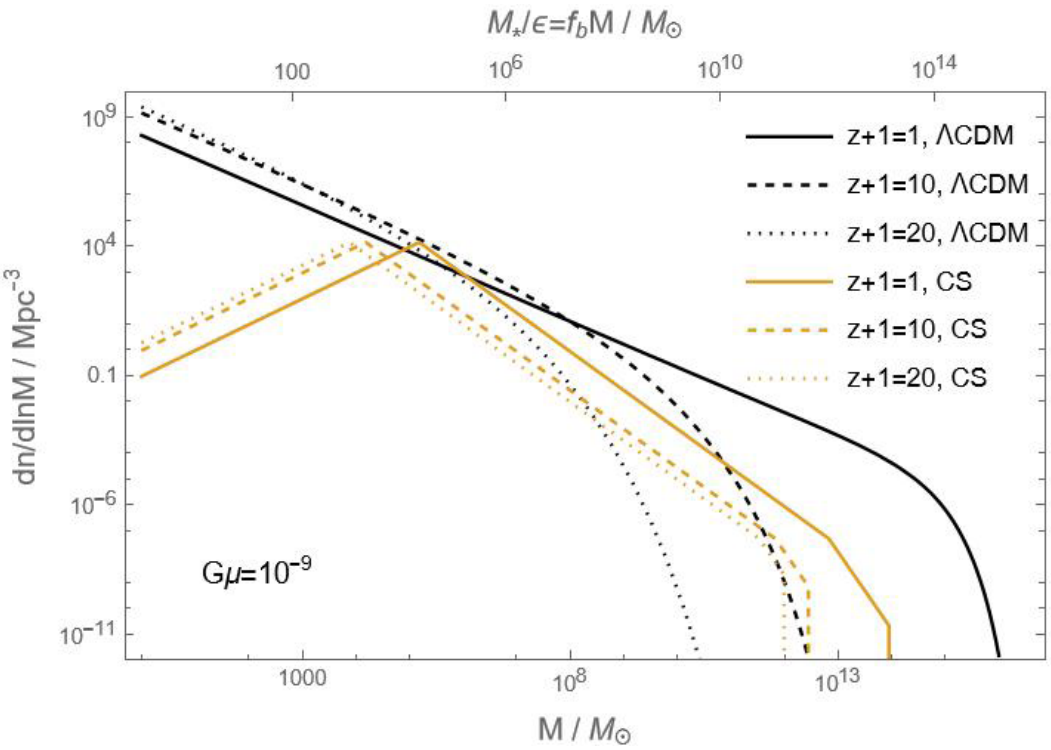
Cosmic strings are linear defects which exist in many particle physics models beyond the Standard Model. If the microscopic forces of Nature are described by such a model, then a network of strings will inevitably form in the early universe and persist to the present time. A good analog model of a cosmic string is a line defect in a metal, and a vortex line in a superfluid is an even better analog model. The network of cosmic strings will contain a distribution of loops with a wide range of sizes. These loops are massive and hence can act as seeds about which matter can cluster in the early universe. In a paper published in the leading journal Physical Review D, the authors have shown that in models with cosmic strings, the string loops will dominate early structure formation, even if their effects are subdominant today.

The magnitude of the effects of strings is determined by their tension (which is in turn determined by the particle physics model which yields the strings). The value of the string tension which gives a good fit to the JWST results is in fact the same which allows string loops to form the seeds for high redshift super-massive black holes.

Citation: Jiao, H., Brandenberger, R., & Refregier, A. (2023). Early structure formation from cosmic string loops in light of early JWST observations. Physical Review D, 108(4), 043510.

Why this matters

There is mounting evidence that the standard scenario of early universe cosmology cannot explain the amount of structure which observations have recently revealed at high redshifts. This study shows that cosmic strings can provide a simple resolution of the current tensions.



Caption: This figure shows that in a model with cosmic strings, it is the strings which dominate the distribution of galaxies in the early universe. The horizontal axis is the mass of a collapsed structure in units of solar masses, and the vertical axis is the mass function, the number density per mass interval of these structures. The figure is for a string tension of 10^{-9} in dimensionless units (this is two orders of magnitude smaller than the current upper bound). The black curves correspond to the predictions of the current paradigm of early universe cosmology, the orange lines are what the cosmic string model predicts. The figure shows that while today (redshift 0) the strings provide a negligible contribution, they dominate at high redshifts.

Is Phosphorus a Limiting Nutrient for Deep Sea Microorganisms?

Dr. Richard LaBrie is a TSI Postdoctoral Researcher in Prof. Nagissa Mahmoudi's lab. He obtained his PhD at Université de Montréal on the interactions between marine microorganisms and organic compounds in the Labrador Sea. His research focuses on what drives the consumption and transformation of dissolved organic matter in the deep ocean.

Microorganisms in the oceans are surrounded by organic compounds that can provide them with carbon and energy. However, only a small proportion of this vast pool of carbon—the second largest reservoir of organic carbon on Earth—is consumed by microorganisms. The reasons why much of this carbon is stored is still an ongoing debate. With an average radiocarbon age of several millennia, deep ocean organic carbon is highly resistant to degradation. It was recently found that algae limited in phosphorus, an essential element for the growth of all living organisms, produced organic compounds that resisted microorganism's consumption for longer periods of time compared to organic compounds produced without phosphorus limitation.

In this study, we explored the possibility that deep ocean microorganisms are limited by phosphorus, thus impacting their capacity to consume organic compounds. To test our hypothesis, we used bottle incubations with seawater from the deep Antarctic Ocean and added different sources of phosphorus to try to stimulate carbon consumption. In addition, we collected samples for high resolution mass spectrometry to characterize the specific molecules that are transformed by microbes.

Microorganisms on ocean worlds would face similar conditions than in the deep ocean: a cold, dark and salty environment with little available substrate for growth. Better understanding what limits life here on Earth will help targeting ocean worlds with the most potential. It would also increase our understanding of how carbon is stored for millennia in the deep ocean and its implications on the global carbon cycle over geological time scales and under the current changes in climate.

Why this matters

What controls the long-term storage of dissolved organic matter in the oceans has been an open question for the past 75 years. Our goal is to understand what constrains this long-term storage while providing clues for life on ocean worlds.

Top right: Deployment of the rosette sampler mounted with 24 Niskin bottles used to sample the ocean; the bottles are sent open, otherwise they would implode due to water pressure, and they are remotely closed on the way up at the desired sampling depth. Bottom right: The crew of RRS Discovery and nPOP (new Perspectives on Ocean Photosynthesis) science party. Credit: Corday Selden)

03

EDUCATION & PUBLIC ENGAGEMENT

One of the core tenets of TSI's mission is to communicate astronomy with the public. TSI runs a variety of public outreach programs, from large events targeted at a general audience, to programs tailored to the needs of specific communities. Our approach to outreach emphasizes inclusion, relationship-building, iteration, and co-creation, with the over-arching goal of demystify astronomy research, showing that science is interesting, accessible, and human. TSI Outreach promotes the research that we do at TSI and the people who do it, providing multiple opportunities for trainees to develop science engagement skills.

We have 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 TSI'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). TSI 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.

In 2023, we welcomed back Astronomy on Tap and were thrilled to see it received as enthusiastically as it had been before its three-year hiatus (see page 24). Public AstroPhysics Nights (see page 18), our public talk series run in collaboration with Physics Outreach featured a broad variety of topics and formats, including traditional talks, Q&As, and panel events. Public Observing Nights (see page 19) continued to run at maximum capacity every month, giving the public the opportunity to tour the Anna McPherson Observatory and look through the telescope.

2023 was also a year of expansion for TSI Outreach. We organised two new activities aimed at children ages 5-12 for 24 heures de science and Science Literacy Week, both of which drew hundreds of people to the McGill campus (see page 22). Science in Space, our collaboration with Physics Outreach and Dell Technologies aimed at girls and nonbinary kids ages 10-12, went from operating in one school to operating in 5 schools in the Montreal area. A new collaboration with Branches Indigenous Outreach led to a total of six events aimed at Indigenous youth, both on campus and in community (page 21). We also began preparations for the total solar eclipse on April 8th, which you can read about on page 26.

TSI Outreach also had multiple opportunities this year to present our outreach work to academic audiences. We were invited to participate in McGill's first-ever Outreach Symposium, which brought together researchers and practitioners across the university who actively engage in communicating their research to the public. TSI & Physics Outreach were also invited to give a colloquium talk to the Physics Department about the work we've done.

The success of TSI's Outreach programs is due in no small part to the team of students, postdocs, faculty, and staff who volunteer their time to make our broad portfolio of programming possible. We would like to thank the over 60 volunteers who gave us their time in 2023. We're thrilled to see where there dedication and ingenuity take TSI Outreach next!

Opposite page: child observing with our telescopes in Chisasibi; grad student Hannah Fronenberg giving a public talk. From top: poster for volunteer recruitment picnic; outreach coordinators testing an outreach module; Physics department members sampling outreach activities following the Outreach Committee's colloquium in November 2023; the members of the 2023-24 Physics & TSI Outreach Committee.

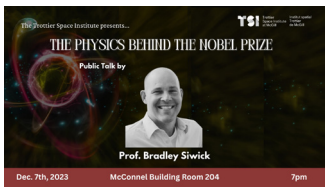
PUBLIC TALKS

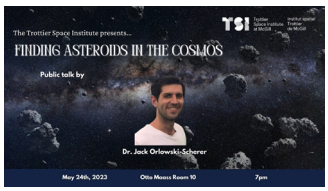
Public AstroNights, our monthly public talk series, have been a mainstay of the Montreal astronomy scene since 2011. Originally founded by AstroMcGill in 2011, they are now run by TSI Outreach in collaboration with the Physics Department. Public AstroNights rotate between a variety of formats designed to increase interactivity, including panel events that bring together multiple researchers, Q&As sessions, and traditional talks. Speakers are usually TSI or McGill Physics professors, postdoctoral fellows, or graduate students, although we also welcome invited speakers from other institutions.

Our public talks take place in person on the McGill campus, attracting an average of 200 people each month. The accompanying live-stream provides opportunities for our online audience to actively participate as well. All our talks are posted to our YouTube channel, where they garner hundreds (sometimes thousands) of views. We are continually astonished by the enthusiasm of our audience, who return month after month and engage speakers in lively Q&A sessions!

From exoplanet research to theoretical cosmology to next generation telescopes, we're looking forward to the future of Public AstroPhysics Night!

25 Jan	**Prof. Nagissa Mahmoudi, Prof. Richard Leveille, Brady O'Connor** *(McGill EPS, McGill NRS)* 'Life in Our Universe'
22 Feb	**Dr. Adélie Gorce** *(TSI & McGill Physics)* 'Une sombre histoire de l'univers'
28 Mar	**Hannah Fronenberg** *(TSI & McGill Physics)* 'Did the Big Bang Really Happen?'
26 Apr	**Soud Al Kharusi & Nicholas Vieira** *(all: TSI & McGill Physics)* 'Seeing the Universe with Light, Gravity, and Particles!'
24 May	**Dr. John Orlowski-Scherer** *(TSI & McGill Physics)* 'Finding Asteroids in the Cosmos'
14 Sep	**Prof. Adrian Liu** *(TSI & McGill Physics)* 'Mapping the Cosmos'
05 Oct	**Matthew Lundy, Dr. Heidi White, Guillaume Poulin** *(McGill; iREx; AstroLab Mont-Megantic)* 'Eclipse Enigmas'
16 Nov	**Dr. Robert Main** *(TSI & McGill Physics)* 'Harnessing the Power of Interstellar Plasma Lenses
07 Dec	**Prof. Bradley Siwick** *(McGill Physics)* 'The Physics Behind the Nobel Prize'





OBSERVING NIGHTS

Atop the Rutherford Physics Building here at McGill is the Anna I. MacPherson observatory. This consists of a 14-inch Celestron telescope in a dome, several smaller portable telescopes, and a small 1400 MHz radio telescope. The rooftop location provides one of the best observing experiences in Montreal for objects such as the moon, Saturn, Jupiter, nebulae, and much more. The observatory is run by students in the Department of Physics and TSI, led by the Observatory Coordinator, graduate student Matthew Lundy. The Observatory Coordinator and a team of dedicated volunteers run a variety of observing nights aimed at different audiences, inside and outside McGill. The observatory can also occasionally accommodate visits from private groups. While a majority of observing nights take place in the Anna MacPherson Observatory, our coordinators also host off-site events using our portable telescopes.

Public Observing Nights

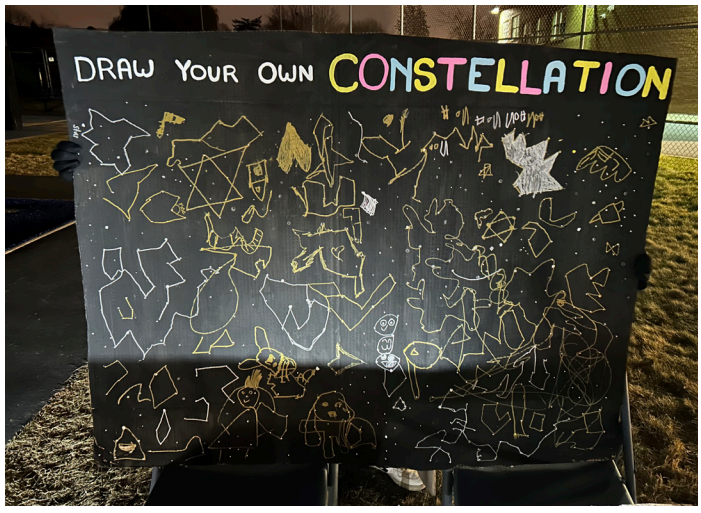
The observatory opens its doors every month to the public for “Public Observing Nights”. These nights feature a guided tour of the observatory followed by observing of different astronomical targets. They have proved wildly popular, with the 60 open slots often filling up within hours of the event being advertised on our social media channels.

McGill Observing Nights

A perk of having an observatory on campus is that we can reach out to astronomy enthusiasts from all across the university. The observatory regularly host groups from the McGill community. This year, we welcomed groups from summer programs and visiting students. The Observatory Coordinator also hosted bi-weekly observing nights for undergraduates to learn how to use the telescopes and to acquire observational astronomy skills.

Observing with Schools

Schools and CEGEPs in the Montreal area can also request a guided observing experience either at our observatory, or an observing visit directly at the school with our smaller telescopes. We were invited for the second year in a row by JPPS to be a part of one of their Shabbat events, bringing together understandings of the sky from the Jewish faith with the work that astronomers do. Outreach volunteers gave a short presentation and then set up the portable telescopes for the Grade 3 class and their families. The almost 100 attendees were thrilled to look through the telescopes and engage in other activities to learn about astronomy.



SCIENCE IN SPACE: HOW TO TELESCOPE

Science in Space: How to Telescope is an informal science learning program co-founded in 2022 by the Trottier Space Institute, McGill Physics, and Dell Technologies/Girls Who Game. The program is organized and run by TSi grad student Alice Curtin, TSI Program Administrator Carolina Cruz-Vinaccia, and Physics Undergrad Advisor Dr. Kim Metera. The program is aimed at girls and students of marginalised genders between the ages of 10 and 12 (grades 5-6), as research shows that the years immediately preceding the transition to high school are a crucial determinant of retention of girls in STEM. Science in Space is designed to mitigate girls' attrition from STEM by fostering a sense of belonging and community, thus increasing student engagement and confidence in using STEM to tackle real-world problems. Over the course of 10 weeks, students design and build telescopes in Minecraft with the guidance of graduate student mentors (who themselves identify as members of marginalised groups in STEM).

