DUNLAP INSTITUTE
for **ASTRONOMY** *&* **ASTROPHYSICS**

Dunlap Institute for
Astronomy & Astrophysics
UNIVERSITY OF TORONTO

ACCELERATING UNIVERSE
2015 - 2016 ANNUAL REPORT

Prof. Bryan Gaensler

Director's Message

The past year has been one of accelerating growth for the Dunlap Institute.

Most notable has been the addition of two new faculty members, taking our faculty complement to five. It is with great excitement that we have welcomed Professor Suresh Sivanandam, a talented experimentalist and former Dunlap Fellow; and Professor Renée Hložek, an innovative cosmologist and Rhodes Scholar. With Suresh and Renée now on board, the Dunlap has a broad capacity for excellence in our research and training programs.

There are now over 50 members of the institute, including 30 students and postdoctoral researchers. One of our fundamental goals is to provide the stimulating research environment needed for these students and postdocs to flourish, and it is thus very satisfying that many of Dunlap's highest profile discoveries from the last year have been led by our young researchers.

Dunlap scientists have spent many years developing the Gemini Planet Imager (GPI), an investment that is now beginning to reap rich returns in the rapidly moving field of extrasolar planets. In August 2015, Dunlap Fellows Jeff Chilcote and Jérôme Maire, and Dunlap PhD student Max Millar-Blanchaer, were part of the team that announced the discovery of a young analogue of Jupiter orbiting the star 51 Eridani (pg. 10). A month later, Max led a GPI study that has given us our best view yet of an extrasolar planet orbiting its parent star. We can expect more spectacular results from GPI in the years ahead.

I have become personally intrigued by the new phenomenon of Fast Radio Bursts (FRBs), an enigmatic population of bright, brief flashes of radio waves about which very little else is known. The Dunlap has been very active in this new field: Dunlap student Liam Connor has made a strong case that FRBs are embedded in dense gaseous environments; while Dunlap Associate, Prof. Ue-Li Pen, was part

Cover

Left: South Pole Telescope

Right: Dunlap Fellow Tyler Natoli and graduate student Matt Young remove a South Pole Telescope-3G detector assembly (pg. 5) from the cryostat in the Dunlap Institute's Long Wavelength Laboratory.

Credit: Prof. Keith Vanderlinde; U.S. National Science Foundation

Prof. Bryan Gaensler welcoming students to the 2015 Dunlap Summer School.

“One of our fundamental goals is to provide the stimulating research environment needed for these students and postdocs to flourish”

of the team that made the first-ever measurement of magnetised gas around FRBs (pg. 12). Many more detections of FRBs are needed, which will soon be provided by the CHIME telescope (pg. 4) with which Dunlap researchers are heavily involved.

Meanwhile, in a spectacular feat of computation, Dunlap researcher Dustin Lang has reprocessed data from NASA's WISE satellite to derive a new infrared catalogue of 400 million stars and galaxies. These precision measurements greatly improve previous state-of-the-art photometry, and allow astronomers to now extract infrared properties of almost any optical object in the sky. Creative ways to extract new science from existing public data is becoming an increasingly important part of all of modern astronomy and is a growing focus for the institute.

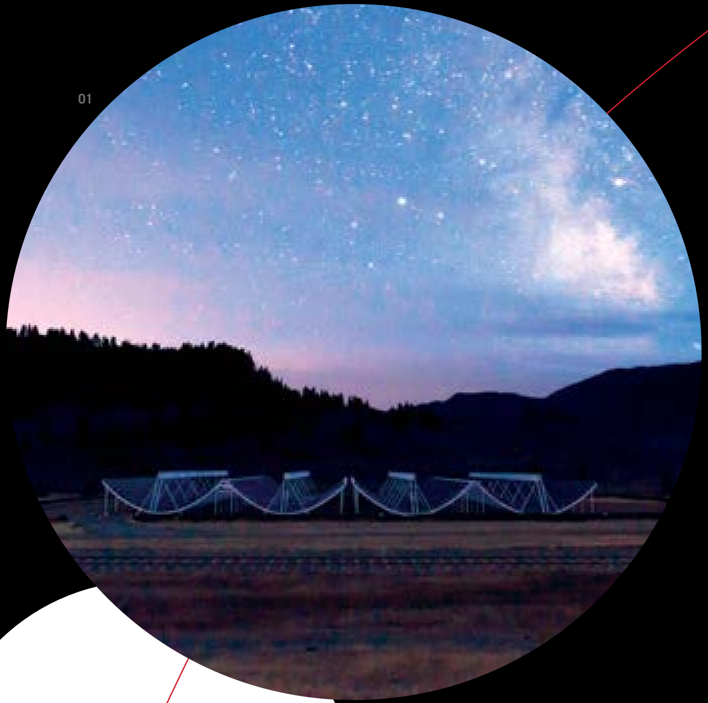
We continue to find new and more ambitious ways to excite the public about science and, in September 2015, we were able to attract thousands of people to the University of Toronto campus to watch a total lunar eclipse (pg. 20).

I'm very excited by our new partnership with Discover the Universe/À la découverte de l'univers (pg. 22), wherein we aim to train high-school teachers across Canada how to teach astronomy—in both English and French. Through a great multiplicative effect, they in turn will reach students.

We are also growing our set of programs on training and development. We held another successful West Africa International Summer School for Young Astronomers in 2015, and in 2016 are excited to launch our new Mauna Kea Graduate School, in which students will travel to Hawaii and take data on Gemini North's world-class, 8-metre facility.

It has personally been very rewarding to work alongside such a motivated and talented team. The Dunlap Institute is active on many fronts, and yet all our events, programs and public activities are delivered with the highest level of professionalism. All our members and staff can take great pride in the quality of our research, the breadth and depth of our international standing, and the ongoing relevance of our public message.

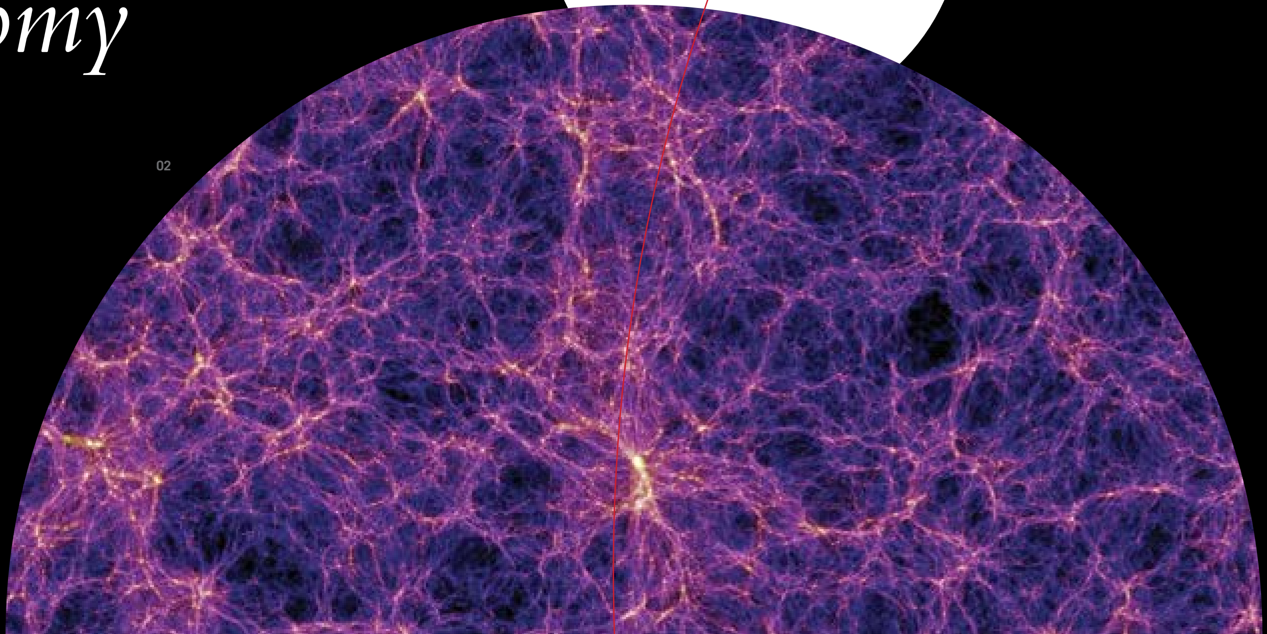
01



Technology

Accelerating the Technology of Astronomy

02



01. The Canadian Hydrogen Intensity Mapping Experiment (CHIME) at the Dominion Radio Astrophysical Observatory, NRC, in B.C.

Credit: Dr. Peter Klages; Dunlap Institute

02. A computer simulation shows a "cosmic web" of dark matter at a time in the history of the cosmos when dark energy is accelerating the expansion of the Universe.

Credit: Springel, et al

Technology

The Technology of Astronomical Discovery

Prof.
Keith Vanderlinde

Technological developments have always been the hidden hand driving advances in astrophysics, from early lenses to modern CCDs.

Nanotechnology has made huge strides in recent years, and meta-materials—substances and surfaces made of carefully engineered and patterned microscopic structures—have started finding their way into mainstream instruments, with sub-wavelength structures that manipulate light across the electromagnetic spectrum.

Optical telescopes like the Dragonfly Array use these meta-materials to produce high-performance anti-reflection coatings, while microwave telescopes like the polarization-sensitive Atacama Cosmology Telescope (ACTpol) and the third-generation South Pole Telescope (SPT-3G; pg. 5) are exploring the use of similar patterned or etched coatings. Between those wavelengths, high-fidelity filters designed to remove atmospheric emission lines from infrared light are being patterned directly into optical fibres.

The atmosphere has long been the bête noire of astronomers, and resources have been poured into overcoming its effects through adaptive optics or even space telescopes. The Balloon-borne Imaging Testbed (BIT) and its follow-up SuperBIT (pg. 6) are exploring a new model for escaping the atmosphere: floating on top of it. Between precision pointing capabilities and ultra-long-duration super-pressure balloon flights, this platform is opening a new window for atmosphere-free observations.

Radio astronomy largely escapes these concerns and, thanks to developments in the telecommunication sector and the exponential growth in computational capabilities, has experienced a remarkable renaissance over the last decade. The Canadian Hydrogen Intensity Mapping Experiment (CHIME; pg. 4) and the Murchison Widefield Array (MWA) exemplify this new paradigm—wide-field telescopes driven by sophisticated backend processing and offline analyses—and both are being rapidly extended to capitalize on this moment in astrophysical history.

MWA is beginning a major upgrade to bring higher-resolution imaging to the instrument, while CHIME will soon deploy two large extensions to its digital backend, providing access to the time-variable radio sky in a way never before possible. By late 2016, it will begin daily monitoring of hundreds of radio pulsars, followed shortly afterwards by an unprecedented survey for Fast Radio Bursts.

The accelerating pace of technological advancements mirrors the accelerating expansion of the Universe, and the Dunlap Institute is playing a leading role in leveraging those advancements and turning them into the instruments that will make the groundbreaking astronomical discoveries of tomorrow.

Close-up of Dragonfly Array lenses

Credit: P. Van Dokkum, R. Abraham, J. Brodie

Technology

Supercomputing the Universe

01. CHIME "half-pipe" dishes near Penticton B.C. were completed in 2015.

Credit: Nolan Denman; Dunlap Institute

02. Graduate student Nolan Denman working on a CHIME correlator node. Together, 256 nodes combine to form the correlator which processes CHIME's data.

A team of astronomers and cosmologists is building an innovative, all-Canadian radio telescope to map the largest volume of space ever surveyed—an expanse billions of light-years deep that encompasses half the sky.

The Canadian Hydrogen Intensity Mapping Experiment (CHIME) will map the distribution of hydrogen gas in the early Universe, an epoch when dark energy first began to play an important role in the evolution of the cosmos.

With the three-dimensional map, astronomers will study Baryonic Acoustic Oscillations, or BAOs, "ripples" in the density of galaxies. Because all BAOs measure approximately 500 million light-years across, they can be used as "standard rulers" to measure cosmic distances and, in turn, measure the accelerating expansion of the Universe. These observations will shed light on the enigmatic engine driving that acceleration: dark energy.

And because CHIME surveys the entire northern sky for 24 hours of every day, it will also be used to study Fast Radio Bursts (pg. 12) and other short-lived cosmic phenomena which are missed by radio telescopes that observe relatively small sections of the sky or make short observations.

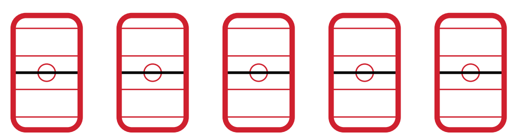
CHIME, which will map the sky from its location near Penticton, B.C., is a collaboration between the University of Toronto, UBC, McGill University and the Dominion Radio Astrophysical Observatory. At the Dunlap, a team of graduate students and postdoctoral fellows is led by Prof. Keith Vanderlinde and is currently focused on building the "super-computer" that will process the enormous amounts of data the experiment will generate.

CHIME's four, curved half-pipe-shaped dishes reflect radio waves to 1024 receivers or feeds, evenly spaced along horizontal beams running the length of each half-pipe. The signals from each feed are then processed and combined in the same way signals from two radio telescopes thousands of kilometres apart can be combined—a technique called interferometry.

When fully operational, CHIME will yield close to a terabyte of data every second (equal to approximately 3% of global Internet traffic) and this torrent of data will require a prodigious amount of computer processing power. The experiment gets this power from 1024 high-performance graphics-processing units (GPUs), similar to those being built into the next generation of video game consoles.

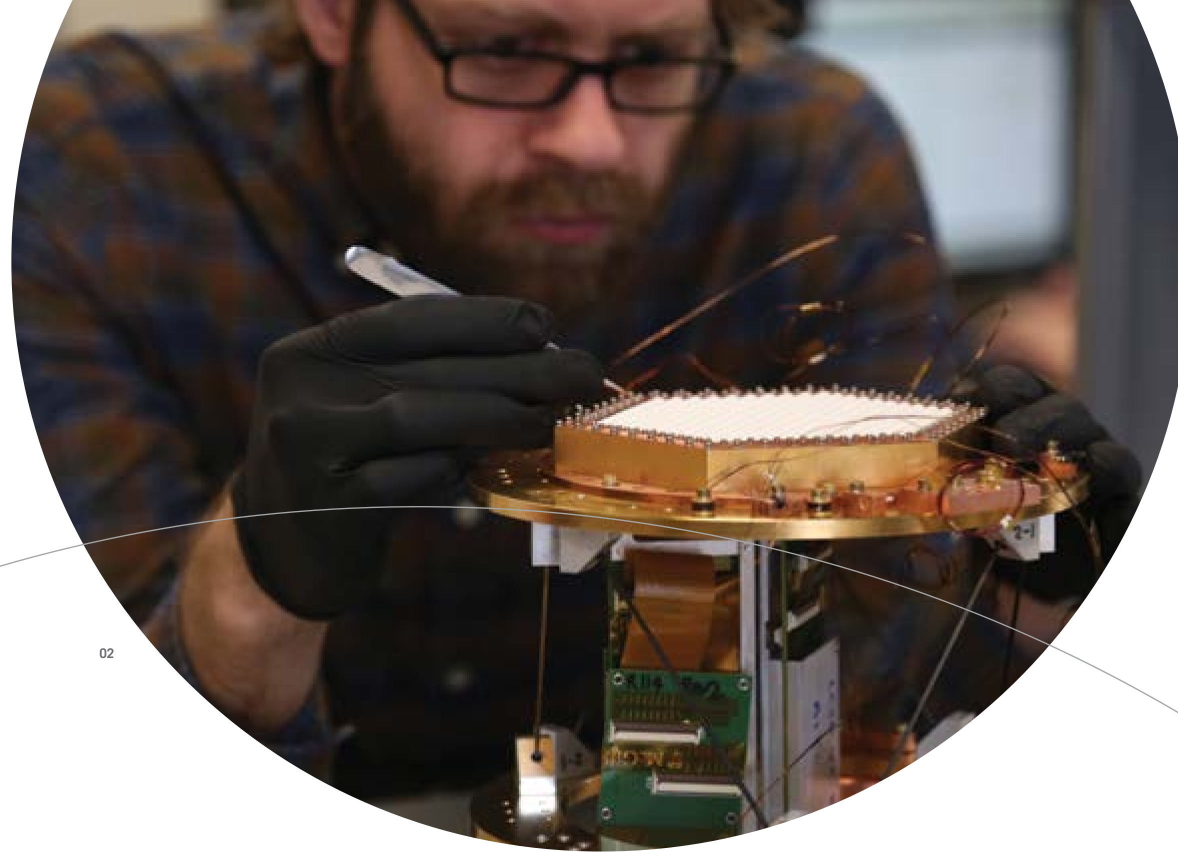
CHIME will begin mapping the Universe in 2016.

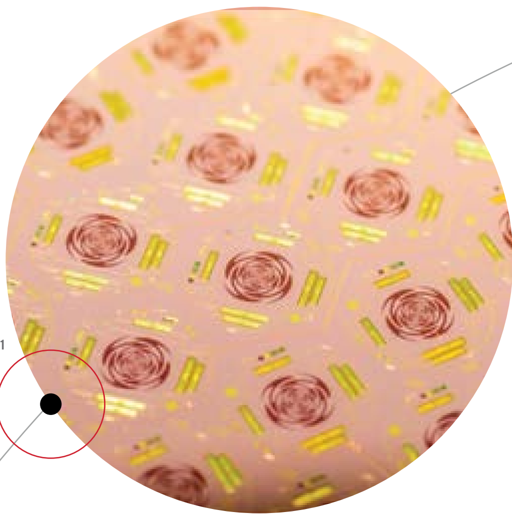
COLLECTING AREA OF CHIME = 5 NHL HOCKEY RINKS



Technology

Antarctic Cosmology





One of the harshest, most unforgiving environments on the planet is also one of the best locations from which to study the early Universe.