The program is inquiry-based and student driven; students ultimately decide which astronomical phenomena they'd like to study and design a telescope to do so. In the first half of the program, facilitators and mentors deliver the basics of astronomy through game-based activities, giving the students the foundation they need to tackle the design of the with a celebratory pizza party and showcase, where each group presented their telescope to the other groups, mentors, and teachers. Through this program, students gain familiarity with observational astronomy, develop collaborative project design skills, and gain a sense of community in STEM. Students not only develop a community within their own school network, but also within the larger Montreal area with graduate and undergraduate student mentors who support the girls in developing their project and act as role models.

2023 was a year of major growth for Science in Space. We took on a total of four new schools (two in Fall 2023 and two planned for Winter 2024), in addition to the school we've been working with since 2022, for a total reach of over 100 students. One of these schools was also an experiment in expanding the scope of the program, as it ran as part of an afterschool STEM program which also included boys. Our team of volunteers also doubled, with approximately 10 graduate and undergraduate students acting as mentors.

We incorporated a feedback-gathering mechanism in the form of "mission logs", exit tickets that the students filled out at the end of each session. The feedback allowed us to make adjustments to the program in real-time in response to students' concerns, improving their overall experience and the impact of the program. A majority of students reported feeling excited about science and enjoying the opportunity to learn about space while playing Minecraft. The sense of community formed by the program was the most notable impact; almost all of the students said that their favourite part of the program was working with each other, making new friends, and having a space of their own.

We look forward to what 2024 will bring! To learn more about the program, visit https://www.scienceinspace.ca/

INDIGENOUS OUTREACH

Leveraging the power of astronomy education to empower students to engage with academia and pursue higher education in the sciences , TSI connected with McGill's Branches Pick Your Path program, a mentorship program for Indigenous CEGEP students. As part of this collaboration, TSI organized a total of 7 events in 2023, including 4 workshops at McGill and 3 visits to the Cree Nation of Chisasibi in the James Bay region of Quebec.

Workshops at McGill

TSI hosted two workshops for Pick Your Path students (January 2023 and October 2023) on astronomy basics and what being an astronomer entails. These workshops also included an observing component, where students were given a tour of the Anna McPherson Observatory by the Observatory Coordinator. On both occassions, the workshops were well-received; participants were enthusiastic, asking more questions than our graduate student volunteers had the time to answer! TSI also organized visits to the Anna McPherson observatory for undergraduate students participating in the IMPRESS summer program (August 2023) and for a group of 60+ visiting grade 11 students from Chisasibi (November 2023).

Trips to Chisasibi

February 2023, Cree Science Fair: TSI graduate students and the TSI Program Admin delivered workshops for high school students as part of the programming for the Cree Science Fair. The first of these was a hands-on workshop on how telescopes work, where a total of 80 students in grades 10 and 11 experimented with lenses to make their own simple Galileo telescopes. We also collaborated with McGill students in Mathematics to deliver a workshop on algorithmic thinking using beadwork to grade 10 students. We also ran observing sessions, offering the community at large the chance to use our telescopes. The observing sessions proved propular, with community members braving temperatures below -40 C for their turn at our solar telescope during the day, and to get a glimpse of the moon during the nighttime session.

March 2023, Career Exploration Fair: TSI graduate students participated in Chisasibi's Career Exploration Fair, running a workshop on careers in astronomy six times over the course of the 2-day event. The workshop centered on a Q&A where participants could ask our grad students anything they wanted to know about space. The engaging nature of the workshop made it a huge hit with the young adults who participated!

August 2023: TSI graduate students delivered a workshop on the science of eclipses and how to view them safely for students in grades 7 and 8 in Chisasibi. They also ran our "Seeing Light in Space" workshop for grade 9 students, where students learn some of the basics of how astronomers collect and astronomers process astronomical data. Our students also brought our telescopes with them to run solar and nighttime observing sessions the broader community.

SCIENCE FESTIVALS

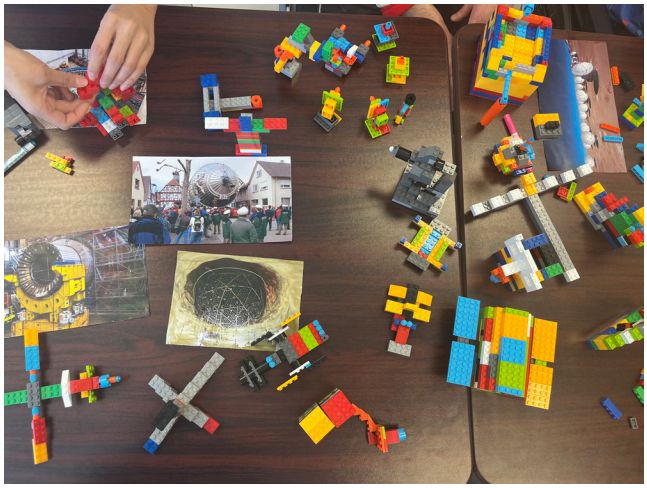
In addition to our regular programming, TSI Outreach also participates in events organized by external partners that seek to increase awareness of and access to science in general and astronomy in particular.

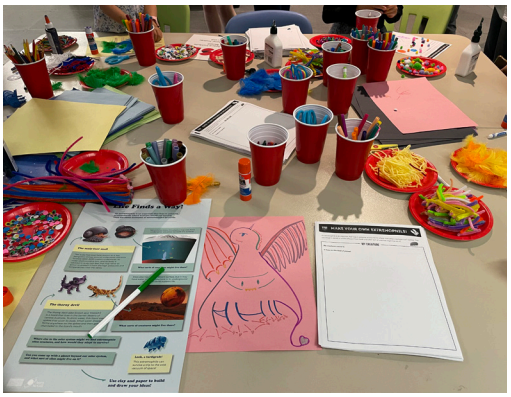
24 heures de science

24 heures de science is a province-wide celebration of science where organizations across Quebec host events and activities to increase public engagement with science. TSI joined forces with the Department of Physics and the Department of Earth and Planetary Sciences to host a day-long activity fair for children ages 6-12 in the Rutherford Physics Building on May 6th, 2023. “From Planets to Particles: An Exploration Mini-Fair” featured over ten hands-on activities and demos focused on a variety of topics within physics, astronomy, and planetary sciences, all of which were busy from start to finish! Children could design parachutes to experiment with gravity, build their own telescopes out of LEGO, use lessons learned from design a lifeform that could survive on other planets, learn about craters, our solar telescope. Earth and Planetary Sciences also ran activities children how to identify rocks and minerals (including some that the children superconducting train demo and the cloud chamber (designed by a Physics research project) were also huge hits, drawing crowds of eager children the day.

The event was a rousing success; we counted over 750 attendees throughout the 6 hours that the activities were running! Children were given “activity passports” that they could get stamped at each station, and many of them stayed for hours trying all the activities in order to fill up their passports! The reactions from attendees were overwhelmingly positive; parents enthusiastically thanked us for putting on the event and told us how much their kids were enjoying the activities. The energy was palpable and electrifying, and seeing the children’s joy and engagement was well worth the effort that went into planning an event of this size.

The event would not have been possible without the 25 students and postdocs who volunteered their time on a Saturday, nor without the hard work of the TSI & Physics Outreach Committee We look forward to making “From Planets to Particles” an annual event!





AstroFest at the Planetarium

On June 3rd, 2023 Montreal's Planétarium Rio Tinto Alcan hosted Astrofest, a daylong event for astronomy enthusiasts of all ages. The program included arts and crafts for all age groups, presentations, an astrophotography exhibit, information booths, workshops, and a talk by Canadian Space Agency astronaut David Saint-Jacques, and nighttime observing. TSI ran a booth featuring "Life Finds a Way", where children learn about extremophiles - organisms that thrive in extreme environments - by designing one of their very own. We ask participants to think of a world other than Earth, like a planet in our solar system, a moon, or an exoplanet, and about the kind of life that could develop in different environmental conditions. They can then use a variety of available materials, including crayons, markers, feathers, pompoms, googly eyes, and more to bring their creature to life. The activity proved immensely popular, welcoming over 400 children (and their parents!) during the eight hours that the booth was open. Our team of 10 volunteers ran the activity in a variety of languages, including not only English and French, but also Spanish, Portuguese, Mandarin, and Italian. We look forward to participating in Astrofest again in 2024!

Science Literacy Week

Science Literacy Week is a nation-wide event that showcases the many ways kids and families can explore and enjoy the diversity of Canadian science. Libraries, museums, science centres, schools and not-for-profits come together to highlight the books, movies, podcasts and events that share exciting stories of the science, discoveries and ingenuity shaping our lives. For this year's edition, TSI Outreach joined forces with Physics Outreach to run a half-day activity fair on Sept. 23, 2023. "Life Finds a Way: An Activity Fair" featured three hands-on activities aimed at children ages 6-12. Attendees learned about what extremophiles can teach us about possible life on other planets by designing their own creatures, built their most creative energy generators using LEGO, and experimented with making lamps out of potatoes. Over the course of the afternoon, we welcomed around 250 children and their parents to the Rutherford Building. The success of the activity has us already eager to repeat it in 2024.

ASTRONOMY ON TAP MTL

Montreal has been a satellite location of the popular Astronomy on Tap (AoT) series since 2017. Originally established by members of AstroMcGill (now TSI Outreach), AoT MTL events were jointly organized with our colleagues at the Trottier Institute for Research on Exoplanets (iREx) until March 2020 when the COVID-19 pandemic forced AoT MTL into hiatus. Spring 2023 saw the return of AoT-MTL, now organised by a team of postdoctoral researchers and graduate students at McGill and UdeM, iin collaboration with the Center for Research in Astrophysics of Quebec (CRAQ), the Trottier Institute for Research on Exoplanets (iREx), and the Trottier Space Institute at McGill (TSI).

AoT are free events aimed at making space-related research more accessible to the community by combining short, engaging science presentations with themed trivia games and prizes in a social venue. Events are held monthly and alternate between English and French nights, with the occasional fully bilingual edition. Montreal was the first satellite location to have bilingual AoT events, and has served as a model for other satellite locations.

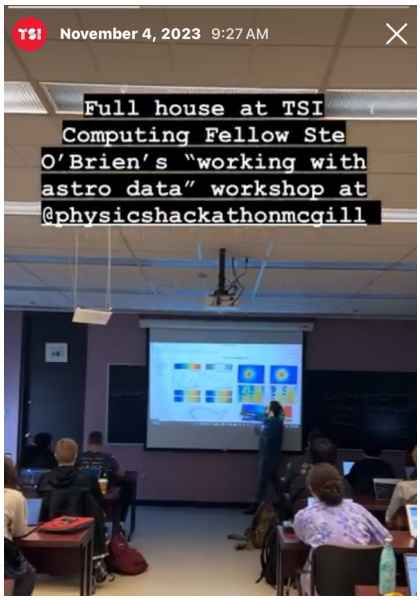
Unlike most traditional outreach efforts, AoT reaches a more diverse audience of adults in a location where people gather to socialize. AoT is also more informal, engaging and relatable than traditional hour-long lectures, reaching an audience that is new to astronomy and space sciences. AoT also offers a unique opportunity for scientists at all levels to develop professional skills such as networking, stage presence and vocal projection, and delivering scientific yet nontechnical presentations for general audiences.

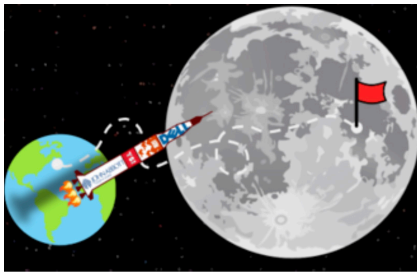
AoT's return was a resounding success. Our regular venue at Siboire, which fits around 100 people, is at capacity every month. The audience enthusiastically participate in the trivia games and never run out of questions for the astronomers after their 15-minute talks. We're thrilled to say that AoT MTL is here to stay!

MCGILL PHYSICS HACKATHON

TSI has been an active supporter of the McGill Physics Hackathon for the last five years, providing financial and logistical support to the weekend-long event, and sponsoring a prize for the best astronomy-themed project. The McGill Physics Hackathon is a friendly programming competition where students team up to write programs to visualize or calculate something related to physics. The broad nature of the prompt has given rise to a wide variety of creative projects, from simulations to to visualize space-time distortion and gravitational interaction, to projects that bring quantum principles to classic games. The Hackathon draws students at all levels, from upper high school all the way to graduate school, all of whom have access to mentors who can provide advice on how to design, implement, and present their projects. The caliber of this year's projects was particularly high and the awards were hotly contested, with the Astro Prize ultimately going to To the Moon & Back—a Space Rocket Simulator.

TSI's contribution the the Hackathon this year also extended to hosting workshops and attending the networking event, to expose participants to the opportunities available to them at TSI. TSI's Program Admin ran a short workshop on giving project presentations, providing students with a set of guidelines and tips on how to effectively communicate their hackathon projects to the judges. TSI's Computing Fellow ran a workshop on working with astronomical data, which is explained in more detail below.





To the Moon & Back—a Space Rocket Simul

Interactive Rocket Moonlanding Simulator!

Winner: Best Astro Project

Workshop: Accessing & Analyzing Astronomical Data

As part of this year's hackathon, TSI hosted a workshop on accessing and analyzing astronomical data using Python. The workshop was attended majoritarily by undergraduate students (75%) with the remainder being CEGEP students (25%). This workshop focused on introducing students to packages which are commonly used in astronomical data processing and analysis such as NumPy, Pandas, AstroPy, Astroquery and Matplotlib. As part of the workshop, students learned how to access data taken by the Gaia mission, an ESA which aims to provide a three-dimensional map of our galaxy by providing high precision positional and radial velocity measurements of starts within our galaxy and local cluster.

This workshop had three major goals. Firstly, the students learned how to query databases maintained in support of the Gaia mission. Next, the students learned some basic data processing using Pandas and NumPy to manipulate large datasets (around 1 million entries), and how to use AstroPy to perform common operations within astronomy such as unit conversions. Finally, students learned how to produce a scientific quality plot using Matplotlib. The workshop is designed to cover these three goals while also introducing concepts in astronomy such as astronomical distances, parallax, brightness, and apparent and absolute magnitudes. As an added bonus, a focus was put on accessibility when presenting data. Using the cmasher package, students learned how to make plots which utilized colorblind friendly colour maps. The result of this workshop was the creation of an iconic plot in astronomy called a Hertzsprung-Russell Diagram.

Overall feedback was positive, with some highlights of the workshop including creating accessible scientific plots, being able to follow along to a live coding exercise, and learning how to access and manipulate publicly available data.

ROAD TO ECLIPSE 2024

On the afternoon of April 8th, Montreal will experience a total solar eclipse for the first time in over 90 years. The path of totality (the region where the eclipse will be total) crosses southern Quebec, including the greater Montreal area, Montérégie and the Eastern Townships. In Montreal, the eclipse itself will begin at around 2:15 pm, hit totality at around 3:20 pm, and end by 4:30 pm. To celebrate this once-in-a-lifetime celestial event (Montreal won't see another total eclipse for another 200 years), the TSI is planning a series of events that will run from October 2023 to April 2024, culminating in an Eclipse Fair and Viewing Party on the McGill campus.

Public Talk: Eclipse Enigmas

Our eclipse series kicked off on October 5th, 2023 with Eclipse Enigmas, a public panel that brought together three astronomers from institutions across Quebec to answer questions about what eclipses are, why they happen, and how we can view them. Guillaume Poulin (Science Communicator at Astrolab de Mont-Megantic) provided an explainer of what causes eclipses, the different kinds of eclipses, and why total solar eclipses like the one we will see on April 8th are so special. Dr. Heidi White (Outreach Officer at iREx at University of Montreal) followed with a talk about the links between eclipses and the search for exoplanets. FInally, Matthew Lundy (PhD candidate at McGill Physics & TSI) provided an introduction to the history of eclipse observations and how to observe eclipses in the present day. The speakers' brief talks were followed by a 45-minute Q&A session, where the audience of around 100 people were able to ask their most pressing questions about eclipses.

A Solar Wink

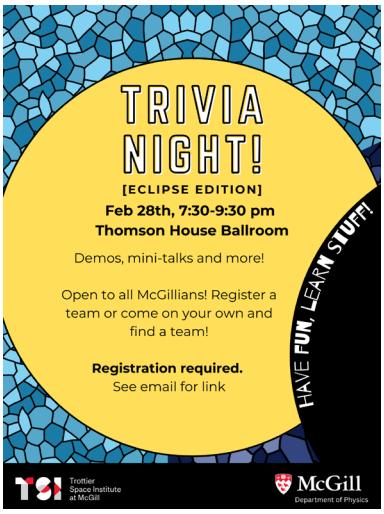
TSI volunteers participated in an event organized by our friends at the Institut Trottier de recherche sur les exoplanètes (iREx) for the partial solar eclipse that took place on October 14, 2023. The event featured a number of activities for the general public to learn about eclipses and also offered an opportunity to observe the partial eclipse. A group of 6 TSI volunteers participated in the event, bringing our solar telescopes and Sunspotters so that attendees could experiment with different ways of viewing the eclipse, beyond eclipse glasses. While this partial eclipse had only 28% coverage in Montreal, it still served as a great opportunity to get the public excited for next year's total eclipse!

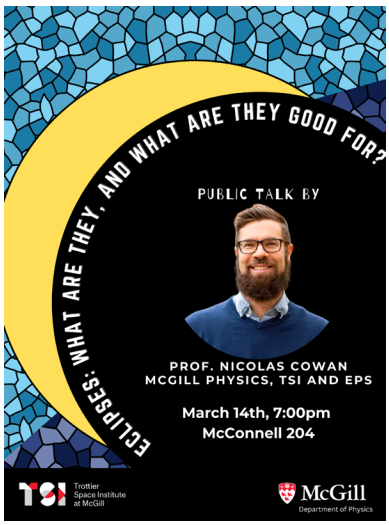
This page, from top: Poster for Eclipse Enigmas on October 5th 2024; panelists Matthew Lundy, Guillaume Poulin, and Heidi White answering audience questions at Eclipse Enigmas (photo credit: Zarif Kader, McGill University); TSI volunteers setting up the SunScopes at "A Solar WInk" on the UdeM campus on October 14th, 2023 (photo credit: Amélie Philibert, Université de Montréal); TSI volunteer Samantha Wong showing an event attendee how to view the eclipse through the solar telescope at "A Solar WInk" (photo credit: Amélie Philibert, Université de Montréal). Opposite page: posters for TSI's eclipse events (artwork credit: Dr. Saniya Heeba, McGill University).

Preparing for Eclipse 2024

We have purchased 25,000 pairs of eclipse glasses which will be distributed to our community and to attendees of our viewing party. We are also preparing programming aimed at different sectors of our community to create awareness of the eclipse, educate the public about the science behind eclipses and how to view them safely, build excitement for our flagship event !

- **AstroTrivia Night - Eclipse Edition:** An evening of eclipse and astronomy-themed trivia aimed primarily at the McGill community, including students, faculty, and staff. Attendees will get to test to their knowledge about the mysteries of the Cosmos and expand their knowledge about eclipses through mini-talks featuring TSI astronomers.
- **Public Talk:** In this public lecture aimed at the general public, TSI professor Nicolas Cowan will dive into the world of eclipses and their connections to exoplanet research.
- **Eclipse module for elementary schools:** In collaboration with McGill Physics Outreach's Space Explorers program, we are developing a module on eclipses that will be deployed in Montreal-area elementary schools in February and March 2024. Students will learn about what eclipses are, why they happen, and how to observe them safely. They will also make their own pinhole viewer to view the eclipse indirectly.





The Main Event - Eclipse Fair & Viewing Party

On the day of the eclipse, TSI will host an Eclipse Fair & Viewing party open to the McGill community at large and the general public. Programming will include hands-on activities, demos, and solar observing with our telescopes, culminating in collective viewing of the totality of the eclipse. TSI is the main organizer, but we are collaborating with units across McGill, including the Department of Physics, the Department of Earth & Planetary Sciences, the Redpath Museum, and the McGill Library, in order to offer multiple perspectives on the significance of eclipses. We are also collaborating with partners at the Gault Nature Reserve and the MacDonald Campus, where parallel viewing parties will be taking place, to provide eclipse glasses. We're planning for a crowd of at least 10,000 people and hoping that the weather cooperates!

SUMMER CAMPS & WORKSHOPS

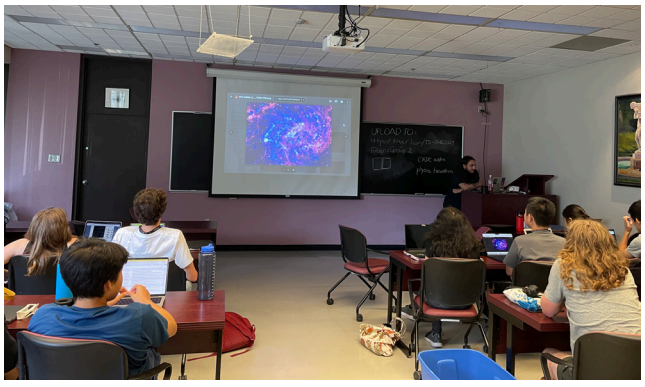
TSI is often contacted by groups organizing summer programming. This year, we organized 3 events for visiting high school students, including two groups from the School of Continuing Education, a science summer camp, and Shad McGill.

Exploring the World of STEM - School of Continuing Education

McGill's School of Continuing Education organised the inaugural run of Exploring the World of STEM, a summer program for high school students who are interested in learning more about STEM careers. TSI hosted two workshops on July 6th, 2023,"Comic Curisotiy" and "Seeing Light in Space". "Cosmic Curiosity" is Q&A based activity with current TSI graduate students meant to introduce astronomy as a field, talk about pathways into astronomy, and give students a chance to ask their most pressing space-related questions. "Seeing Light in Space" is an interactive workshop about how we see astronomical objects and how we process images. Students get to process your own astronomical images using the tools provided by the NASA Astrophoto Challenge. Both of the activities were well-received, with over 80 students participating.

Explorations Summer Camp

TSI hosted a two-hour visit from a group of ten students ages 13-15 who were participating in Explorations Summer Camp. The workshop centred around optics, with modules on the electromagnetic spectrum, how light travels, and culminating in a hands-on component where the students get to make a simple Galileo telescope using lenses.



Shad McGill

TSI had the opportunity to host a workshop for Shad McGill, a month-longlive-in summer enrichment program focused on STEAM (science, technology, engineering, arts & math) for students in grades 10 and 11 from across Canada. The group of over 50 students spent all day with us, participating in three workshops, lab tours, and a visit to the Anna McPherson Observatory. The students got to learn about astronomy as a career path during the "Cosmic Curiosity" Q&A, processed their own astronomical images in "Seeing Light in Space", and explored the climate and habitability of exoplanets using the Climate App in "Climates of Exoplanets". They also visited the labs of Prof. Cynthia Chiang and Prof. Matt Dobbs, where they got an introduction from McGill students about what it's like to work in an instrumentation lab. The day culminated with a tour of the observatory and some solar observing on the roof of the Rutherford Physics Building.

TSI IN THE MEDIA

'Astronomers capture radio signal from distant galaxy', McGill Newsroom , 16 Jan 2023 [Arnab Chakraborty]

'Astronomers captured a radio signal from the most distant galaxy', Tech Explorist , 23 Jan 2023 [Arnab Chakraborty]

'Experts: International Day of Women and Girls in Science', McGill Newsroom , 09 Feb 2023 [Eve J Lee]

'Fast Radio Bursts Reveal The Milky Way's Halo Is Surprisingly Light', IFL Science , 31 Mar 2023 [Amanda Cook]

'MYSTERY BURSTS GIVE ASTRONOMERS A VIEW INTO GALAXY HALOS', Sky & Telescope , 12 Apr 2023 [Amanda Cook]

'McGill takes part in 24 Hours of Science', McGill Reporter , 17 May 2023 [Carolina Cruz-Vinaccia]

'Science and stargazing in Chisasibi', McGill Reporter , 01 Jun 2023 [Carolina Cruz-Vinaccia]

'Experts: Canadian astronomers set to join Ariel space mission', McGill Newsroom , 25 Jul 2023 [Nicolas Cowan, Jared Splinter]

'Wind, stars, seals, and mires: A radio astronomer's journey to Marion Island', McGill Reporter , 24 Aug 2023 [Ronniy, Tristan, Mohan]

'Nicolas Cowan joins Ariel space telescope mission', McGill Reporter , 24 Aug 2023 [Nicolas Cowan]

'Nineteen McGill researchers honoured by the Royal Society of Canada', McGill Newsroom , 05 Sep 2023 [Matt Dobbs]

'Natalya Gomez named recipient of 2023 AGU James B. Macelwane Medal', McGill Newsroom , 13 Sep 2023 [Natalya Gomez]

'How To Explore The Early Universe', Quanta Magazine , 20 Sept 2023 [Cynthia Chiang]

'The Experimental Cosmologist Hunting for the First Sunrise', Quanta Magazine , 20 Sep 2023 [Cynthia Chiang]

'The Floor is Magma! (But that's a good thing)', Astrobites , 21 Sep 2023 [Keavin Moore]

'Study of Exoplanet TRAPPIST-1 b reveals new insights into its atmosphere and star', McGill Newsroom , 25 Sep 2023 [Nicolas Cowan]

'The weird hum coming from the start of the Universe', BBC , 03 Oct 2023 [Cynthia Chiang]

'Seals, seabirds and scientists: Why this remote island is a radio astronomer's paradise', CTV News , 09 Oct 2023 [Mohan Agrawal, Tristan Menard, Cynthia Chiang]

'Charles Gale, Kenneth Ragan, and Mark Sutton (Physics) appointed Fellows of the Canadian Association of Physicists', McGill Newsroom , 18 Oct 2023 [Kenneth Ragan]

'Nicolas Cowan selected for prestigious Arthur B. McDonald Fellowship', McGill Newsroom , 01 Nov 2023 [Nicolas Cowan]

'Giant black hole is one of the earliest ever seen — with clues for how these weird objects form', Nature , 06 Nov 2023 [Daryl Haggard]

'Bringing physics and space to life in Montreal classrooms', Impact McGill , 22 Nov 2023 [Alice Curtin]

'Prestigious Mitacs Awards Celebrate Canada's Top Innovators', Mitacs , 22 Nov 2023 [Hannah Fronenberg]

'McGill researcher's work on the Big Bang earns her coveted Mitacs Award', CBC Radio , 22 Nov 2023 [Hannah Fronenberg]

'Mitacs celebrates researcher spearheading the development of next-gen AI networks', Financial Post , 23 Nov 2023 [Hannah Fronenberg]

'Canadian Innovators Receive Prestigious Mitacs Awards for Breakthroughs', Canadian SME , 23 Nov 2023 [Hannah Fronenberg]

'McGill researcher wins Mitacs award for groundbreaking work to push the frontiers of space', Suburban , 26 Nov 2023 [Hannah Fronenberg]

'Canadian innovators celebrated at 13th annual Mitacs Awards', Rabble , 28 Nov 2023 [Hannah Fronenberg]

'Prestigious Mitacs Awards Celebrate Canada's Top Innovators', Canadian Industry , 28 Nov 2023 [Hannah Fronenberg]

'HANNAH FRONENBERG: Outstanding Innovation — International/ Innovation exceptionnelle - international', Mitacs Canada , 30 Nov 2023 [Hannah Fronenberg]

'Crossing the generational divide: what established scientists and early-career researchers can learn from each other', Nature , 18 Dec 2023 [Victoria Kaspi]

04

INREACH

Fostering cross-fertilization of ideas, interdisciplinary interactions, and collaborations among Institute members is one of the main missions of TSI. 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.

With COVID-19 restrictions fully lifted, 2023 saw a rekindling of the bustling, homey ambience of the TSI house. Our discussion groups and journal clubs kept going strong, experimenting with new formats to increase and maintain engagement from longtime TSI members and newcomers alike. The TSI Jamboree moved venues to the lecture hall at the Redpath museum to accommodate a larger crowd, with faculty from across TSI highlighting the progress made by their groups. Numerous social events took place throughout the year, including mainstays like the Summer Solstice Picnic, the TSI Halloween Party, and the Winter Solstice Party. We also hosted a joint mixer with iREx, to foster more connections between the two institutes.

From seminar series to discussion groups to social events, there's never a dull moment at TSI!

JOURNAL CLUBS

TSI members organise a variety of journal clubs and discussion groups that span across the various disciplines represented at TSI. From general discussions like astro-ph and Random Papers, to more niche groups, there's something for everyone at TSI!

Astro-ph Discussion

Astro-ph is a weekly journal discussion that takes place every Wednesday afternoon at TSI over donuts and coffee. 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!

Cosmo-ph Discussion

Cosmo-ph is a weekly journal club at TSI 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.

Transient Discussion

Transient Discussion is a weekly journal club centred around transients -- astrophysical phenomena that change their brightness over a relatively short time. It brings together researchers from across TSI to discuss any topics that are transients-related e.g., supernovae, pulsars, FRBs, accreting binaries, etc. Each week, a different person walks the group through a relevant paper over the course of about 30 minutes. Transit discussion also occasionally has guest speakers or visitors.

Planet Lunch

Planet Lunch brings together researchers from the Earth & Planetary Sciences, Atmospheric& Oceanic Sciences, and Physics for a weekly lunch discussion. The goal is to apply geology and planetary atmospheres expertise as studied in our Solar System to exoplanets, to achieve a better understanding of what we are learning from the much less detailed observational data on exoplanets. Experience derived from Solar System studies also guides the development of future astronomical facilities to study exoplanets. Each term, the group chooses a theme related to planetary science and each week someone leads a discussion about a paper or a topic related to that theme.

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?

A WEEK AT TSI

MONDAY

TSI Lunch Talks
12:00 pm

iREx Cafe
2:00 pm

TUESDAY

Grad Student Lunch with Speaker
3:30 pm

TSI Seminar
3:30 pm

WEDNESDAY

APIERY Discussion
2:00 pm

astro-ph Discussion
3:30 pm

THURSDAY

Summer Researc Undergrad Program
12:00 pm

Transient Discussion
3:30 pm

FRIDAY

cosmo-ph Discussion
3:30 pm

SEMINARS

TSI hosts weekly seminars featuring speakers from across North America and beyond. TSI seminars are intended to be accessible to scientists from the entire breadth of backgrounds at TSI, including physics, planetary science, geology, atmospheric science, and astrobiology. Our seminar series is made possible by a generous gift from the Trottier Family Foundation and by funding from the Centre de recherche en astrophysique du Québec (CRAQ).