In Antarctica, the Sun is below the horizon for half the year; winter temperatures routinely plunge to minus 70°C; and the continent is cut off from the rest of the world for eight months.

But the severe conditions are also why it is such a mecca for astronomers. The extremely cold atmosphere holds very little water vapour, a gas that blocks radio waves from space. Plus, the South Pole is located on a 2800-metre-high plateau, so the atmosphere is alpine thin.

Since 2007, astronomers have been observing the Cosmic Microwave Background (CMB)—light from the Universe when it was only 380,000 years old—with the South Pole Telescope (SPT) at the U.S. National Science Foundation's Amundsen-Scott South Pole Station.

They use those observations to study large-scale structure in the cosmos. They are also sifting through the CMB for a signal from when the Universe was less than a second old. The signal—referred to as primordial or gravitational-wave B-modes—would be evidence that the Universe experienced a period of accelerated expansion known as inflation.

Prof. Keith Vanderlinde and Dunlap Fellow Tyler Natoli have both investigated the early Universe from the South Pole, working on and making observations with the SPT.

At the Dunlap Institute, they—along with graduate student Matthew Young (pg. 17)—are working on SPT-3G, the third-generation camera for the Antarctic telescope. Improvements to the instrument's detectors will increase its sensitivity by an order of magnitude and enable ultra-sensitive studies of the polarization of the microwave sky.

In late 2017, Natoli will return to the South Pole to help install the new camera on the SPT. It will mark the next chapter in observing the beginning of time from the bottom of the world.

01. Close-up of the SPT-3G detector array containing 1600 detectors and 530 antennas.

Credit: Reidar Hahn

02. Tyler Natoli preparing the SPT-3G detector assembly for testing. The final 3G camera will include ten assemblies.

Stratospheric Astronomy

Technology

01. SuperBIT prior to a test flight in September 2015. The frame carries the telescope — the octagonal-shaped tube — along with tracking cameras, gyroscopes, a reaction-wheel and electronics.

Credit: Steven Li; Balloon Astrophysics Group, University of Toronto

02. The Earth as seen from SuperBIT from an altitude of nearly 40 kilometres.

Credit: Balloon Astrophysics Group, University of Toronto

For decades, astronomers have launched telescopes into Earth orbit, high above the atmosphere that obscures the objects they are trying to observe. But for a fraction of the cost, telescopes can be carried above most of the atmosphere aboard high-altitude balloons for a view of the cosmos that rivals the view from orbit.

SuperBIT, the Super-pressure Balloon-borne Imaging Telescope, is an optical and near-ultra-violet telescope with a half-metre diameter mirror, designed to be lifted by balloon toan altitude of 39 kilometres.

From that height, the stratospheric observatory will target hundreds of clusters of galaxies. The gravity of a cluster of galaxies acts like a lens, distorting the appearance of galaxies that lie beyond the cluster. By analyzing the distortions, astronomers can map the distribution of dark matter in the clusters, thereby rendering the invisible visible.

It is a remarkable technical challenge to accurately point a telescope, hanging from a balloon, at a cluster of galaxies millions of light-years away for up to 30 minutes; it is comparable to steadily training a telescope on a dime — 100 kilometres away.

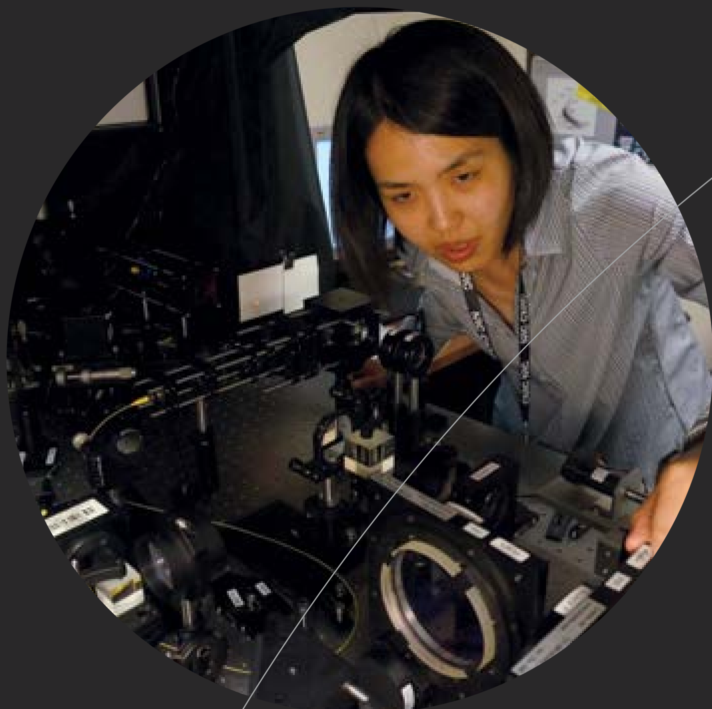
SuperBIT achieves this extraordinary stability through a combination of technologies. The telescope and the two "cradles" holding it are controlled by motors that work independently along three different axes. Three tracking cameras lock onto stars, telling the telescope the direction it's pointed. Gyroscopes fine-tune SuperBIT's motion. Finally, a motor controls a small mirror in the telescope's optical path that further steadies the view.

SuperBIT is the latest stratospheric observatory to be designed, fabricated, tested and launched by an international collaboration that includes the Balloon Astrophysics Group at the University of Toronto. The group is run by Dunlap Associate Prof. Barth Netterfield of the Department of Astronomy & Astrophysics, U of T, and includes graduate students and technicians from U of T and other institutions. (Collaborations pg. 24).

In September 2015, the telescope was launched from the Timmins Stratospheric Balloon Base in northern Ontario for a successful 8-hour test flight. Its last test will be a 24-hour flight from Texas in 2016. And if all goes according to plan, SuperBIT will lift off from New Zealand in 2017, for a three-month mission to the edge of space.

Dr. Etsuko Mieda

Etsuko Mieda was the Dunlap Institute's first graduated PhD. She is currently working as a Dunlap postdoctoral researcher at NRC-Herzberg Astronomy & Astrophysics in Victoria, B.C.



Mieda aligning optical components on the Herzberg NFIRAOS Optical Simulator (HeNOS) bench at NRC-Herzberg that simulates NFIRAOS, the first-light, adaptive-optics system for the Thirty Meter Telescope.

Credit: Dr. Matthias Rosensteiner; NRC-Herzberg

HOW DID YOU FIRST BECOME INTERESTED IN ASTRONOMY?

Back when I was in high school in Sakai City in Japan, I started watching a TV show about the Universe on NHK. And the most shocking fact in the show was that all the heavy elements in me, my desk, a car, in a forest, were all produced in stars! This made me think that regardless of what I do for a living, everything I will be dealing with is ultimately a star product. So, I thought I should study the "original" and I decided to study astronomy.

WHAT ARE YOUR KEY SCIENTIFIC INTERESTS?

I am interested in building astronomical instruments, particularly adaptive-optics (AO) systems. AO systems are crucial for almost all ground-based observations where the Earth's atmosphere degrades what we see. As telescopes get bigger and bigger, like the Thirty Meter Telescope, the development of AO systems becomes more important and more complicated, and I would love to develop AO systems that help achieve a large telescope's full potential.

WHAT ARE YOU WORKING ON RIGHT NOW?

I am working on an instrument called the Truth Wave-Front Sensor (TWFS) which uses a new technique to improve on the AO technique being used on telescopes today. To correct distortions produced by turbulence in the atmosphere, we create an artificial "star" in the sky by shooting a laser that excites the sodium atoms in the atmosphere's sodium layer about 90 kilometres up. AO systems use this artificial star to measure the distortions in the atmosphere and correct for them in the image of our real target. The problem is that the sodium layer changes and this produces "wrong" measurements in the wave-front sensor. The new TWFS will monitor the sodium layer and correct for these changes.

WHAT'S THE MOST REWARDING ASPECT OF YOUR WORK?