Winter/Spring 2023

10 Jan — **Ben Margalit** *(UC Berkeley)*
'Lightning and Thunder: Probing the Dynamic Universe using Multiple Messengers'

17 Jan — **Siddharth Mishra-Sharma** *(MIT/Harvard)*
'Connecting astrophysical observations and dark matter microphysics using neural simulation-based inference'

31 Jan — **Lia Medeiros** *(IAS)*
'Testing Fundamental Physics with the Event Horizon Telescope'

07 Feb — **Christopher Manser** *(Imperial College London)*
'White dwarfs as astrophysical probes: From planetary systems to magnetic fields'

14 Feb — **Claire Ye** *(University of Toronto)*
'Gravitational attraction: dynamically enhanced formation of millisecond pulsars in globular clusters'

21 Feb — **Riccardo Arcodia** *(MIT)*
'X-ray flares from the nuclei of low-mass galaxies'

07 Mar — **Solene Chabanier** *(LBNL)*
'Toward precision cosmology with the Lya forest: theoretical modeling with hydro-dynamical simulations'

14 Mar — **Pradip Gatkine** *(Caltech)*
'Astronomical spectrographs on a chip - Getting ready for the next-generation telescopes'

21 Mar — **Marta Bryan** *(University of Toronto)*
'Exo-Jupiters: The Movers and Shakers of Planetary Systems'

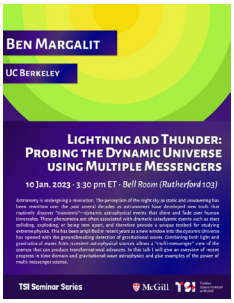
28 Mar — **Sebastian Kamann** *(LIverpool John Moores University)*
'Stellar Clusters as the Nurseries of Black Holes'

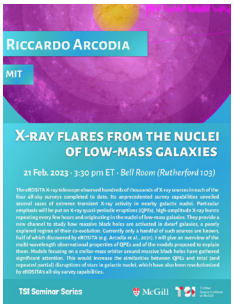
04 Apr — **Aaron Yung** *(Goddard Space Flight Center)*
'Paving the Way for Future Space Telescopes with Theory and Simulations'

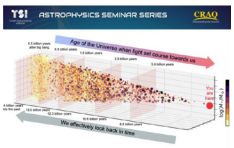
11 Apr — **Erica Lucas** *(TSI & McGill EPS)*
'Seismological Investigations of West Antarctica: From Mantle Structure to Icequakes'

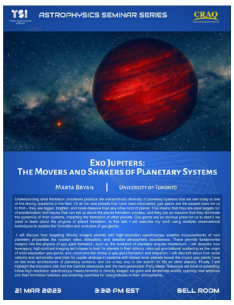
18 Apr — **Chia Min Tan** *(TSI & McGill Physics)*
'Pulsar Science with CHIME'

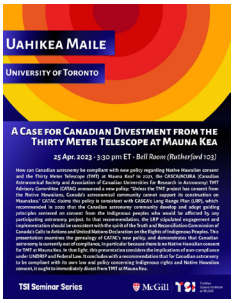
25 Apr — **Uahikea Maile** *(University of Toronto)*
'A Case for Canadian Divestment from the Thirty Meter Telescope at Mauna Kea'

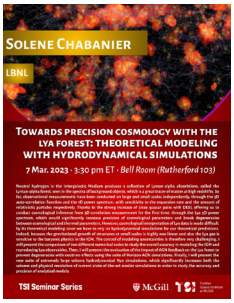


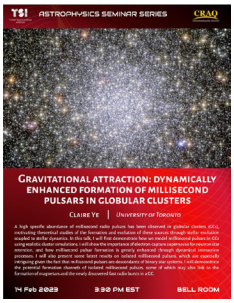


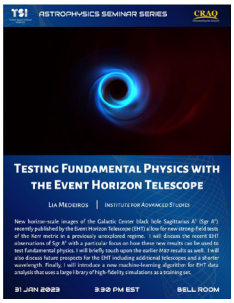












Summer 2023

02 May **Jason Hessels** *(University of Amsterdam & ASTRON)*
'Pinpointing fast radio bursts in space and time'

16 May **Arvind Balasubramanian** *(Tata Institute for Fundamental Research)*
'Radio exploration of the transient sky: Binary mergers and peculiar core-collapse supernovae'

17 Jul **Aion Viana** *(Universidade de São Paulo)*
'News from Indirect Dark Matter Searches'

Fall 2023

19 Sep **Martin Bureau** *(Oxford University)*
'Probing the Invisible: Weighing Supermassive Black Holes'

26 Sep **Rajashree Tri Datta** *(CU Boulder)*
'Tracing Extreme Events from the Ocean to the Surface of the Antarctic Ice Sheet'

03 Oct **Saniya Heeba** *(TSI & McGill Physics)*
'Inelastic Dark Matter Through The Ages'

17 Oct **Rachid Ouyed** *(University of Calgary)*
'Astrophysical magnetohydrodynamic (MHD) Jets: Observations, Theory and Simulations'

24 Oct **Justin Vandenbrouke** *(WIPAC/UW-Madison)*
'Neutrinos from the Galaxy and beyond: astrophysics with IceCube'

31 Oct **Nick Choksi** *(UC Berkeley)*
'Super-Earth Formation: The View From Resonant Planets'

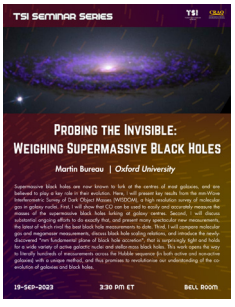
07 Nov **Gourav Khullar** *(University of Pittsburgh)*
'When and where does star formation stop? Stellar Mass Assembly and Quenching in Galaxies across Cosmic Time'

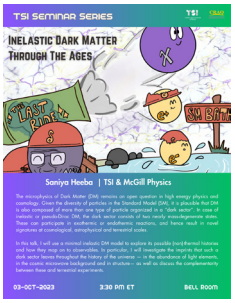
14 Nov **Rahul Kannan** *(York University)*
'Modelling high redshift structure formation and reionization'

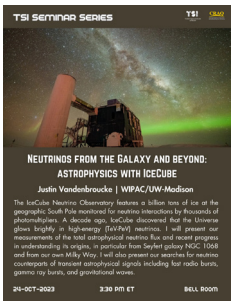
28 Nov **David Dunsky** *(NYU)*
'Gravitational Waves and Primordial Black Holes from Topological Defects in the Early Universe'

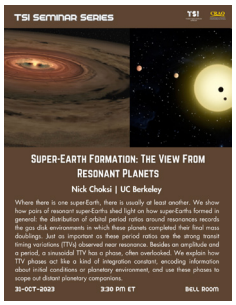
05 Dec **Steven Finkelstein** *(UT Austin)*
'Unveiling the Earliest Galaxies and Super-massive Black Holes with JWST'

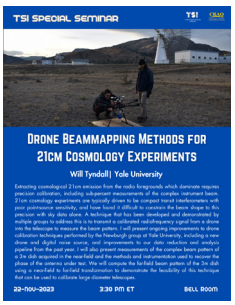
12 Dec **Luis Welbanks** *(Arizona State University)*
'Decoding Exoplanet Atmospheres: The Revolutionary Role of JWST'

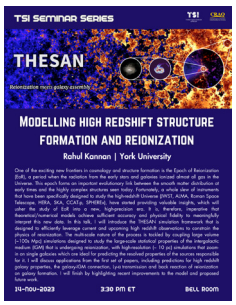


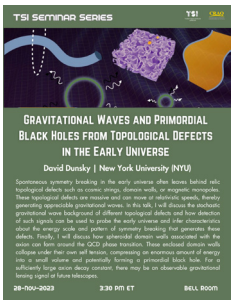


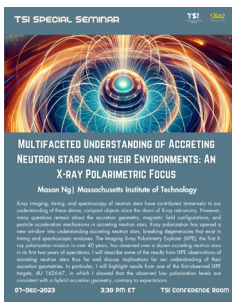


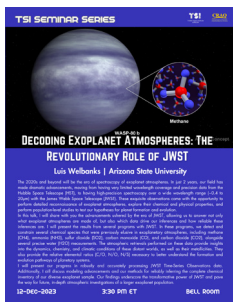












TSI UNDERGRADUATE SUMMER RESEARCHER PROGRAM

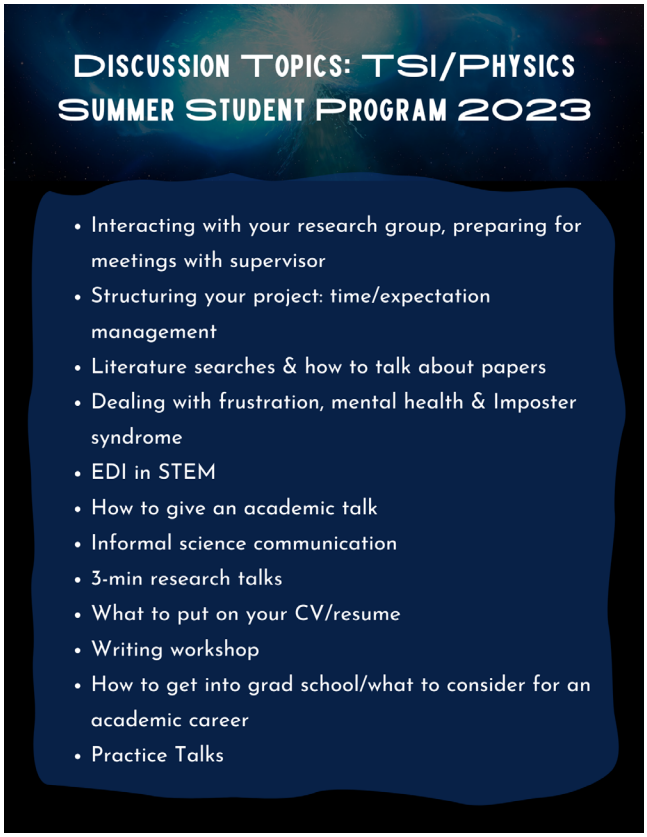
Every summer since its inception, TSI has hosted undergraduate summer research students from McGill and universities across the world. An integral part of the summer research experience at TSI is the TSI Summer Undergraduate Researcher Program, which consists of weekly professional development discussions and an end-of-the-summer Undergraduate Research Showcase. Due to the success of the program and the impact it has on students, TSI expanded the program to also encompass researchers working in other fields of Physics in 2019, a collaboration that persists to this day. The program is open to all undergraduates conducting summer research with TSI-affiliated or Physics-affiliated professors. In 2023, we hosted over 75 undergraduate summer researchers of which approximately 40 were working with TSI faculty members.

Although undergraduate researchers are hired to work in a particular professor's research group, they are encouraged to take part in all TSI activities, including seminars, journal clubs, and informal discussions. Thanks to the friendly community and welcoming environment of TSI, summer undergraduate researchers gain exposure to many different research areas well beyond their own group.

Professional Development Discussions & Workshops

A unique feature of the TSI summer undergraduate research program is our weekly workshop series. The format of these weekly meetings is a facilitated discussion, organised by TSI Program Admin Carolina Cruz-Vinaccia and Physics Undergraduate Advisor Kim Metera, in collaboration with TSI and Physics postdocs. The goal of these weekly meetings is twofold: 1) to provide guidance and mentorship for students at the earliest stage of their research careers: and 2) to foster a sense of community amongst the undergraduate summer researchers, providing space for them to connect with peers outside of their immediate research groups.

Discussions centre issues that are relevant to those embarking on their first research experience, focusing on knowledge assumed to be fundamental but that isn't always formally taught. The first set of topics includes an introduction to research life and communicating effectively with your research group, time-management, and structuring a research project. We then target specific skills that are necessary for researchers now and at future stages of their careers, including how to give effective talks, scientific writing, applying to graduate school, and pursuing non-academic careers. The program takes a holistic approach to what it means to be a researcher, emphasising topics around mental health and workplace climate, such as dealing with frustration, how to tackle impostor syndrome, and equity and inclusion in STEM.



Science communication to a variety of audiences is a central focus of our program. Students are given multiple opportunities to practise their oral communication skills, including workshops on distilling the essence of their research to people outside their field, giving 3 minute talks about their research, and 5-minute scientific talks showcasing the results of their summer research project. They also hone their writing skills through workshops on proposal writing and drafting of CVs and cover letters.

The community that forms during the summer program is as important as the skills that students learn. Student feedback consistently shows that our summer undergraduate researchers appreciate the opportunity to interact with their peers, especially those in other research groups. Students also form connections to department members further along in their research careers, such as the postdoctoral researchers who facilitate some of the sessions, thus expanding their support networks and their perspectives of what a research career entails.

Summer Undergraduate Research Showcase

We cap off the Summer Program with a Research Showcase, where undergraduate summer researchers present their projects to the entire TSI and Physics Department. This year's showcase took place in person over the course of an entire afternoon, though a Zoom option was available for those who wanted to present or attend remotely. There were four blocks of presentations, where a total of 30 undergraduates gave 5-min talks about their research. The audience was enthusiastic and interactive, asking more questions than we had time for! The showcase was followed by an outdoor reception, where presenters and audience members alike were able to celebrate a summer of hard work.

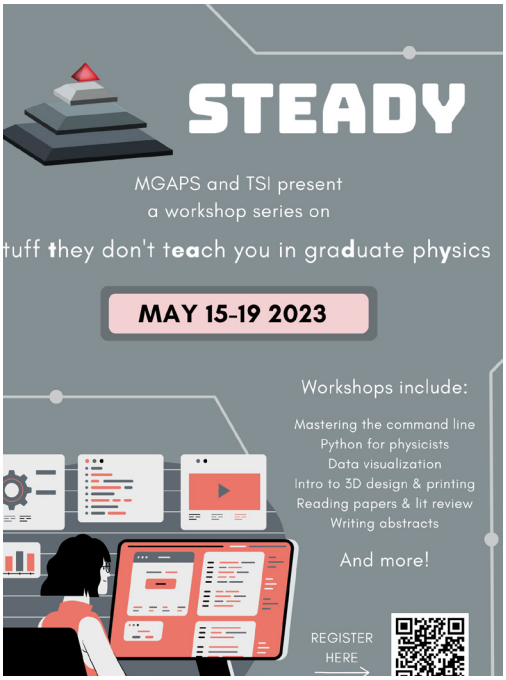
The undergraduate research projects covered a wide range of topics that reflected the diverse and interdisciplinary nature of the TSI. The presentations were evaluated by a panel of postdoc and graduate student judges, whose job was made difficult by the impressive quality of the presentations. Eight students received recognitions: two students received Best Talks awards, 3 received Outstanding Presentation, and an additional 2 received honourable mentions!

Best Presentation	Outstanding Presentations
Simone Têtu Ava Whitehead	Sara Babic Brenna Bordeniuk Ben Cheung

Honourable Mention: Franco Del Balso, Michael Hetu

STEADY WORKSHOP SERIES

Providing professional development opportunities to ensure that our highly qualified personnel (graduate students, undergraduate students, and postdoctoral researchers) have the skills necessary to succeed in their chosen career paths, either inside and or outside academia, is one of the central tenets of TSI. Our members come from a diversity of institutions, countries, and backgrounds, and bring with them a variety of levels of preparation in the skills necessary to successfully carry out research. In order to address this disparity and level the playing field, TSI teamed up with the McGill Graduate Association of Physics Students (MGAPS) to organise the STEADY workshop series from May 15-19, 2023.



The STEADY workshop series built on the model of professional development and community-building that has already proven successful for the Summer Undergraduate Researcher Program, adapted to the needs of graduate students. The topics were informed by the results of a survey that MGAPS had administered to graduate students in Fall 2022. The workshops took place every afternoon for a week, with two 90-minute sessions broken up by a coffee break meant to give students the chance to interact with each other. The wokshop leaders were postdoctoral researchers, staff members, and senior PhD students from across Physics and TSI. The sessions covered a range of essential skills, including data management, scientific computing, literature reviews, design, drafting conferencing abstracts, and science communication. The week was capped by a reception on the TSI lawn for workshop participants, instructors, and organizers.

Interest for this inaugural run was strong; over 60 participants registered, with attendance averaging 35 students per session. Feedback from participants was overwhelmingly positive, with 90% expressing satisfaction and 95% acknowledging the workshops' benefits for their academic and career goals. The workshops also fostered a strong sense of community and interactions between students and instructors.

STEADY 2023 was a successful inaugural joint effort by MGAPS and TSI to provide targeted training for graduate students. The workshop series not only facilitated skill development but also increased awareness of departmental resources and strengthened connections within the academic community. Building on this success, MGAPS and TSI are excited to refine and expand the series for future cohorts.

"The basic idea of the STEADY workshop is incredible. I feel like I learned things I wouldn't have otherwise, and it's going to make my academic (or else...) life a lot easier."

TSI LUNCH TALKS

The Monday Lunch Talk Series has been a mainstay of TSI's inreach programs since the very beginning, providing a forum for TSI grad students, postdoctoral fellows, and faculty members to give short presentations over lunch and then engage in an extended, informal discussion. Lunch talks are held every other Monday during the Fall and Winter terms, and regularly draw upwards of 35 participants. Any TSI member can give a lunch talk and they also serve as a great opportunity for new students and postdocs to introduce themselves to TSI.

Lunch Talks aim to provide an environment for speakers and attendees alike to explore topics beyond their own research. As such, both the format and content of lunch talks tend to be flexible. Lunch Talks have traditionally welcomed any and all formats of talks, including blackboard talks, interactive workshops, more traditional short research talks; the only "rule" is to be light on prepared material and leave plenty of space for discussion! In terms of content, anything goes as long as it's somewhat under the umbrella of space, space-related topics, or any of the other work we do at TSI, including outreach, education, and EDI. Speakers are welcome to practice a conference talk, tell us about a proposal, brainstorm a new idea, test a workshop, or talk about an interesting side-project or interest.

TSI members appreciate having the space to try something new. TSI graduate students got particularly creative; topics included a deep dive into the physics side of the movie 'Oppenheimer' (2023), the impact of communication satellites on astronomy, and a session on accessible representation of astronomical data, including tactile models and sonification of data. A few TSI members chose to test out workshops, including an outreach module on climate change and an interactive activity on equity, diversity, and inclusion in Physics. We also heard from TSI members who had been in the field either visiting telescope sites or on outreach trips to Indigenous communities and shared not just their photos, but their insights and lessons learned. We had a behind-the-scenes look at Canada's participation in the Ariel mission, a talk on how CHIME is secretly an axion experiment, and first-hand account of exploring the Titanic as an Analog to suborbital flight training from visiting professor Alan Stern (Southwest Research Institute). We even got a juggling lesson as part of "The Mathematics of Juggling" run by former postdoctoral research fellow (and avid juggler!) Dr. Adam Lanman.

We're thrilled to have TSI Lunch Talks back on our roster, and look forward to the creative topics that TSI members will propose for future iterations!

A Glimpse into TSI Lunch Talks: 2023

- *'Workshopping EDI activities for CEGEP visits'*
- *'Seeing Like An Astronomer at the Conference of Workshops in Chisasibi'*
- *'Outreach trip to Chisasibi: Travel-log and Lessons learned'*
- *'Climate Conversations at the TSI'*
- *'Sharing astronomy and physics with all of the senses'*
- *'Exploring the Titanic Last Year as an Analog to Suborbital Flight Training'*
- *'Juggling! — Mathematics in Motion'*
- *'The "Ultimate Catastrophe", or How to sell movie tickets'*
- *'Mega-constellation Satellites and Astronomy'*
- *'A Field Trip to the Hydrogen Epoch of Reionization Array'*
- *'Getting Lucky in Space: how to wrangle Canadian participation in a billion dollar mission'*
- *'CHIME is secretly an axion experiment'*

Left (from top): TSI Lunch Talk avatar, created by the talented Dr. Saniya Heeba; slides for lunch talks; examples of the visualizations created by TSI memebrs during Nicole Ford's lunch talk.

COMPUTING AT TSI

Astronomical research is experiencing a renaissance, driven by the production of vast amounts of high-quality data. Modern astronomers' toolkits must now include data analysis for processing, data science for extracting meaningful insights, machine learning for classifying and predicting unseen data, and computational modelling to test predictions against observations. Recognizing that high-performance computing plays a crucial role in modern astronomical research and in advancing our understanding of the universe , TSI hired a Research Computing Fellow in 2023. The Research Computing Fellow's multi-faceted role includes:

- Engaging in computational research projects with research groups within TSI
- Providing in-house expertise and resources to aid computational research.
- Delivering workshops on programming languages, existing technologies, and services available to astronomers.
- Encouraging best practices by developing guides and testing new technologies.

Computing Workshops

Computing workshops open to all TSI members will be scheduled throughout the year. The goal is to produce high quality researchers, ready to tackle any future computational challenges. Three core modules are identified: Containerization, Programming, and Personal Development. The goal of the Containerization module is to train in state-of-the-art practices for development, such as version control (Git and GitHub), containerization (Docker and Apptainer) and continuous integration and deployment (CI/CD). The end goal of this module is for scalable, containerized workflows that can be deployed on any system, from personal laptops to high performance computing (HPC) clusters. The Programming module aims to teach key programming skills and methodologies. Starting from the basic syntax, the module covers functional and object-oriented programming, module/library design and development, and performance and benchmarking with an eye to HPC. Finally, the Personal Development module focuses on supplementary skills such as website development and documentation, discussions on inclusivity in computing and deep dives on worked examples. These workshops will be scheduled throughout the year, open to all TSI members.

Advent of Code

This year the TSI participated in the" Advent of Code", with our own leaderboard for TSI members. The Advent of Code is an advent calendar of daily programming challenges over the advent period (December 1st-25th). All the challenges were Christmas/winter themed, with tasks such as helping Elfs use a trebuchet. Each day participants raced to solve these challenges using programming languages including Python, C++, Perl, Rust and even some folks using Excel! Each day a participant could earn up to 2 golden stars, with the first coming from solving the daily challenge and the second coming from usually solving a complication to the original challenge (for example they were given the wrong instruction manual by the Elfs).

To encourage participation and some friendly competition, we offered three prizes to the top 3 on our leaderboard by January 1st. This was decided by the total number of stars received (a total of 50 were available), with the tie breaker being how quickly the stars were obtained (1st receiving all points, second receiving 1 less point and so on). In total we had 32 participants ranging from undergraduate to faculty. First place went to Post Doc Emilie Storer who won a Celestron telescope. We will see if they can defend their title next year!

Meet TSI Research Computing Fellow, Dr. Stephan O'Brien

In Fall 2023, Dr. Stephan O'Brien joined the Trottier Space Insitute as a Research Computer Technology Fellow. He brings expertise in the areas of computational and data intensive research. In this role, he will participate in research within the TSI; provide advice and expertise in areas relating the computational research; deliver workshops and training on topics within the domain of research computing and assist TSI members with their high-performance computing needs. He has a background in very-high-energy astrophysics and cosmic ray physics, having previously worked on the VERITAS and HELIX experiments. Prior to joining the TSI, he was a McDonald Institute Postdoctoral Scholar working in the McGill Department of Physics.

EQUITY, DIVERSITY & INCLUSION

TSI 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, identifying and addressing areas of underrepresentation in the immediate TSI community, and embedding equity into our inreach and outreach activities.

EDI DIscussion Group: APIERY Discussion

APIERY Discussion (Astronomy/Physics Inclusion, Engagement, Reimagining pedagogY) is a weekly discussion group run by the TSI Program Admin that focuses on science engagement, education, and pedagogy, in order to make our astronomy and physics spaces and practise more inclusive. APIERY is open to everybody at TSI and any of our member departments, regardless of position within the university or level of knowledge. APIERY runs primarily like a journal club; the discussion is based on an academic paper (though other sources like blogs, podcasts, and YouTube videos may also be used.), but the paper is mainly a jumping-off point to discuss a broader topic. While Astronomy and Physics are in the title, discussions also draw upon and are relevant to other areas of science education. Topic selection is a collective effort; at the beginning of each term, we run a brainstorming session where everyone is encouraged to suggest topics. TSI members are encouraged to suggest topics and lead the discussion if they so choose!

Identifying and Addressing Areas of Underrepresentation

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 TSI postdoctoral fellows have been women. For the 2024 cycle, we are looking at how to do the same for racial diversity, particularly to address the lack of Black and Indigenous postdocs. To identify areas where we can do better, TSI teams up the Physics department to develop and deploy a bi-annual climate survey. The climate survey provides insight into the experiences of TSI & Physics to inform the changes needed to create a more inclusive environment. We deployed the most recent version of the survey in 2023, with analysis currently underway and a report expected in 2024. As this is the second iteration of the climate survey, the results may elucidate not only where we stand now, but whether the changes implemented after the 2021 survey have begun to have an impact.

Building and Maintaining Relationships

Fostering equity requires building relationships with equity-oriented organisations within and outside McGill , particularly with those that serve marginalised groups in STEM. TSI has collaborated with McGill's Branches Pick Your Path program, a mentorship program that links Indigenous CEGEP students with McGill students, since 2022. This year, we hosted 4 astronomy workshops for Indigenous youth on the McGill campus and also had the opportunity to run these workshops on-site at the Cree Nation of Chisasibi on three occasions: February 2023, March 2023, and August 2023. TSI also collaborates with Dell Technologies's Girls Who Game program and the Physics Department on Science in Space: How to Telescope, which creates inclusive spaces for girls and nonbinary students within STEM. Students in grades 5 and 6 build their astronomy knowledge and scientific thinking skills through designing and building telescopes in Minecraft, with the aid of TSI and Physics graduate student mentors. TSI collaborates on EDI related issues with similar groups both within and outside McGill. TSI works closely with the EDI Committee in the Physics Department and the EDI Committee in Earth & Planetary Sciences, as well as the EDI Committee of the Center for research in astrophysics of Quebec (CRAQ), and the Faculty of Science's Equity and Climate Committee (SECC).

Embedding EDI into TSI Activities

One of the pillars of TSI's approach to EDI is to build it into our activities as we develop them. On the Outreach side, we employ the principles of Inclusive Science Communication to make our programming more inclusive. To that end, we are intentional about the audience we are trying to reach, collaborate with participants on assessing and adapting programs to fit their needs. On the Inreach side,we foreground inclusion in the evaluation process for TSI's Summer Undergraduate Research Awards and in curating the list of speakers for TSI Seminars.

05
PEOPLE

AWARDS

Faculty Members

Nicolas Cowan
2023 Arthur B. McDonald Fellowship (NSERC)

Matt Dobbs
Elected Fellow of the Royal Society of Canada

Natalya Gomez
- 2023 James B. Macelwane Medal (American Geophysical Union)
- 2023 International Union of Geodesy and Geophysics (IUGG) Early Career Award

Daryl Haggard
2023 Canada Research Chair (Tier 2) in Multi-messenger Astrophysics (Renewal)

Eve J. Lee
Professor M.K. Vainu Bappu Gold Medal (Astronomical Society of India)

Ken Ragan
Appointed Fellow of the Canadian Association of Physicists

Katelin Schutz
2023 Canada Research Chair (Tier 2) in Astrophysics Beyond the Standard Model (New)

Postdoctoral Researchers

Kristen Dage
2023 Einstein Fellowship, NASA Hubble Fellowship Program

Ronniy Joseph
Clark Science Executive Leadership Fund (McGill Faculty of Science)

Stephan O'Brien
McDonald Institute Postdoctoral Scholar Award (Arthur B. McDonald Canadian Astroparticle Physics Research Institute)

Aaron Pearlman
Banting Postdoctoral Fellowship (NSERC)

Graduate Students

Michel Adamič
2023 Edith Engelberg Teaching Award (McGill Physics)

Mohan Agrawal
NSERC PGS-D Scholarship

Bridget Andersen
FRQNT Doctoral Scholarship

Hope Boyce
Dr. Allie V. Douglas Astrophysics Prize (McGill Physics Department)

AWARDS (CONT.)

Alice Curtin
- 'Best Talk' 2023 (CASCA Annual Meeting)
- Community Building Award (McGill Physics Department)

Dvani Dhoshi
- NSERC CGS-M Scholarship
- Lorne Trottier Science Accelerator Fellowship

Nicole Ford
FRQNT Doctoral Research Scholarship

Hannah Fronenberg
Mitacs Award for Outstanding Innovation - International

Simon Guichandut
International internship Scholarship (CRAQ)

Mahesh Herath
Eric Mountjoy Scholarship (McGill Faculty of Science)

Amalia Karalis
FRQNT Masters Scholarship

Anan Lu
2023 Mary Louise Taylor Fellowship (McGill Faculty of Science)

Aditya Karigiri Madhusudhan
Carl Reinhardt Fellowship (McGill Faculty of Science)

Magnus L'Argent
Max Stern Recruitment Fellowship (McGill University)

Sam McNichol
FRQNT Doctoral Research Scholarship

Varun Muralidharan
MITACS Globalink Graduate Fellowship

Lisa Nasu-Yu
Max Stern Recruitment Fellowship (McGill University)

Brady O'Connor
Best Oral Presentation (Joint Symposium of the International Societies of Environmental Biogeochemistry and Subsurface Microbiology)

B. Parazin
Tomlinson Fellowship (McGiill University)

Julia Pasiecznik
Murata Family Fellowship (McGill Faculty of Science)

Bobby Pascua
Jane Street Graduate Research Fellowship finalist

Guillaume Payeur
- FRQNT Masters Scholarship
- NSERC CGS-M Scholarship

Matteo Puel
Dr. Donald G. Hurst fellowship (McGill Faculty of Science)

Matthew Quinn
NSERC CGS-M Scholarship

Nayyer Raza
Walter C. Sumner Memorial Fellowship (McGill Faculty of Science)

Jean-Samuel Roux
FRQNT Doctoral Research Scholarship

Ketan Sand
FRQNT Doctoral Research Scholarship

Jared Splinter
J.B. Lynch Fellowship

Nicholas Vieira
NSERC Canada Graduate Scholarship - Doctoral (CGS-D)

Outreach

Science in Space
Outreach Program Funding (McGill Faculty of Science) - shared by Alice Curtin, Carolina Cruz-Vinaccia, Kim Metera

TSI FELLOWSHIPS

Trottier Space Institute Fellowships are made possible by a generous donation from the Trottier Family Foundation to support TSI postdoctoral researchers and graduate students.