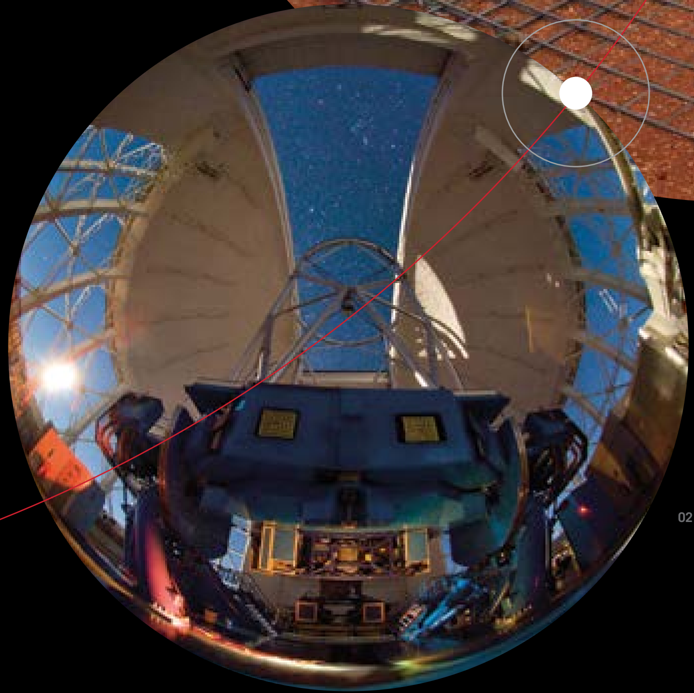
A great thing about working on instrumentation in a lab is that I can do the whole process: design the optics, order components, align components, analyze the data. Nowadays, many astronomers don't even go to telescopes to observe. They submit a proposal, someone else programs the telescope to take data automatically, they download data from a server, they do the analysis. When I go through every step of the way, I feel tremendous achievement.

DUNLAP INSTITUTE
for ASTRONOMY &
ASTROPHYSICS

01

Observational Research

Accelerating Our Understanding of the Universe



02

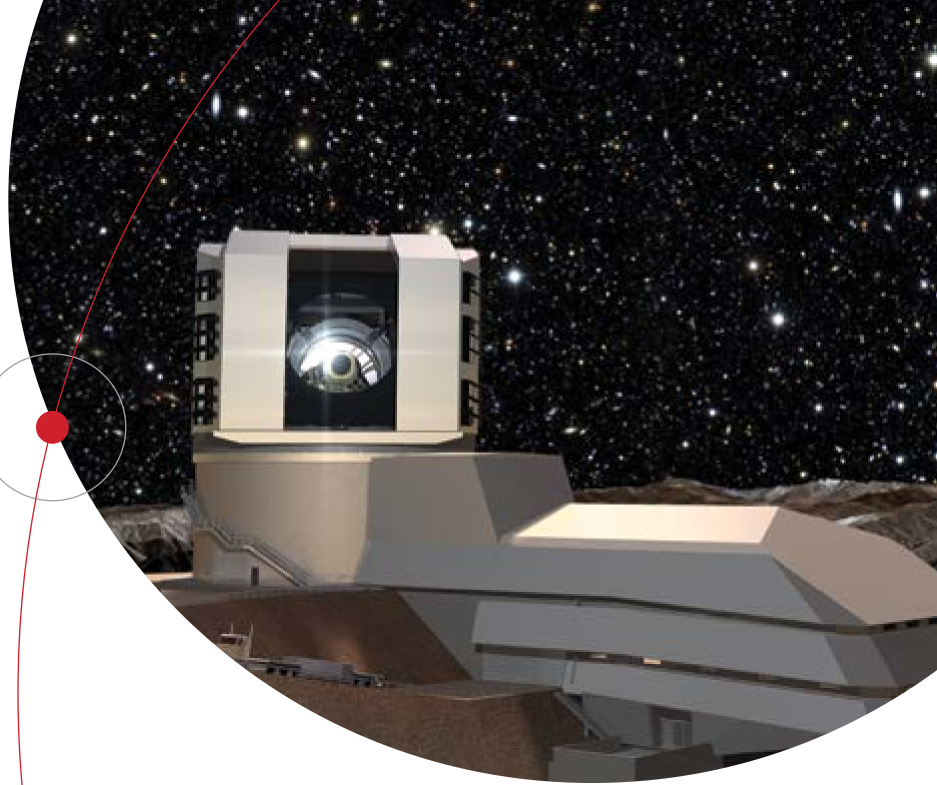
01. The Murchison Widefield Array in Western Australia on the future site of the Square Kilometre Array (back cover).

Credit: Paul Bourke, Jonathan Knispel; WASP (UWA), iVEC, ICRAR, CSIRO

02. Gemini South telescope on Cerro Pachón in Chile.

Credit: Gemini Observatory; AURA

Observational Research



An artist's rendering of the Large Synoptic Survey Telescope being constructed on Cerro Pachón in northern Chile.

Credit: Large Synoptic Survey Telescope (LSST)

Observing the Universe at Different Wavelengths

Prof. Renée Hložek

At the Dunlap Institute, we observe the cosmos across a wide range of wavelengths—from optical to radio—to investigate the full spectrum of questions about the Universe.

At shorter, optical wavelengths, we look for faint galaxies and test theories of structure formation. When looking for faint objects, sometimes the trick is to multiply your efforts rather than build one large telescope; this is the approach taken with Dragonfly—a telescope array comprising multiple telephoto lenses with innovative lens-coatings that greatly reduce internally scattered light.

This year, we joined the Large Synoptic Survey Telescope (LSST) collaboration. The LSST will scan the sky at optical wavelengths once every three days, building up a detailed picture of the distant Universe that will enable our search for transient objects which appear to us for only brief periods of time.

But we can also probe structure formation using infrared light. One of the research drivers at the Dunlap is to tackle problems in galaxy formation and evolution. Galaxies don't exist in isolation and our research aims to understand how the gas in the halo of a cluster interacts with the gas of its member galaxies, through novel instrumentation efforts like the Wide-Field Infrared Spectrograph (WIFIS).

Long-wavelength microwaves also give us insight into the young and distant Universe. We study the nascent light of the cosmos from the ground and from balloons at sites in the Atacama Desert in northern Chile and in the Antarctic—a truly global effort.

Radio-wavelength observations allow us to ask questions about the large-scale structure of the Universe using neutral hydrogen gas. Through our pioneering work on radio telescopes like CHIME (pg. 4), we endeavor to image neutral hydrogen to unprecedented distances—opening up a new window on the cosmos.

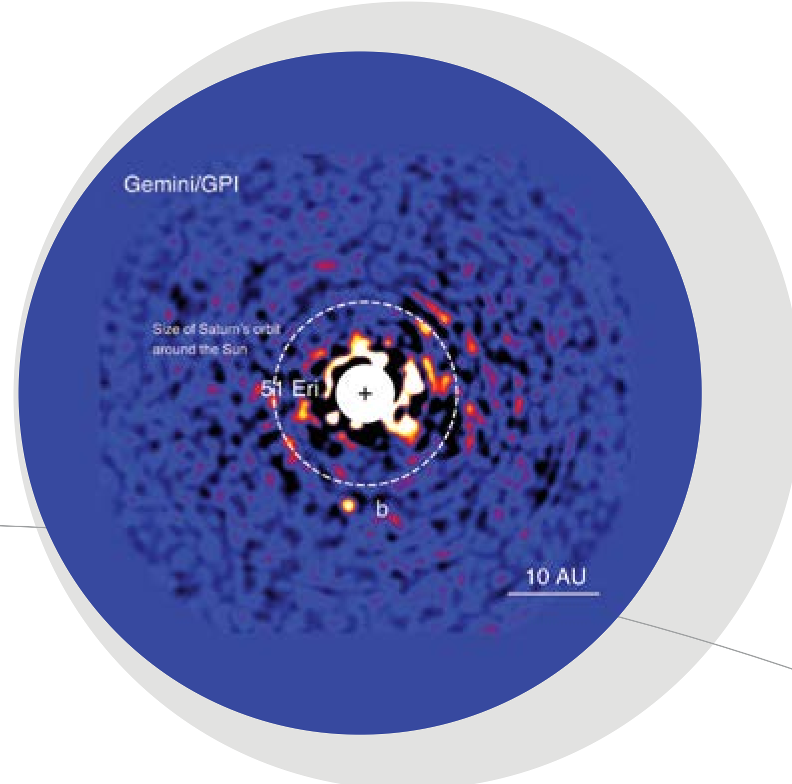
We can use the polarization of radio waves to probe the magnetic properties of galaxies, clusters of galaxies, and the gas between galaxies themselves.

Just like the optical sky, the radio sky is also changing, and characterizing the transient radio sky is yet another of our research challenges.

It is only by making observations of the sky across a wide range of wavelengths that we can understand the cosmos in all her facets.

Observational Research

First Discovery for a New Planet Hunter



The star 51 Eridani is hidden in the centre of the image; 51 Eri b is shown as “b”.

Credit: J. Rameau (UdeM) and C. Marois (NRC Herzberg)

In August 2015, an international team of astronomers announced the discovery of a new exoplanet, a planet outside our Solar System, called 51 Eri b. It was the first exoplanet to be discovered with the Gemini Planet Imager, or GPI: an adaptive-optics, imaging spectrograph on the Gemini South Telescope in northern Chile.

In the past two decades, thanks largely to the Kepler space telescope, exoplanets have been discovered at an unprecedented pace. But Kepler finds planets indirectly; GPI, which saw first light in November 2013, is one of only a few instruments that enables astronomers to actually see these distant worlds; as such, they can study their nature by spectroscopically analyzing their light.

The newly discovered 51 Eri b is exactly the type of planet GPI was designed to find. It orbits a relatively young, 20-million-year-old star named 51 Eridani, at a distance slightly farther than Saturn circles the Sun.

Of all the exoplanets discovered through direct-imaging, 51 Eri b is the faintest and, at twice the mass of Jupiter, also the lowest mass. What's more, 51 Eri b is the coolest of the exoplanets discovered through direct imaging; its atmosphere is about 430°C—much cooler than most other exoplanets.

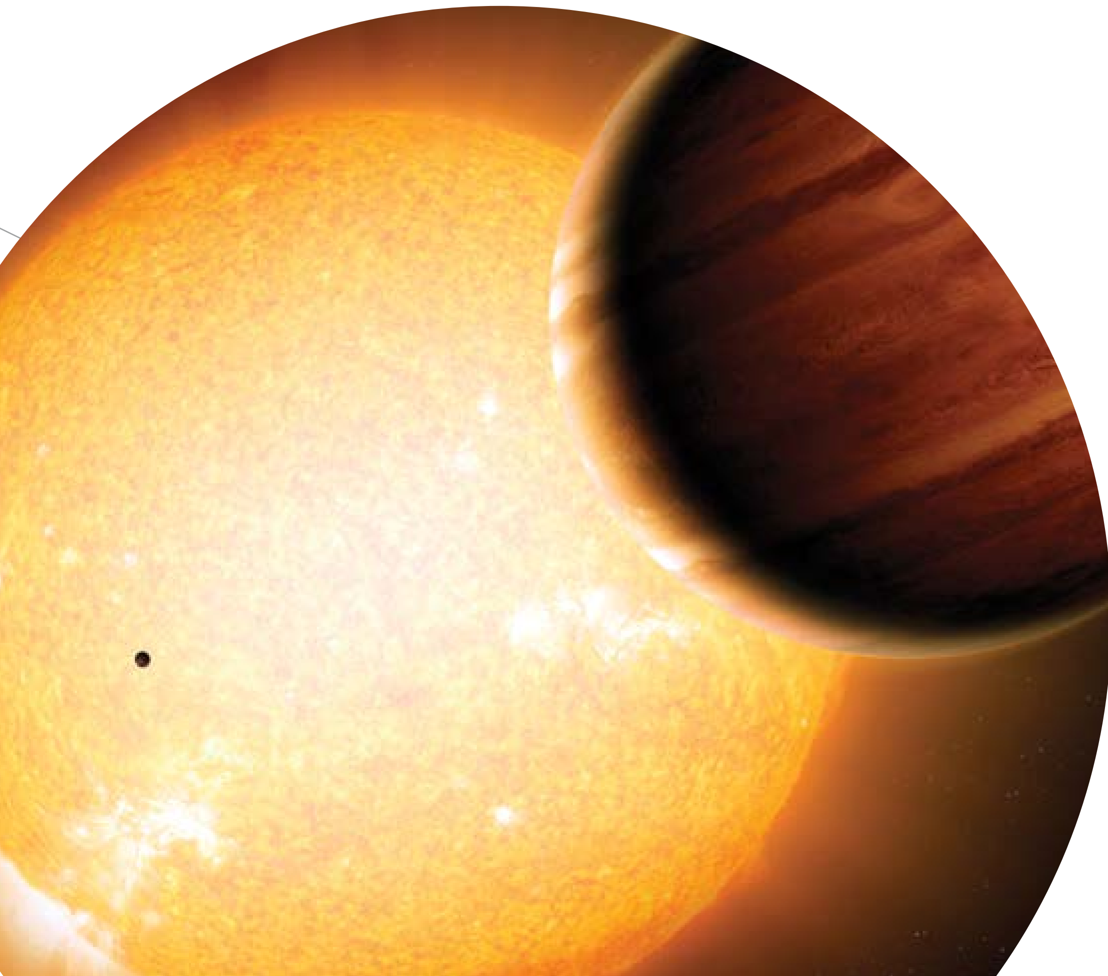
Combined with the age of the system, this is a clue that the distant planetary system may have formed through a process called core-accretion that can also lead to smaller, rocky planets like Earth. It's a significant clue as we try to understand how planetary systems form and how many may look like our own.

The paper announcing the discovery was published in the journal Science, and its co-authors included Dunlap Fellows Jeffrey Chilcote and Jérôme Maire, as well as U of T PhD-candidate Max Millar-Blanchaer—all of whom played a role in developing GPI.

51 Eri b promises to be just the first of GPI's finds as the GPI Exoplanet Survey targets 600 stars over the next 3 years in its quest to see new worlds.

Observational Research

Warm Jupiters Are Not Alone



During the past two decades, the flood of detections of planets beyond the Solar System, so-called exoplanets, has revealed planetary systems very unlike our own. In particular, hundreds of systems harbour Jupiter-like worlds orbiting their parent stars much closer than Jupiter and Saturn orbit the Sun.

Some have orbits a fraction of the diameter of Mercury's; they are heated to extremely high temperatures because of their proximity to their parent star and are known as Hot Jupiters. A rarer type have orbits comparable to Venus and Earth's and are known as Warm Jupiters. Both intrigue astronomers who strive to understand whether they formed in situ—where we see them—or formed much further out and migrated inward to their current positions.

Following four years of analysis of Kepler space telescope observations, Dunlap/Centre-for-Planetary-Sciences Fellow Chelsea Huang and her U of T colleagues found that almost half of the 27 Warm Jupiters they studied have companion "super-Earth" planets in relatively nearby orbits.

It's thought that these giants could not have formed so close to their parent stars because they couldn't have accumulated large, gas-giant-like atmospheres; therefore, they must have formed in the outer regions of their systems and migrated inward through a series of ever-shrinking orbits. However, in this scenario, they would have cleared any nearby planets from their path as they spiralled inward.

Therefore, the presence of these companions "super-Earths" is strong evidence that the Warm Jupiters formed in situ. In fact, there is more analysis to come and it's possible the number of Warm Jupiters with companions is even higher.

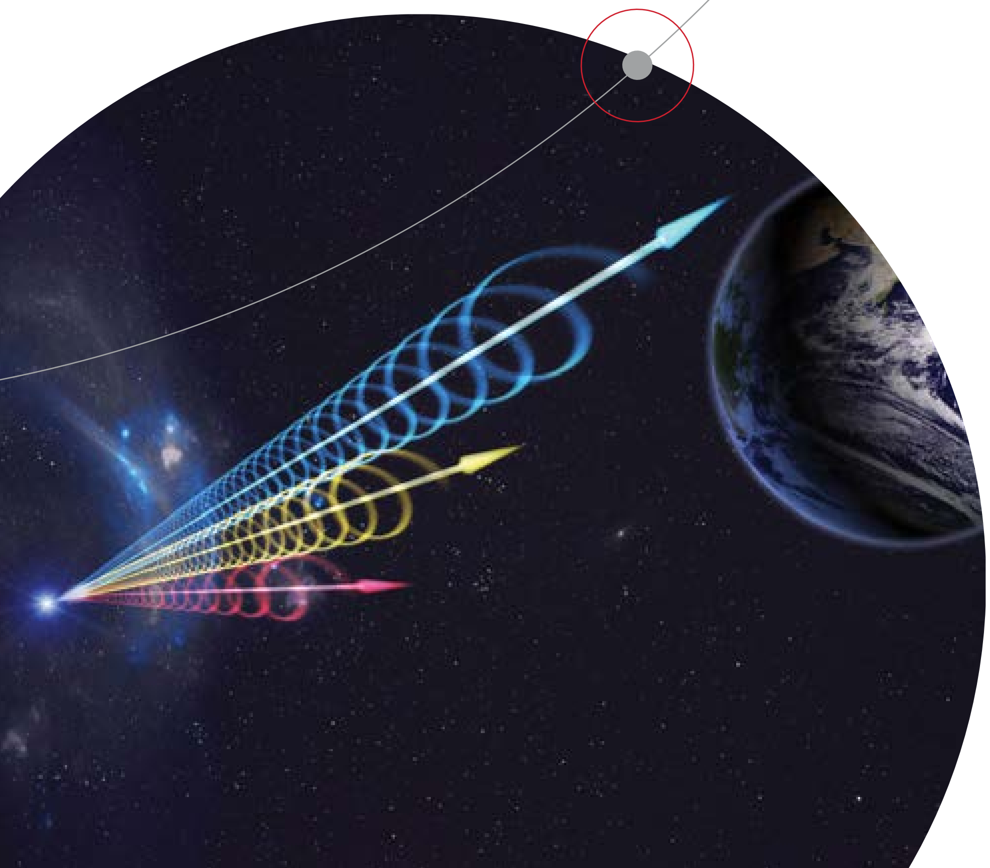
In addition to the insight into Warm Jupiters, the study also provided the most conclusive evidence yet that Hot Jupiters, distinct from their cooler cousins, lack close companions and therefore, likely migrated to their current, fiery orbits.