Current TSI Postdoctoral Fellows

TSI Postdoctoral Fellowships recognize excellence in research and are awarded by a committee of faculty members across different fields of TSI.

Yayaati Chaachan

Physics • Prof. Eve Lee's Group

Dr. Chaachan has been a TSI fellow and CITA National Fellow since Fall 2022. Using both telescopic observations and theory, he studies how the process of planet formation leaves its imprint on the compositions, demographics, and orbital architectures of planets around the Sun and other stars.

Arnab Chakraborty

Physics • Prof. Matt Dobbs's Group

Dr. Chakraborty joined TSI in Fall 2021. He analyses CHIME data to measure the power spectrum of cosmological 21cm signal via Intensity mapping. His ultimate goal is to measure the acceleration of the Universe by measuring the Baryon Acoustic Scale using CHIME. He also develops software tools to calibrate upcoming radio telescope, such as CHORD.

Cherie Day

Physics • Prof. Cynthia Chiang's Group

Dr. Day has been a TSI postdoctoral fellow since Winter 2022. She develops instrumentation aimed at detecting faint cosmic radio signals from the most distant parts of the Universe to understand the formation of the very first stars and how the Universe has evolved over cosmic history

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.

Richard LaBrie

EPS • Prof. Nagissa Mahmoudi's Group

Dr. Labrie joined TSI in June 2023. His work seeks to understand what limits life in the deep ocean and what controls carbon degradation. He use an array of microbiology and organic geochemistry methods to understand the interactions between bacterial communities and dissolved organic matter, and what leads to consumption versus sequestration.

Erica Lucas

EPS • Prof. Natalya Gomez's Group

Dr. Lucas joined TSI in Winter 2023. She studies the influence of mantle heterogeneity on glacial isostatic adjustment in West Antarctica.

Aaron Pearlman

Physics • Prof.Vicky Kaspi's Group

Dr. Pearlman has been a TSI postdoctoral fellow in Prof. Vicky Kaspi's group since 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.

Mawson Sammons

Physics • Prof Vicky Kaspi's Group

Dr. Sammons joined TSI in October 2023. His work aims to understand how the structure of our Universe influences what we see from distant sources of light, such as fast radio bursts so we might better understand both. Specifically, he has focussed on the effects of gravitational lensing and plasma scintillation

Debanjan Sarkar

Physics • Prof. Adrian Liu's Group

Dr Sarkar joined TSI in August 2023. He uses line intensity mapping techniques to study cosmology and astrophysics, with a particular emphasis on theoretical modeling. Currently, his focus is on simulating the 21-cm intensity mapping signal anticipated for the CHORD telescope. Additionally, he investigates the bispectrum signal for future galaxy surveys.

Emilie Storer

Physics • Prof. Jonathan Siever's Group

Dr. Storer joined TSI in Fall 2023. Her work focuses on extracting cosmological information from complex datasets with multiple systematics. These include measurements of the CMB with the Atacama Cosmology Telescope (ACT) and Simons Observatory (SO) and measurements of the global 21-cm signal with PRISM. Her primary focus is on characterizing and correcting for instrument beams

Bailey Tetarenko

Physics • Prof. Daryl Haggard's Group

Dr. Tetarenko has been a TSI Postdoctoral Fellow since Summer 2022. She focuses on the study of the physical processes governing astrophysical accretion discs in compact binary systems in our Galaxy. Her work develops a new framework, using powerful Bayesian analysis and tomography, to map the physical properties of astrophysical accretion discs on micro-arcsecond scales.

Former TSI Postdoctoral Fellows: Where Are They Now?

Kristen Dage
NASA Einstein Fellow
Wayne State University

Peter Sims
Assist. Research Scientist
Arizona State University

Jack Orlowski-Scherer
University of Pennsylvania

Ronniy Joseph
Project Manager, CHIME/FRB
McGill University

Amy Steele
Senior Research Associate
Planetary Science Institute

TSI Graduate Fellows (Incoming)

Recognizing the high calibre of our graduate students; every new MSc or PhD student supervised by a TSI faculty member receives a fellowship and the title of TSI Graduate Fellow. As a result, all TSI graduate students receive a portion of their funding from the Trottier Family Foundation's gift. Our incoming 2023 TSI Graduate Fellows are featured below.

Roman Akhmetshyn
Supervisor: Nicolas Cowan
Department: Physics

Laurie Anna Thi-Tâm Amen
Supervisor: H. Cynthia Chiang
Department: Physics

Dhvani Doshi
Supervisor: Nicolas Cowan
Department: Physics

Stephen Fay
Supervisor: Jonathan Sievers
Department: Physics

Jennifer Glover
Supervisor: Nicolas Cowan
Department: Physics

Ian Hendricksen
Supervisor: H. Cynthia Chiang
Department: Physics

Naman Jain
Supervisor: Vicky Kaspi
Department: Physics

Patrick Janulewicz
Supervisor: Tracy Webb
Department: Physics

Magnus L'Argent
Supervisor: Vicky Kaspi
Department: Physics

Kyle Miller
Supervisor: Matt Dobbs
Department: Physics

Georgia Mraz
Supervisor: Nicolas Cowan
Department: Physics

Varun Muralidharan
Supervisor: Jim Cline
Department: Physics

Lisa Nasu-Yu
Supervisor: H. Cynthia Chiang
Department: Physics

Julia Pasiecznik
Supervisor: Robert Brandenberger
Department: Physics

Guillaume Payeur
Supervisor: Robert Brandenberger
Department: Physics

Leandro Rizk
Supervisor: Ken Ragan
Department: Physics

Vincent Savignac
Supervisor: Eve J. Lee
Department: Physics

Maya Tartarelli
Supervisor: Eve J. Lee
Department: Physics

Not Pictured:

- Shronim Tiwari (Physics)
- Avery Albert (Natural Resource Sciences)

TSI SUMMER UNDERGRADUATE RESEARCH AWARDS

TSI Summer Undergraduate Research Awards (TSI SURAs), established in 2021, fund excellent undergraduate students interested in pursuing research with TSI faculty members. The program's acts as a financial complement to our existing Summer Undergraduate Research Program and aims to make more opportunities for summer research accessible, existing alongside other McGill summer undergraduate fellowship programs (NSERC USRA & McGill SURA). 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 TSI's commitment to equity, diversity, and inclusion in mind. Applications are evaluated by the TSI Summer Undergraduate Award Committee, which is composed of postdoctoral researchers and the TSI Program Admin (see page xx). The TSI Program Administrator runs in-person and online information sessions for applicants, to ensure that they understand the 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.

In this third year of the program, we received over 120 applications from students enrolled universities across Canada. We awarded 7 TSI SURAs, all of which were accepted. The 2023 cohort of awardees spans the breadth of research areas at TSI, with students working on everything from black holes to building instrumentation to microbial assays. You can learn more about some members of our third cohort and their experiences with the program, in their own words, below.

Natalia Martorella • McGill University • Prof. Ken Ragan

Title: Assessing Reliability of Gammapy for VERITAS Research

The intent of this project was to compare analysis results obtained with the in-development open-source Python package, Gammapy, to results obtained with closed-source software, VEGAS and Event Display, in previous VERITAS papers. More specifically, this was done by developing light curves, spectral energy distributions, and sky maps of various gamma-ray emitting celestial objects. This experience was incredibly useful and engaging, as I was able to meet and work with many other undergrads performing research to increase my network, learn a lot about how the research world and greater academia operates, and notably increase my skills in science communication and data analysis. I loved every bit of it and will be taking all of this valuable information with me throughout my career.

Alexandra Rochon • McGill University • Prof.Natalya Gomez & Prof. Nicolas Cowan

Title: Ice Sheet Models for Exoplanets

I adapted a paleo-Earth ice sheet numerical model to study the water cycle of tidally locked exoplanets on the cold limit of the habitable zone. I really enjoyed my project and the TSI SURA gave me my first full-time research experience! As I am close to graduating, I know this project gave me the skills to take on graduate school and I am very grateful everything for this opportunity has brought me.

Tal Sharoni • McGill University • Prof. Vicky Kaspi

Title: Improving the Daily Monitoring Pipeline for CHIME/FRB

I aimed to improve the daily monitoring report for CHIME/FRB with a Python script. I helped to develop a pipeline to streamline the daily report and make the daily metrics accessible, as well as a Grafana dashboard to facilitate easier visual comparison of the metrics. My favourite part of the experience was participating in team meetings and the TSI meetings where I could share my progress and learn about emerging fields in astrophysics from both experts and fellow students.

Ava Whitehead • McGill University • Prof. Richard Leveille

Title: Microbialites on Mars? A SEM Investigation of Microbialites from Cenote Azul, Mexico

My research focused on a Scanning Electron Microscope (SEM) analysis on modern microbialites from Cenote Azul, with the goal of understanding these structures in an astrobiological context. By using SEM to better understand how to identify and characterize the microbialites that we find on Earth, we can improve our toolkit in searching for past/present biosignatures on other terrestrial planets such as Mars. I gained some great connections with students and faculty at McGill while participating in the TSI summer program! The program gave me the opportunity to improve my research and presentation skills, and prepared me to continue with research in a MSc capacity at McGill University.

Not Pictured: **Raghav Bhargava** (University of Ottawa • Prof. Lyle Whyte) ; **Benjamin Cheung** (McGill University • Prof.Daryl Haggard) ; **Aditya Chugh** (University of Toronto • Prof. Katelin Schutz)

TSI DIRECTORY

Faculty Members

Robert Brandenberger (Phys)
Cynthia Chiang (Phys)
Jim Cline (Phys)
Nicolas Cowan (Phys/EPS)
Andrew Cumming (Phys)
Matt Dobbs (Phys)
Natalya Gomez (EPS)
Daryl Haggard (Phys)
David Hanna (Phys)
Yi Huang (AOS)
Vicky Kaspi (Phys)
Eve J. Lee (Phys)
Adrian Liu (Phys)
Nagissa Mahmoudi (EPS)
Ken Ragan (Phys)
Katelin Schutz (Phys)
Jonathan Sievers (Phys)
Tracy Webb (Phys)
Lyle Whyte (NRS)

Associate Members

René Doyon (UdeM)
Oscar Hernandez (Phys)
Yasher Hezaveh (UdeM)
Richard Léveillé (EPS)
Laurence Perrault-Levasseur (UdeM)

Staff

Carolina Cruz-Vinaccia
Stephan O'Brien
Vincie Tang

Postdoctoral Researchers

Heliudson Bernardo (Phys)
Yayaati Chachan (Phys)
Arnab Chakraborty (Phys)
Christina Davis (NRS)
Cherie Day (Phys)
Wellington De Oliveira Avelino (Phys)
Mona Jalilvand (Phys)
Ronniy Joseph (Phys)
Vignesh Krishnamurthy (Phys)
Richard LaBrie (EPS)
Robert Main (Phys)
Ryan McKinven (Phys)
Joshua Montgomery (Phys)
Tristan Ménard (Phys)
Thomas Navarro (EPS)
Giang Nguyen (Phys)
John Orlowski-Scherer (Phys)
Aaron Pearlman (Phys)
Masoud Rafiei-Ravandi (Phys)
Mawson Sammons (Phys)
Saniya Heeba (Phys)
Debanjan Sarkar (Phys)
Peter Sims (Phys)
Emilie Storer (Phys)
Bailey Tetarenko (Phys)

Graduate Students

Thomas Abbott (Phys)
Michel Adamic (Phys)
Mohan Agrawal (Phys)
Roman Akhmetshyn (Phys)
Avery Albert (NRS)
Laurie Anna Thi-Tâm Amen (Phys)
Bridget Andersen (Phys)
Srobona Basak (Phys)
Vadim Bidula (Phys)
Matteo Blamart (Phys)
Olivia Blenner-Hasset (NRS)
Louis-Jacques Bourdages (NRS)
Nirmalya Brahma (Phys)
Christian Capanelli (Phys)
Matias Castro Tapia (Phys)
Rebecca Ceppas de Castro (Phys)
Hoi-Man Kelvin Chan (Phys)
Paul Chouha (Phys)
Vincent Comeau (Phys)
Alice Curtin (Phys)
Caitlin Mackenzie Dewar (Phys)
Taylor Dibblee-Barkman (Phys)
Dhvani Doshi (Phys)
Aline Favero (Phys)
Stephen Fay (Phys)
Nicole Ford (Phys)
Hannah Fronenberg (Phys)
Kit Gerodias (Phys)
Erin Gibbons (EPS)
Jennifer Glover (Phys)
Simon Guichandut (Phys)
Aryana Haghjoo (Phys)
Timothy Hallatt (Phys)
Raphael Hardy (Phys)
Ian Hendricksen (Phys)
Mahesh Herath (EPS)
Lawrence Herman (Phys)
Michael Jafs (Phys)
Naman Jain (Phys)
Patrick Janulewicz (Phys)
Hao Jiao (Phys)
Zarif Kader (Phys)
Amalia Karalis (Phys)
Aditya Karigiri Madhusudhan (Phys)
Melisa Kozey (NRS)
Magnus L'Argent (Phys)
Samuel Laliberte (Phys)
Benoit Laurent (Phys)
Anan Lu (Phys)
Matthew Lundy (Phys)
Keza (Kevin) Marimbu (Phys)
Lisa McBride (Phys)
Francis McGee (Phys)
Samuel McNichol (EPS)
Marcus Merryfield (Phys)
Clinton Kyle (Kyle) Miller (Phys)
Keavin Moore (EPS)
Georgia Mraz (Phys)
Varun Muralidharan (Phys)
Lisa Nasu-Yu (Phys)
Brady O'Connor (NRS)
Robert Pascua (Phys)
Julia Pasiecznik (Phys)
Guillaume Payeur (Phys)
Syed Nayyer Raza (Phys)
Leandro Rizk (Phys)
Maclean Rouble (Phys)
Jean-Samuel Roux (Phys)
Ketan Sand (Phys)
Vincent Savignac (Phys)
Hugo Schérer (Phys)
Vishwangi Shah (Phys)
Jared Splinter (EPS)
Maya Tartarelli (Phys)
Shronim Tiwari (Phys)
Nicolas Vieira (Phys)
Samantha Wong (Phys)
Qing Hao Xu (Phys)

Undergraduate Students

Jasmine Asfour-Palacios (Phys)
Maryn Askew (Phys)
Sara Babic (Phys)
Christopher Barbarie (Phys)
Vlad Calinescu (Phys)
Rick Cao (Phys)
Ben Cheung (Phys)
Aditya Chugh (Phys)
Rafael Cottom (Phys)
Evan Davies-Velie (Phys)
Franco Del Balso (Phys)
Yael Demers (Phys)
Abigail Denney (Phys)
Maya Goss (Phys)
Michael Hetu (Phys)
Rawan Karam (Phys)
Magnus L'Argent (Phys)
Marc-Olivier Lalonde (Phys)
Katherine Lei (Phys)
Marissa Lindon (Phys)
Gabrielle MacKinnon (Phys)
Natalia Martorella (Phys)
Olivia Pereira (Phys)
Leandro Ritz (Phys)
Alexandra Rochon (Phys/EPS)
Vincent Savignac (Phys)
Tal Sharoni (Phys)
Keith Sheppard (Phys)
Sloane Sirota (Phys)
Kayla Spencer-Young
Jenny Su (Phys)
Emilia Vlahos (Phys)
Ava Whitehead (EPS)
Tianzhuo Xiao (Phys)
Mariah Zeroug (Phys)

TSI GOVERNANCE

TSI Board 2023

External Members

Lorne Trottier • *Co-founder · Matrox*

Marc Guilbert • *Chief Financial Officer · Kelvin Zero Inc.*

Juna Kollmeier • *Staff Scientist · Carnegie Observatories*

Internal McGill Members

Chris Manfredi • *Provost*

Martha Crago • *Vice Principal - Research & Innovation*

Bruce Lennox • *Dean, Faculty of Science*

TSI Members

Vicky Kaspi • *TSI Director; Professor, Physics*

Ken Ragan • *TSI Associate Director ; Professor, Physics*

Matt Dobbs • *Professor, Physics*

Robert Brandenberger • *Professor, Physics*

Nagissa Mahmoudi • *Assist. Professor, Earth & Planetary Sciences*

Aaron Pearlman • *Postdoctoral Researcher, Physics*

Leandro Rizk • *MSc Student, Physics*

Fellowships Committee

Adrian Liu *[Chair]* • *Assistant Professor, Physics*

Jim Cline • *Professor, Physics*

Daryl Haggard • *Associate Professor, Physics*

Nagissa Mahmoudi • *Assist. Professor, Earth & Planetary Sciences*

Ken Ragan • *Professor, Physics*

TSI Seminar Committee

Katelin Shutz *[Co-Chair]* • *Assistant Professor, Physics*

Tracy Webb *[Co-Chair]* • *Associate Professor, Physics*

Saniya Heeba • *Postdoctoral Fellow, Physics*

Vignesh Krishnamurthy • *Postdoctoral Fellow, Physics*

Erica Lucas • *Postdoctoral Fellow, Earth & Planetary Sciences*

Jack Orlowski-Scherer • *Postdoctoral Fellow, Physics*

Carolina Cruz-Vinaccia • *TSI Program Administrator*

Undergraduate Summer Awards Committee

Carolina Cruz-Vinaccia • *TSI Program Administrator*

Saniya Heeba • *Postdoctoral Fellow, Physics*

Vignesh Krishnamurthy • *Postdoctoral Fellow, Physics*

Kimberly Metera • *Undergraduate Advisor, Physics*

Stephan O'Brien • *Postdoctoral Fellow, Physics*

Peter Sims • *Postdoctoral Fellow, Physics*

Outreach Committee

Thomas Brunner • *Associate Professor, Physics*

Lillian Childress • *Associate Professor, Physics*

Carolina Cruz-Vinaccia • *TSI Program Administrator*

Alice Curtin • *PhD Student, Physics*

Hannah Fronenberg • *PhD Student, Physics*

David Gallacher • *PhD Student, Physics*

Matthew Lundy • *PhD Student, Physics*

Kimberly Metera • *Undergraduate Advisor, Physics*

Celina Pasiecznik • *PhD Student, Physic*

06

IMPACT

FACILITIES USED BY TSI 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)

Australian Telescope Compact Array
(Haggard)

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

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

CHORD The Canadian Hydrogen Observatory and Radio transient Detector
(Chiang, Dobbs, Kaspi, Liu, Sievers)

Event Horizon Telescope Array
(Haggard)

European Southern Observatory: La Silla 3.6 m Telescope
(Cowan)

Gemini Observatory
(Cowan, 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 Binocular Telescope
(Webb)

Large Millimeter Telescope Alfonso Serrano
(Webb)

Magellan Telescopes
(Webb)

Observatoire du Mont-Mégantic
(Cowan)

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
(Haggard, Webb)

VERITAS Gamma-ray Observatory
(Hanna, Ragan)

Space-based Telescopes

NASA/James Webb Space Telescope
(Cowan, Haggard)

NASA/Hubble Space Telescope
(Cowan, Haggard, Lee, Webb)

NASA/Kepler Mission
(Cowan)

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

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

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

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

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

NASA/Spitzer Space Telescope
(Cowan, Haggard, Webb)

NASA/Fermi mission
(Haggard, Ragan)

NASA/Transiting Exoplanet Survey Satellite
(Cowan, Lee)

FACULTY COLLABORATIONS

Ariel (European Space Agency's M4 mission) • *(Cowan, Lee)*

The Canadian Data Intensive Astrophysics PLatform (CanDIAPL) • *(Haggard)*

CASE - Contribution to Ariel Spectroscopy of Exoplanets • *(Cowan)*

CSA's CASTOR - Cosmological Advanced Survey Telescope for Optical and Ultraviolet Research • *(Haggard, Cowan)*

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

CHORD The Canadian Hydrogen Observatory and Radio transient Detector • *Chiang, Dobbs, Kaspi, Liu, Sievers*

D3A: Deep Dish Development Array • *(Chiang, Dobbs, Sievers)*

Event Horizon Telescope Collaboration • *(Haggard)*

Next Generation Event Horizon Telescope Collaboration • *(Haggard)*

GBNCC The Green Bank North Celestial Cap Pulsar Survey • *(Kaspi)*

HELIX - High Energy Light Ion eXperiment • *(Hanna)*

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

High-altitude Aerosols, Water vapour, and Clouds (HAWC satellite) • *(Huang)*

HIRAX • *(Chiang, Dobbs, Sievers)*

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

Laser Interferometer Space Antenna (LISA) Consortium (European Space Agency's L3 mission) • *(Haggard)*

Massive Ancient Galaxies At z>3 NEar-infrared Survey (MAGAZ3NE) • *(Webb)*

Maunakea Spectroscopic Explorer • *(Haggard, Webb)*

MBH CoLAB Montréal Black Hole Collaboration • *(Haggard, Webb)*

MIST - Mapper of the IGM Spin Temperature • *(Chiang, Sievers)*

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

NASA's Advanced X-ray Imaging Satellite (AXIS) • *(Haggard)*

NASA's Arcus Observatory • *(Haggard)*

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

NASA's Survey and Time-domain Astrophysical Research eXplorer (STAR-X) • *(Haggard)*

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

NIRPS Near Infrared Planet Spectrograph • *(Cowan)*

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

POLARBEAR • *(Dobbs)*

PITCH BLACK - JCMT Large Program • *(Haggard)*

PRIZM/ALBATROS • *(Chiang, Sievers)*

The Simons Observatory • *(Sievers)*

SpARCS the Spitzer Adaptation of the Red-Sequence Cluster Method • *(Webb)*

SPIRou Spectro-Polarimetre InfraRouge Science Legacy Survey • *(Cowan, Lee)*

SPT The South Pole Telescope • *(Dobbs)*

The Simons Array • *(Dobbs)*

Vera C. Rubin Observatory • *(Haggard)*

VERITAS • *(Hanna, Ragan)*

PUBLICATIONS

Aaltonen, L. A. (2023) Author Correction: Pan-cancer analysis of whole genomes. Natur, 614, E39.

Abbott, R. et al [Chime/Frb Collaboration] (2023) Search for Gravitational Waves Associated with Fast Radio Bursts Detected by CHIME/FRB during the LIGO-Virgo Observing Run O3a. ApJ, 955, 155.

Abbott, T. M. C. et al [DES, SPT Collaborations] (2023) Joint analysis of Dark Energy Survey Year 3 data and CMB lensing from SPT and Planck. III. Combined cosmological constraints. PhRvD, 107, 023531.

Abdurashidova, Z. et al [HERA Collaboration] (2023) Improved Constraints on the 21 cm EoR Power Spectrum and the X-Ray Heating of the IGM with HERA Phase I Observations. ApJ, 945, 124.

Acharyya, A. et al [H. E. S. S. Collaboration] (2023) Multiwavelength Observations of the Blazar PKS 0735+178 in Spatial and Temporal Coincidence with an Astrophysical Neutrino Candidate IceCube-211208A. ApJ, 954, 70.

Acharyya, A. et al [VERITAS Collaboration] (2023) A VERITAS/Breakthrough Listen Search for Optical Technosignatures. AJ, 166, 84.

Acharyya, A. et al (2023) VERITAS Discovery of Very High Energy Gamma-Ray Emission from S3 1227+25 and Multiwavelength Observations. ApJ, 950, 152.

Acharyya, A. et al (2023) VERITAS and Fermi-LAT Constraints on the Gamma-Ray Emission from Superluminous Supernovae SN2015bn and SN2017egm. ApJ, 945, 30.

Acharyya, A. et al (2023) Search for Ultraheavy Dark Matter from Observations of Dwarf Spheroidal Galaxies with VERITAS. ApJ, 945, 101.

Akiyama, K. et al [Event Horizon Telescope Collaboration] (2023) First M87 Event Horizon Telescope Results. IX. Detection of Near-horizon Circular Polarization. ApJL, 957, L20.

Alexandrov, L. B. et al (2023) Author Correction: The repertoire of mutational signatures in human cancer. Natur, 614, E41.

Alizai, K. et al (2023) A catalogue of unusually long thermonuclear bursts on neutron stars. MNRAS, 521, 3608.

Allart, R. et al(2023) Homogeneous search for helium in the atmosphere of 11 gas giant exoplanets with SPIRou. A&A, 677, A164.

Allison, P. et al (2023) Electron-beam calibration of aerogel tiles for the HELIX RICH detector. NIMPA, 1055, 168549.

Allys, E. et al [LiteBIRD Collaboration] (2023) Probing cosmic inflation with the LiteBIRD cosmic microwave background polarization survey. PTEP, 2023, 042F01.

Alonso-Álvarez, G., Bleau, K., Cline, J. M. (2023) Distortion of neutrino oscillations by dark photon dark matter. PhRvD, 107, 055045.

Alonso-Álvarez, G., Cline, J. M., Xiao, T. (2023) The flavor of QCD axion dark matter. JHEP, 2023, 187.

Amaro-Seoane, P. et al (2023) Astrophysics with the Laser Interferometer Space Antenna. LRR, 26, 2.

Amiri, M. et al [CHIME Collaboration] (2023) Detection of Cosmological 21 cm Emission with the Canadian Hydrogen Intensity Mapping Experiment. ApJ, 947, 16.

Andersen, B. C. et al (2023) CHIME Discovery of a Binary Pulsar with a Massive Nondegenerate Companion. ApJ, 943, 57.

Andersen, B. C. et al [Chime/Frb Collaboration] (2023) CHIME/FRB Discovery of 25 Repeating Fast Radio Burst Sources. ApJ, 947, 83.

Andersen, B. C. et al (2023) Flux Calibration of CHIME/FRB Intensity Data. AJ, 166, 138.

Balkenhol, L. et al [SPT-3G Collaboration] (2023) Measurement of the CMB temperature power spectrum and constraints on cosmology from the SPT-3G 2018 T T , T E , and E E dataset. PhRvD, 108, 023510.

Bégin, T. et al (2023) Extended radio emission in the galaxy cluster MS 0735.6+7421 detected with the Karl G. Jansky Very Large Array. MNRAS, 519, 767.

Bellotti, S. et al (2023) Monitoring the large-scale magnetic field of AD Leo with SPIRou, ESPaDOnS, and Narval. Towards a magnetic polarity reversal?. A&A, 676, A56.

Blamart, M., Laliberte, S., Brandenberger, R. (2023) TCC bounds on the static patch of de Sitter space. JHEP, 2023, 193.

Bloxam, K., Huang, Y. (2023) Radiative and dynamic contributions to the observed temperature trends in the Arctic winter atmosphere. ClDy, 60, 257.

Boucher, A. et al (2023) CO or no CO? Narrowing the CO abundance constraint and recovering the H2O detection in the atmosphere of WASP-127 b using SPIRou. MNRAS, 522, 5062.

Brahma, N., Berlin, A., Schutz, K. (2023) Photon-dark photon conversion with multiple level crossings. PhRvD, 108, 095045.

Brahma, N., Heeba, S., Schutz, K. (2023) Resonant pseudo-Dirac dark matter as a sub-GeV thermal target. PhRvD, 109, 035006.

Brahma, S., Brandenberger, R., Laliberte, S. (2023) Spontaneous symmetry breaking in the BFSS model: analytical results using the Gaussian expansion method. EPJC, 83, 904.

Brandenberger, R. (2023) Superstring cosmology - a complementary review. JCAP, 2023, 019.

Brandenberger, R. et al (2023) Graviton to photon conversion via parametric resonance. PDU, 40, 101202.

Brandenberger, R., Kamali, V., Ramos, R. O. (2023) Decay of ALP condensates via gravitation-induced resonance. JCAP, 2023, 009.

Brandenberger, R., Mitchell, G. A. (2023) A bouncing cosmology from VECROs. EPJC, 83, 308.

Brogi, M. et al (2023) The Roasting Marshmallows Program with IGRINS on Gemini South I: Composition and Climate of the Ultrahot Jupiter WASP-18 b. AJ, 165, 91.

Bruna, M. et al(2023) Combining photometry and astrometry to improve orbit retrieval of directly imaged exoplanets. MNRAS, 519, 460.

Carmona, A. et al (2023) Near-IR and optical radial velocities of the active M dwarf star Gl 388 (AD Leo) with SPIRou at CFHT and SOPHIE at OHP. A 2.23 day rotation period and no evidence for a corotating planet. A&A, 674, A110.

Chachan, Y., Lee, E. J. (2023) Small Planets around Cool Dwarfs: Enhanced Formation Efficiency of Super-Earths around M Dwarfs. ApJL, 952, L20.

Chang, C. et al [SPT Collaborations] (2023) Joint analysis of Dark Energy Survey Year 3 data and CMB lensing from SPT and P l a n c k . II. Cross-correlation measurements and cosmological constraints. PhRvD, 107, 023530.

Chen, S. et al (2023) Sea Ice Extent Prediction with Machine Learning Methods and Subregional Analysis in the Arctic. Atmos, 14, 1023.

Chen, Y-T., Huang, Y., Merlis, T. M. (2023) The Global Patterns of Instantaneous CO2 Forcing at the Top of the Atmosphere and the Surface. JCli, 36, 6331.

Cline, J. M. et al (2023) Blazar Constraints on Neutrino-Dark Matter Scattering. PhRvL, 130, 091402.

Cline, J. M. et al (2023) PeV-scale leptogenesis, gravitational waves, and black holes from a SUSY-breaking phase transition. PhRvD, 107, 095011.

Cline, J. M. & Puel, M. (2023) NGC 1068 constraints on neutrino-dark matter scattering. JCAP, 2023, 004.

Cline, J. M. et al (2023) Phantom fluid cosmology: Impact of a phantom hidden sector on cosmological observables. PhRvD, 108, 095033.

Cook, A. M. et al (2023) An FRB Sent Me a DM: Constraining the Electron Column of the Milky Way Halo with Fast Radio Burst Dispersion Measures from CHIME/FRB. ApJ, 946, 58.

Cortés-Zuleta, P. et al (2023) Optical and near-infrared stellar activity characterization of the early M dwarf Gl 205 with SOPHIE and SPIRou. A&A, 673, A14.

Couture, D., Gagné, J., Doyon, R. (2023) Addressing Systematics in the Traceback Age of the β Pictoris Moving Group. ApJ, 946, 6.

Cramer, W. J. et al (2023) A Large-scale Kinematic Study of Molecular Gas in High-z Cluster Galaxies: Evidence for High Levels of Kinematic Asymmetry. ApJ, 944, 213.