Artist's rendering of a Warm Jupiter and a companion planet in orbit around a star.

Credit: Detlev Van Ravenswaay; Science Photo Library

Observational Research

Another Piece in the Fast Radio Burst Puzzle



In December 2015, an international team of astronomers announced the discovery of a flash of radio energy from space known as a Fast Radio Burst or FRB. At the time, 16 FRBs had been discovered, but this one—designated FRB 110523—was unique.

FRBs last only a few thousandths of a second but contain the energy the Sun puts out in a few months. They were first detected by astronomers using the Parkes radio telescope in Australia and astronomers think that thousands might be flashing in our sky every day.

Both their distance and true nature remain mysteries. Astronomers hypothesize that they come from the birth of black holes, mergers of neutron stars, or flares from magnetars—stars with powerful magnetic fields.

The December announcement was made by a team that included Dunlap Associate Prof. Ue-Li Pen, from the Canadian Institute for Theoretical Astrophysics at the U of T

The team's analysis of FRB 110523 provided an important clue into the true nature of the phenomena. It revealed that the orientation of the FRB's radio waves had been "twisted" somewhere along their path to us—a phenomenon known as Faraday rotation—indicating that the signal had passed through a powerful magnetic field on its way to Earth.

The analysis also provided evidence that the signal originated as far as six billion light-years away and that the burst passed through two distinct clouds of gas on its journey to us. This suggests that the enigmatic source may be a supernova, or may have occurred in the interior of a star-forming nebula. It also makes it much less likely that FRBs are at cosmological distances.

Fast Radio Bursts continue to make astronomical headlines and, using instruments like CHIME (pg. 4), astronomers from the Dunlap Institute and U of T will continue to search for pieces to the FRB puzzle.

Artist impression of a Fast Radio Burst (FRB) reaching Earth.

Credit: Jingchuan Yu, Beijing Planetarium

Prof. Renée Hložek

Prof. Renée Hložek is a Dunlap faculty member. She studied at the University of Pretoria and the University of Cape Town. She received her DPhil in Astrophysics from the University of Oxford in 2011, where she was a Rhodes Scholar.

Hložek is a senior TED Fellow and gave a TEDTalk in Long Beach, CA, in 2013.

Credit: Ryan Lash

HOW DID YOU FIRST BECOME INTERESTED IN ASTRONOMY?

I was originally drawn to physics and mathematics more than astronomy. I loved watching the show *MacGuyer* because he solved problems in interesting ways and tried to understand the root causes of things. Plus, when I was young, my mom joked that I could do anything I wanted in life—I could even become an astrophysicist. I think she picked a job that seemed so extreme just to inspire creativity. But it made me think about myself as boundless and capable of anything!

WHAT ARE YOUR KEY SCIENTIFIC INTERESTS?

II'm interested in cosmology. Specifically I want to know what the initial conditions, or starting points, of the Universe are and how they translate into what we see today. I'm particularly interested in how we map our theories of dark matter and dark energy onto our observations. How do we decide between competing models of the Universe? How do we get the most out of our observations?

HOW ARE YOU GOING ABOUT ANSWERING THOSE QUESTIONS?

II work in a number of collab-orations. One of them, the Atacama Cosmology Telescope, in the Atacama Desert, measures microwaves. I have also just joined the Large Synoptic Survey Telescope (LSST) which will measure Type Ia supernovae, which can be used as "standard candles" for measuring distances in the Universe.

WHAT OTHER ISSUES IN SCIENCE/ASTRONOMY ARE YOU PARTICULAR INTERESTED IN?

I'm really passionate about getting more people into science that have been less represented in the past. We are now slowly bringing more women into STEM subjects (we still have a long way to go!) and the conversations are changing, which is fantastic. But we still haven't made enough progress in changing the racial profile of my field. I come from South Africa where we are still only slowly recovering from a racialized education system, and so these are issues that are really close to my heart. I think we need to make more effort to change the faces of our institutions and I can't wait for the day when my colleagues are diverse in terms of race, gender, sexual identity, socio-economic status and physical ability.

01

Training

Accelerating the Next Generation of Scientists

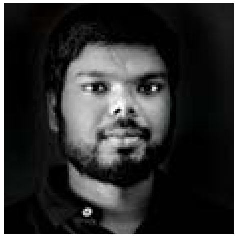
02

01. Some of the 38 students from 14 countries who attended the 2015 Introduction to Astronomical Instrumentation Summer School.

02. A student assembles an interferometer during a summer school lab.

Training

Training the Next Generation of Scientists



Prof. Suresh Sivanandam

Training is one of the chief mandates of the Dunlap Institute. Situated within one of the largest postsecondary educational institutions in Canada, we provide world-class, hands-on educational experiences for undergraduate and graduate students, as well as postdoctoral fellows. It is at the heart of our institution.

The training resources provided by the Dunlap are unique within the Canadian astronomical community and have benefited hundreds of students and dozens of postdoctoral fellows in a short, five-year period.

A key example is the Dunlap's Introduction to Astronomical Instrumentation Summer School, which has garnered world-wide acclaim and routinely draws a significant fraction of its applicants from outside North America. There are very few programs like it in the world.

The Dunlap also continues to invest in the Professional Development Program (PDP) of the Institute for Science and Engineer Educators (ISEE). We continue our commitment to the Summer Undergraduate Research Program (SURP) and, of course, the Dunlap Fellowship Program—from which I have personally benefited greatly.

Looking to the future, we are expanding our training program to include key areas that are traditionally not addressed in the academic environment.

For example, while graduate students and postdocs have outstanding research experiences, they are often not trained in career development; they are often not supported in developing the well-rounded toolset that will make them compelling candidates for long-term careers within astronomy and related fields. In response to this need, we are developing a program that will provide this important additional training.

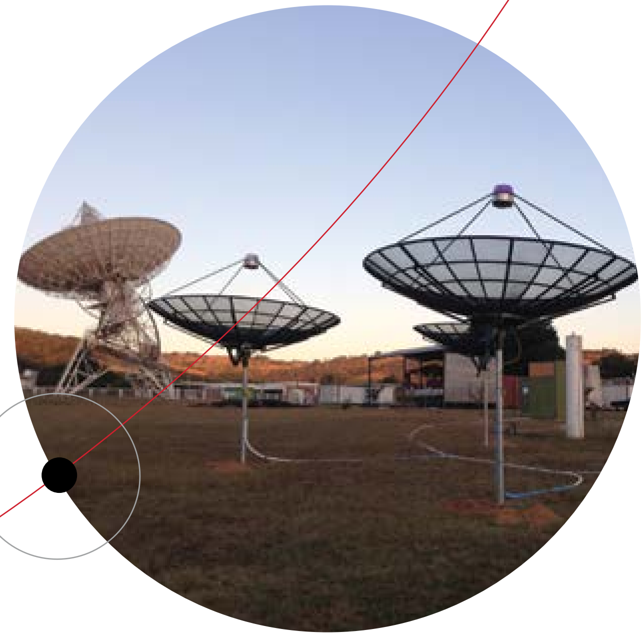
We are also running a pilot program in 2016 that provides a select number of Canadian students with hands-on experience at world-class astronomical facilities. As participants in the Dunlap Mauna Kea School, students will visit some of the largest astronomical observatories in the world at Mauna Kea, Hawaii, including Gemini, the Canada-France-Hawaii Telescope and Keck. There, they will carry out a scientific program and, more importantly, get a glimpse of a future career as a member of the next generation of astronomers.

Canada-France-Hawaii Telescope

Credit: Vadim Kurland

Training

Training the Next Generation of Astronomers



02

01

The Dunlap Institute is dedicated to providing world-class training, mentoring, research opportunities, and career experience to undergraduate and graduate students in the astronomy program offered by the Department of Astronomy & Astrophysics.

There are many opportunities for training and experience, including the Dunlap's annual Introduction to Astronomical Instrumentation Summer School, U of T astronomy's Summer Undergraduate Research Program, the Mauna Kea School (which will provide students with an opportunity to gather data while at the Gemini-North Observatory in Hawaii), career mentoring workshops, and more.

Of course, training and career experience also comes from the postdoctoral fellows and professors supervising students' research projects.

In 2015, first-year graduate student Deborah Lokhorst began working with Dunlap Fellow Laura Newburgh and Prof. Keith Vanderlinde on HIRAX, the Hydrogen Intensity and Real-time Analysis eXperiment. When completed, HIRAX will comprise an array of 1024 radio dishes in the Karoo Desert in South Africa. It is the southern counterpart to CHIME (pg. 4) and will probe dark energy and the accelerating Universe by mapping hydrogen gas in the early cosmos.