Curtin, A. P. et al (2023) Limits on Fast Radio Burst-like Counterparts to Gamma-Ray Bursts Using CHIME/FRB. ApJ, 954, 154.

Dage, K. C. et al (2023) Far ultra-violet insights into NGC 1399's globular cluster population. MNRAS, 518, 87.

Donati, J-F. et al, [SLS Collaboration] (2023) The magnetic field and multiple planets of the young dwarf AU Mic. MNRAS, 525, 455.

Donati, J-F. et al [SLS Collaboration] (2023) Magnetic fields and rotation periods of M dwarfs from SPIRou spectra. MNRAS, 525, 2015.

Dong, F. A. et al (2023) The second set of pulsar discoveries by CHIME/FRB/Pulsar: 14 rotating radio transients and 7 pulsars. MNRAS, 524, 5132.

Doyon, R. et al (2023) The Near Infrared Imager and Slitless Spectrograph for the James Webb Space Telescope. I. Instrument Overview and In-flight Performance. PASP, 135, 098001.

Durand, M. et al (2023) Effects of marine diesel on microbial diversity and activity in high Arctic beach sediments. MarPB, 194, 115226.

Fiore, W. et al (2023) The Green Bank North Celestial Cap Survey. VIII. 21 New Pulsar Timing Solutions. ApJ, 956, 40.

Fouqué, P. et al (2023) The SPIRou legacy survey. Rotation period of quiet M dwarfs from circular polarization in near-infrared spectral lines: The SPIRou APERO analysis. A&A, 672, A52.

Fuentes, J. R. et al (2023) Rotation Reduces Convective Mixing in Jupiter and Other Gas Giants. ApJL, 950, L4.

Fuentes, J. R. et al (2023) Heat Transport and Convective Velocities in Compositionally Driven Convection in Neutron Star and White Dwarf Interiors. ApJ, 950, 73.

Fung, A. et al (2023) New bounds on light millicharged particles from the tip of the red-giant branch. PhRvD, 109, 083011.

Gagnon-Hartman, S., Ruan, J., Haggard, D. (2023) Debiasing standard siren inference of the Hubble constant with marginal neural ratio estimation. MNRAS, 520, 1.

Gan, T. et al (2023) A Massive Hot Jupiter Orbiting a Metal-rich Early M Star Discovered in the TESS Full-frame Images. AJ, 166, 165.

Gao, J. et al (2023) Aerosol Effects on Clear-Sky Shortwave Heating in the Asian Monsoon Tropopause Layer. JGRD, 128, e2022JD036956.

Gardner, J. P. et al (2023) The James Webb Space Telescope Mission. PASP, 135, 068001.

Gerstung, M. et al (2023) Author Correction: The evolutionary history of 2,658 cancers. Natur, 614, E42.

Good, D. C. et al (2023) Nondetection of CHIME/Fast Radio Burst Sources with the Arecibo Observatory. ApJ, 944, 70.

Gorce, A. et al (2023) Impact of instrument and data characteristics in the interferometric reconstruction of the 21 cm power spectrum. MNRAS, 520, 375.

Guichandut, S. & Cumming, A. (2023) The Imprint of Convection on Type I X-Ray Bursts: Pauses in Photospheric Radius Expansion Lightcurves. ApJ, 954, 54.

Hardy, R., Charbonneau, P., Cumming, A. (2023) Magnetohydrodynamical Torsional Oscillations from Thermoresistive Instability in Hot Jupiters. ApJ, 959, 41.

Hasebe, T. et al [LiteBIRD Collaboration] (2023) Sensitivity Modeling for LiteBIRD. JLTP, 211, 384.

Heeba, S., Lin, T., Schutz, K. (2023) Inelastic freeze-in. PhRvD, 108, 095016.

Hinkley, S. et al (2023) Direct discovery of the inner exoplanet in the HD 206893 system. Evidence for deuterium burning in a planetary-mass companion. A&A, 671, L5.

Hood, J. C. et al (2023) Simultaneous Millimeter-wave, Gamma-Ray, and Optical Monitoring of the Blazar PKS 2326-502 during a Flaring State. ApJL, 945, L23.

Howard, W. S. et al (2023) Characterizing the Near-infrared Spectra of Flares from TRAPPIST-1 during JWST Transit Spectroscopy Observations. ApJ, 959, 64.

Hu, C-P. et al (2023) Monitoring observations of SMC X-1's excursions (MOOSE) - II. A new excursion accompanies spin-up acceleration. MNRAS, 520, 3436.

Huang, H. & Huang, Y. (2023) Diagnosing the Radiation Biases in Global Climate Models Using Radiative Kernels. GeoRL, 50, e2023GL103723.

Huang, H. & Huang, Y. (2023) Radiative sensitivity quantified by a new set of radiation flux kernels based on the ECMWF Reanalysis v5 (ERA5). ESSD, 15, 3001.

Jiao, H., Brandenberger, R., Refregier, A. (2023) Early structure formation from cosmic string loops in light of early JWST observations. PhRvD, 108, 043510.

Johnson, M. D. et al (2023) Key Science Goals for the Next-Generation Event Horizon Telescope. Galax, 11, 61.

Jorstad, S. et al (2023) The Event Horizon Telescope Image of the Quasar NRAO 530. ApJ, 943, 170.

Jungdal-Olesen, G. et al (2023) Sea level response to late Pliocene-Quaternary erosion and deposition in Scandinavia. QSRv, 301, 107938.

Kammerer, J. et al (2023) The Near Infrared Imager and Slitless Spectrograph for JWST. V. Kernel Phase Imaging and Data Analysis. PASP, 135, 014502.

Keller, P. M. et al (2023) Search for the Epoch of Reionization with HERA: upper limits on the closure phase delay power spectrum. MNRAS, 524, 583.

Kiefer, F. et al (2023) A sub-Neptune planet around TOI-1695 discovered and characterized with SPIRou and TESS. A&A, 670, A136.

Li, Y. et al (2023) Author Correction: Patterns of somatic structural variation in human cancer genomes. Natur, 614, E38.

Lim, O. et al (2023) Atmospheric Reconnaissance of TRAPPIST-1 b with JWST/NIRISS: Evidence for Strong Stellar Contamination in the Transmission Spectra. ApJL, 955, L22.

Mahmoudi, N. et al (2023) Biogeochemistry of Earth before exoenzymes. NatGe, 16, 845.

Mainali, R. et al (2023) Spectroscopy of CASSOWARY gravitationally lensed galaxies in SDSS: characterization of an extremely bright reionization-era analogue at z = 1.42. MNRAS, 520, 4037.

Mckinven, R. et al (2023) A Large-scale Magneto-ionic Fluctuation in the Local Environment of Periodic Fast Radio Burst Source FRB 20180916B. ApJ, 950, 12.

Mckinven, R. et al (2023) Revealing the Dynamic Magnetoionic Environments of Repeating Fast Radio Burst Sources through Multiyear Polarimetric Monitoring with CHIME/FRB. ApJ, 951, 82.

Merryfield, M. et al (2023) An Injection System for the CHIME/FRB Experiment. AJ, 165, 152.

Michilli, D. et al (2023) Subarcminute Localization of 13 Repeating Fast Radio Bursts Detected by CHIME/FRB. ApJ, 950, 134.

Mindorff, L. M. et al (2023) Isotopic and microbial evidence for biodegradation of diluted bitumen in the unsaturated zone. EPoll, 322, 121170.

Moore, K., Cowan, N. B., Boukaré, C-É. (2023) The role of magma oceans in maintaining surface water on rocky planets orbiting M-dwarfs. MNRAS, 526, 6235.

Morello, G. et al (2023) TOI-1442 b and TOI-2445 b: Two potentially rocky ultra-short period planets around M dwarfs. A&A, 673, A32.

Moutou, C. et al (2023) Characterizing planetary systems with SPIRou: M-dwarf planet-search survey and the multiplanet systems GJ 876 and GJ 1148. A&A, 678, A207.

Nair, S. et al (2023) The X-ray point source population hosted by globular clusters in the elliptical galaxy NGC 4261. MNRAS, 524, 3662.

Navarro-Almaida, D. et al (2023) Linking the dust and chemical evolution: Taurus and Perseus. New collisional rates for HCN, HNC, and their C, N, and H isotopologues. A&A, 670, A110.

Noirot, G. et al (2023) The first large catalogue of spectroscopic redshifts in Webb's first deep field, SMACS J0723.3-7327. MNRAS, 525, 1867.

O'Neil, S. et al (2023) Endothermic self-interacting dark matter in Milky Way-like dark matter haloes. MNRAS, 524, 288.

Omori, Y. et al [DES Collaboration, SPT Collaboration] (2023) Joint analysis of Dark Energy Survey Year 3 data and CMB lensing from SPT and Planck. I. Construction of CMB lensing maps and modeling choices. PhRvD, 107, 023529.

Orlowski-Scherer, J. et al (2023) GBT/MUSTANG-2 9 resolution imaging of the SZ effect in MS0735.6+7421. Confirmation of the SZ cavities through direct imaging (Corrigendum)". A&A, 676, C2.

Ould-Elhkim, M. et al (2023) Wapiti: A data-driven approach to correct for systematics in RV data. Application to SPIRou data of the planet-hosting M dwarf GJ 251. A&A, 675, A187.

Pagano, M. et al (2023) Characterization of inpaint residuals in interferometric measurements of the epoch of reionization. MNRAS, 520, 5552.

Pan, Z. et al (2023) Measurement of gravitational lensing of the cosmic microwave background using SPT-3G 2018 data. PhRvD, 108, 122005.

Pcawg Transcriptome Core Group et al (2023) Author Correction: Genomic basis for RNA alterations in cancer. Natur, 614, E37.

Pollard, O. G. et al (2023) Quantifying the uncertainty in the Eurasian ice-sheet geometry at the Penultimate Glacial Maximum (Marine Isotope Stage 6). TCry, 17, 4751.

Pozuelos, F. J. et al (2023) A super-Earth and a mini-Neptune near the 2:1 MMR straddling the radius valley around the nearby mid-M dwarf TOI-2096. A&A, 672, A70.

Prather, B. S. et al [Event Horizon Telescope Collaboration] (2023) Comparison of Polarized Radiative Transfer Codes Used by the EHT Collaboration. ApJ, 950, 35.

Radica, M. et al (2023) Awesome SOSS: transmission spectroscopy of WASP-96b with NIRISS/SOSS. MNRAS, 524, 835.

Rauscher, E., Cowan, N. B., Luger, R. (2023) Warm Jupiters Beyond the Tidal Synchronization Limit may Exhibit a Wide Range of Secondary Eclipse Depths. AJ, 165, 261.

Rheinbay, E. et al (2023) Author Correction: Analyses of non-coding somatic drivers in 2,658 cancer whole genomes. Natur, 614, E40.

Rico, K. I. et al (2023) Resolving the fate of trace metals during microbial remineralization of phytoplankton biomass in precursor banded iron formation sediments. E&PSL, 607, 118068.

Rieke, M. J. et al (2023) Performance of NIRCam on JWST in Flight. PASP, 135, 028001.

Roelofs, F. et al (2023) Polarimetric Geometric Modeling for mm-VLBI Observations of Black Holes. ApJL, 957, L21.

Roffman, J. et al (2023) Spatial and temporal variability of 21st century sea level changes. GeoJI, 235, 342.

Romero, C. E. et al (2023) Inferences from Surface Brightness Fluctuations of Zwicky 3146 via the Sunyaev-Zel'dovich Effect and X-Ray Observations. ApJ, 951, 41.

Sánchez, J. et al [DES Collaboration, SPT Collaboration] (2023) Mapping gas around massive galaxies: cross-correlation of DES Y3 galaxies and Compton-y maps from SPT and Planck. MNRAS, 522, 3163.

Sand, K. R. et al (2023) A CHIME/FRB Study of Burst Rate and Morphological Evolution of the Periodically Repeating FRB 20180916B. ApJ, 956, 23.

Schiappucci, E. et al [DES Collaboration, SPT-3G Collaboration] (2023) Measurement of the mean central optical depth of galaxy clusters via the pairwise kinematic Sunyaev-Zel'dovich effect with SPT-3G and DES. PhRvD, 107, 042004.

Shin, K. et al (2023) Inferring the Energy and Distance Distributions of Fast Radio Bursts Using the First CHIME/FRB Catalog. ApJ, 944, 105.

Sivaramakrishnan, A. et al (2023) The Near Infrared Imager and Slitless Spectrograph for the James Webb Space Telescope. IV. Aperture Masking Interferometry. PASP, 135, 015003.

Sousa, A. P. et al (2023) New insights on the near-infrared veiling of young stars using CFHT/SPIRou data. A&A, 670, A142.

Spilker, J. S. et al (2023) Spatial variations in aromatic hydrocarbon emission in a dust-rich galaxy. Natur, 618, 708.

Swiggum, J. K. et al (2023) The Green Bank North Celestial Cap Survey. VII. 12 New Pulsar Timing Solutions. ApJ, 944, 154.

Taylor, J. et al (2023) Awesome SOSS: atmospheric characterization of WASP-96 b using the JWST early release observations. MNRAS, 524, 817.

Thorngren, D. P., Lee, E. J., Lopez, E. D. (2023) Removal of Hot Saturns in Mass-Radius Plane by Runaway Mass Loss. ApJL, 945, L36.

Thygesen, E. et al (2023) Globular cluster ultraluminous X-ray sources in the furthest early-type galaxies. MNRAS, 518, 3386.

Torne, P. et al (2023) A Search for Pulsars around Sgr A* in the First Event Horizon Telescope Data Set. ApJ, 959, 14.

Touchette, D. et al (2023) Microbial Characterization of Arctic Glacial Ice Cores with a Semiautomated Life Detection System. AsBio, 23, 756.

Vaughan, S. R. et al (2023) Chasing rainbows and ocean glints: Inner working angle constraints for the Habitable Worlds Observatory. MNRAS, 524, 5477.

Vieira, N. et al (2023) Spectroscopic r-Process Abundance Retrieval for Kilonovae. I. The Inferred Abundance Pattern of Early Emission from GW170817. ApJ, 944, 123.

Wang, X. et al (2023) Convectively Transported Water Vapor Plumes in the Midlatitude Lower Stratosphere. JGRD, 128, e2022JD037699.

Wilensky, M. J. et al (2023) Bayesian jackknife tests with a small number of subsets: application to HERA 21 cm power spectrum upper limits. MNRAS, 518, 6041.

Xia, Y. et al (2023) Stratospheric Ozone Loss Enhances Summer Precipitation Over the Southern Slope of the Tibetan Plateau. GeoRL, 50, e2023GL103742.

Yu, Q. & Huang, Y. (2023) A Dissection of the Inter-Model Spread of the Aerosol Direct Radiative Effect in CMIP6 Models. GeoRL, 50, e2023GL105112.

Yu, Q. & Huang, Y. (2023) Distributions and Trends of the Aerosol Direct Radiative Effect in the 21st Century: Aerosol and Environmental Contributions. JGRD, 128, e2022JD037716.

Zannoni, M. et al (2023) A SQUID controller unit for space-based TES sensor readout. NIMPA, 1046, 167806.

Zhang, S. Y. et al (2023) Testing the Interaction between a Substellar Companion and a Debris Disk in the HR 2562 System. AJ, 165, 219.

McGill