In April 2016, Lokhorst travelled to South Africa to help build prototype dishes for HIRAX. Over the course of her trip, she met and worked with collaborators at the University of KwaZulu-Natal in Durban, the Durban University of Technology, as well as the Hartebeesthoek Radio Astronomy Observatory (HartRAO).

The work, the collaboration with colleagues around the world—even the opportunities to explore a new country—provided Lokhorst with a glimpse at a future in astronomy.

01. Graduate student Deborah Lokhorst in the lab at the University of KwaZulu-Natal in Durban, South Africa.

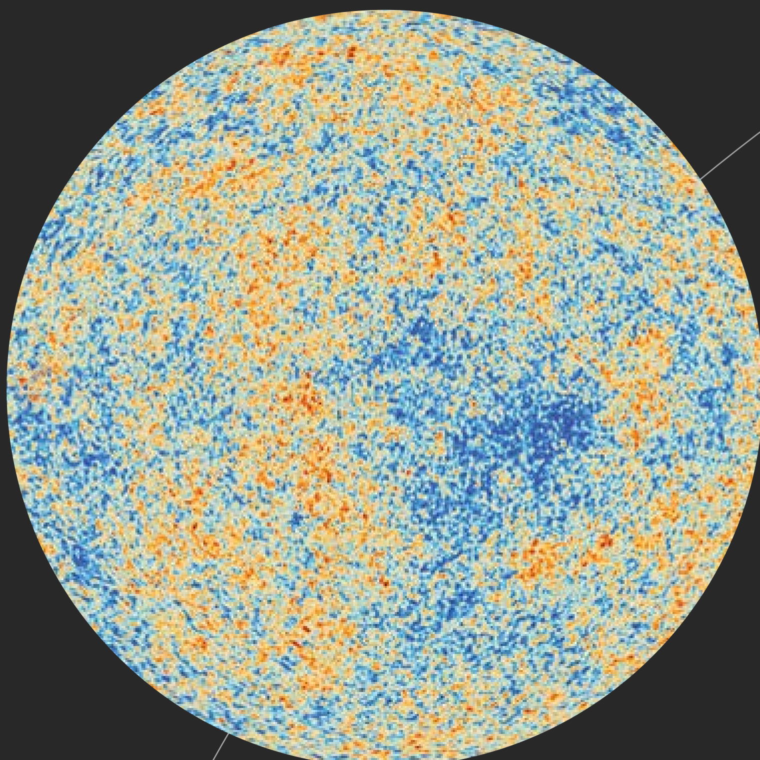
Credit: Dr. Laura Newburgh: Dunlap Institute

02. Three HIRAX prototype radio dishes at the Hartebeesthoek Radio Astronomy Observatory. In the background is the HartRAO 26m radio telescope.

Credit: Deborah Lokhorst; Dunlap Institute

Matthew Young

Matthew Young is a first-year astronomy graduate student. He is from Perth and did his undergraduate degrees at the University of Western Australia.



The Cosmic Microwave Background (CMB) is light from the Universe 380,000 years after the Big Bang. Different colours indicate the uneven distribution of matter which led to the formation of clusters and superclusters of galaxies.

Credit: ESA; Planck Collaboration

HOW DID YOU FIRST BECOME INTERESTED IN ASTRONOMY?

I've been interested in astronomy for as long as I can remember. One of my earliest memories is having a NASA space shuttle as my favourite toy. I was really lucky growing up in Western Australia where the night sky can be breathtaking. I remember spending countless nights as a kid lying on a trampoline and just staring at all the stars.

WHAT ARE YOUR KEY SCIENTIFIC INTERESTS?

My main interests are in cosmology and the very early Universe. Its incredible to think of the Universe as one single entity where everything interacts in so many different ways. I'd love to be able to answer some of the remaining questions about the inflationary era right after the Big Bang, as well as its influence on that primordial plasma.

HOW ARE YOU GOING ABOUT ANSWERING THOSE QUESTIONS?

Most recently, I've been testing the third-generation camera for the South Pole Telescope (pg. 5). This camera will allow the telescope to extract precise polarization information from the Cosmic Microwave Background, which will help advance a number of fields, including large-scale structure formation, particle physics and cosmic inflation.

WHAT'S BEEN THE MOST EXCITING OR REWARDING MOMENT OR ASPECT OF YOUR CAREER?

The most exciting moment of my career so far was being accepted into the graduate astronomy program here at U of T. I had set that goal about two years before applying, so it was very exciting to see that dream come true. I also have a background in Mechatronic Engineering, so having the Dunlap in Toronto provided the perfect opportunity to work on both instrumentation and cosmology.

WHAT INSPIRES YOU?

The thing that inspires me most is the question: Why? Why do things work the way they do? Why are things the way they are? I've always been deeply curious about the way things work, and it's helped me to always ask questions and to not just take things at face value. I consider myself incredibly lucky to be where I am today, being able to ask questions about how the Universe works—on the largest physical scales, all the way down to the quantum.

01

Public Outreach

Accelerating Public Engagement in Astronomy

02

01. Thousands crowded into King's College Circle to see the eclipse.

Credit: Lorne Bridgman

02. Students waiting to see the September 2015 Supermoon total lunar eclipse.

Public
Outreach

Crowds hoping the skies will clear.

Credit: © Lorne Bridgman

A Year of Engaging the Public

Prof. Michael Reid

This year has been a very strong year for outreach at the Dunlap Institute, with big events, big partnerships and big impact.

Last summer, we were joined by our new events coordinator Zoë Jaremus. Right away, Zoë helped organize our biggest public outreach event ever. Our celebration of the September 2015 "supermoon" total lunar eclipse (pg. 20). For the event, we invested in a fleet of new telescopes, which will be used to offer more large-scale, public sky-viewing events in the future.

One of our long-term goals is to help teachers deliver astronomy curriculum to their students, most of whom lack the expertise to comfortably teach astronomy. This year, Dunlap became the major sponsor of Discover the Universe/À la découverte de l'univers, an online teacher-training service. (pg. 22)

Dunlap is committed to training the next generation of astronomers. And we want to train a unique breed of astronomer: ones who can not only do groundbreaking science, but who are also skilled in communicating that science to the public. This year, we inaugurated a new Outreach Support Scientist (OSS) program, a paid position in which young astronomers learn about outreach and help develop new programming. Our first OSS, Alysa Obertas, is developing new content for the U of T planetarium—which saw a doubling in business this year—and we look forward to expanding the OSS program in the coming years.

In the coming year, we will also be building on our recent successes. Astronomy on Tap T.O. is a night of astronomy talks, games, prizes and conversation with U of T astronomers and in the fall of 2016, we will be having a special scaled-up version of "Tap" at a larger venue and with special guest speakers. Plus, in August of 2017, we'll welcome the public to view a solar eclipse with us.

There are lots more programs and events in development. It's shaping up to be another big year!

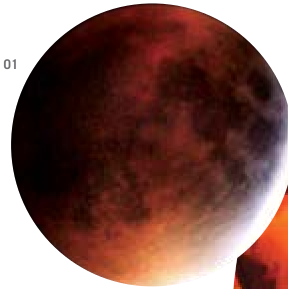
PLANETARIUM SHOW ATTENDANCE

General public: 3601
Golden Age of Astronomy (pg. 21): 936
AstroTours: 816
Science Rendezvous: 40
Undergraduate courses: 1700

Public Outreach

A Super Party for a Supermoon

01



02

01. Sam Haque was one of the winners in the Dunlap's total lunar eclipse photo contest.

Credit: Sam Haque

02. Astronomy graduate student Siqi Liu helps a member of the public navigate the virtual Universe using the World Wide Telescope.

Torontonians demonstrated their fascination with the night sky when thousands packed U of T's King's College Circle for the Dunlap Institute's Supermoon Total Lunar Eclipse Viewing Party on September 27th, 2015.

The eclipse they came to see was special in many ways. It was the last total lunar eclipse visible from Toronto until 2019. The eclipsed moon was at the closest point to the Earth in its orbit—often referred to as a "supermoon." What's more, the celestial event coincided with the Chinese Mid-Autumn Festival.

The crowd in King's College Circle was estimated at nearly ten thousand, which was still only a fraction of the nearly 20 thousand who expressed interest in attending on the event's Facebook page.

"It's very exciting to know that so many people are interested in astronomy," said Michael Reid, the Dunlap's public outreach coordinator. "We've been building toward bigger and bigger events over the past few years. We were fortunate to reach so many people through the Transit of Venus at Varsity Stadium event in 2012, and this was another great opportunity."

As with most public outreach organized by the Dunlap, the eclipse viewing party was the result of a partnership with other U of T units, including the Department of Astronomy & Astrophysics and U of T Science & Engineering Engagement.

But no amount of planning can predict the weather and unfortunately, clouds hid the moon for almost the entire night. Nonetheless, the crowd enjoyed the warm weather and the picnic-like atmosphere. Many brought their own telescopes, binoculars and cameras, and queried the U of T astronomers in attendance. They brought blankets, board games, snacks and Mid-Autumn Festival moon cakes.

It was only after midnight that the clouds parted briefly, giving the most dedicated a short glimpse of the moon as it made its way out of the Earth's shadow.

Public
Outreach

United by the Stars

01

02

As the Syrian refugee crisis unfolded around the world in 2015, U of T astronomy graduate students felt compelled to ask how they could help.

"I couldn't do only astronomy in the face of millions of people being displaced from their homes, with no idea where they'd end up or what their futures would be," said graduate student Jielai Zhang.

The students' response to the global emergency was to develop a special public planetarium show—the proceeds from which they would donate to Red Cross Canada to aid Syrian refugees here and living in camps overseas. The fund-raising goal they set for themselves was an ambitious $10,000.

The show, titled *The Golden Age of Astronomy*, was developed with the help of graduate students expert in Middle Eastern and Islamic history, and was presented by the students, an astronomy postdoctoral fellow and a staff member. It explored astronomical advances made during the Islamic Golden Age and how those advances connect to today's astronomical discoveries.

The shows, which were supported by the Dunlap Institute and the Department of Astronomy and Astrophysics, were extremely popular. And through ticket sales from 30 nearly sold-out performances—as well as through public donations and the donated stipends normally paid to presenters—the students surpassed their goal and raised a total of $10,769.

Though the shows are no longer running, the students' efforts haven't ended. They hope to present *The Golden Age of Astronomy* to Syrian refugees who have settled in Toronto in the spirit of welcoming them to their new home and inspired by the idea that all the people of the world are united by the stars.

01. *Credit: Photo composite, Charles Zhu; Astrolabe, Musée national de la Marine de Paris; Hubble Space Telescope, NASA*

02. The team behind *The Golden Age of Astronomy*

Public
Outreach

Helping Students Discover the Universe

Julie Bolduc-Duval delivering a webinar to teachers across the country.

Credit: Julie Bolduc-Duval

In 2016, the Dunlap Institute took a significant step forward in fulfilling its mandate of helping teachers teach astronomy. The institute began a partnership with Discover the Universe/À la découverte de l'univers which had already been providing training and resources to Canadian educators teaching astronomy since it was launched in 2011.

Originally a legacy program of the International Year of Astronomy, Discover the Universe has provided educators with astronomy workshops and webinars, as well as teaching modules and activities.

Workshops are based on the school curriculum and include classroom activities, teaching resources and tips on how to teach astronomy in a fun and innovative way. They are typically three-week programs which include a weekly webinar.

Other webinars help educators at different levels understand and teach a variety of topics in astronomy—from the Sun and eclipses, to Solar System objects, to more advanced topics like gravitational waves.

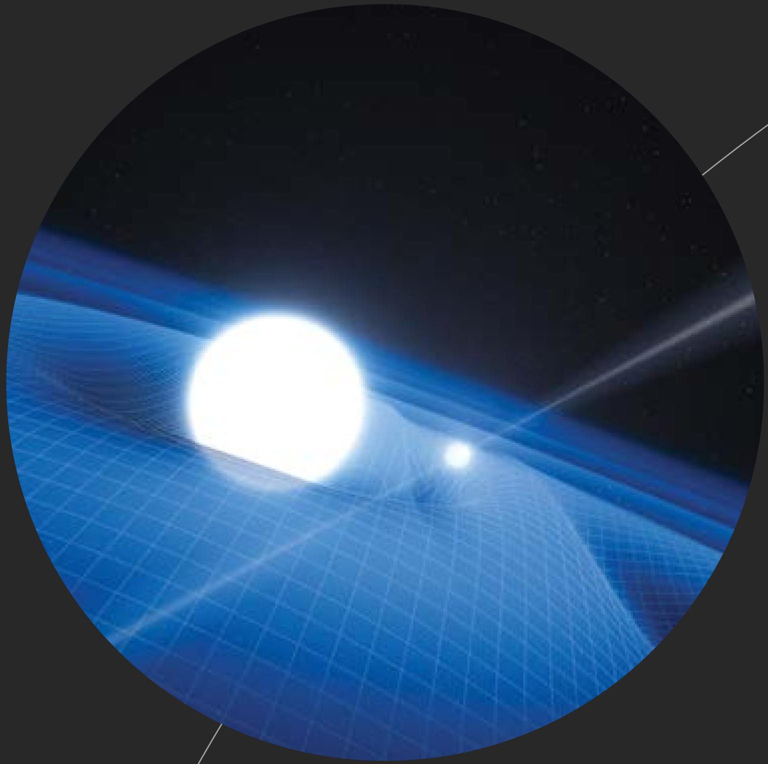
Julie Bolduc-Duval has been the coordinator for Discover the Universe since its launch and has taught physics and astronomy in various settings across the country for over 15 years. In partnership with the Dunlap, she will be developing teaching modules—helping the institute help students discover the wonders of the Universe.

In the coming year, the program will be scaled up with more scientists training teachers in topics ranging from moon phases to the Big Bang. And 2017 will see the launch new bilingual teaching modules matched to the pan-Canadian astronomy curriculum.

"Targeting teachers rather than students has a great multiplicative effect," says Dunlap director, Prof. Bryan Gaensler, "and we hope this initiative can break down the sense of fear both teachers and students often feel when they encounter advanced science topics."

Dr. John Antoniadis

Dr. John Antoniadis is a Dunlap Fellow. He received his PhD from the Max Planck Institute for Radio Astronomy.



Antoniadis's 2013 research showed that the orbital period of a white dwarf star (l.) around the neutron star PSR J0348+0432 (r.) was decaying exactly as predicted for a system losing energy by radiating gravitational waves.

Credit: ESO/L. Calçada

WHAT ARE YOUR KEY RESEARCH INTERESTS?

My main interests are neutron stars and compact objects—their structure, evolution and fundamental properties. Neutron stars can be thought of as giant atomic nuclei about 20km in diameter that outweigh the entire Solar System. Some of the most extreme neutron stars we know of spin as fast as 700 times per second and harbour magnetic fields a trillion times stronger than the Earth's. Observations of neutron stars can be used to test some of the most fundamental questions in modern physics—from the properties of gravitational waves, to the production of heavy elements, which are essential for life.

HOW ARE YOU GO ABOUT ANSWERING QUESTIONS ABOUT THESE OBJECTS?

For my research, I like to construct theoretical stellar models, and make observations of peculiar objects that don't fit in the standard picture. It is often the case that these outliers help to push the field forward!

WHAT'S BEEN THE MOST EXCITING MOMENT IN YOUR CAREER?

I had my first "eureka moment" in grad school, while I was observing with the Very Large Telescope in Chile. When I checked the data at the end of the run, I realized I had discovered the most massive neutron star known to date. This object generated a lot of discussion afterwards, but for a few hours, I was the only one who knew about it!

WHAT OTHER SCIENTIFIC PATHS INTEREST YOU?

If I were to go to graduate school again, I think I would choose a topic related to supernovae simulations. I find it fascinating that we can now use computers to approximate such complex phenomena in detail. Then, had I not been an astronomer, I think I would have liked to study human evolution.

WHAT INSPIRES YOU?

As an astronomer, inspiration is not hard to find. Personally, I am fascinated by the big open questions in physics, like the behaviour of matter in the most extreme conditions, and the properties of the four fundamental forces. But, I also find inspiration in the everyday. This may sound surprising, since most of the time, all I do is stare at a computer screen. But sometimes even small things—like finding a bug in a program, or wrapping up a calculation—can be extremely gratifying.

Faculty, postdoctoral fellows and graduate students from the Dunlap Institute, Department of Astronomy & Astrophysics (DAA) and Canadian Institute for Theoretical Astrophysics (CITA) are members of research and instrumentation collaborations that include astronomers from institutions around the world.

Collaborations

–
2015 - 2016

LEGEND

U of T Astronomer	Institution

ARO VLBI
Algonquin Radio Observatory
Very-Large Baseline Interferometer

U of T Astronomer	Institution
Prof. Keith Vanderlinde	Algonquin Radio Observatory (ARO)
Prof. Ue-Li Pen	Max-Plank Institut fur Radioastronomie (MPIfR)
Prof. Marten Van Kerkwijk (DAA)	Curtin U
Dr. I-Sheng Yang (Perimeter/CITA)	
Dana Simard	
Robert Main	
Daniel Baker (Physics)	

CHARIS
Coronagraphic High Angular Resolution
Integral Field Spectrograph

U of T Astronomer	Institution
Dr. Jeffrey Chilcote	NASA Goddard Space Flight Center
	National Astronomical Observatory of Japan
	Princeton U
	Subaru Telescope
	U Tokyo

DECaLS
Dark Energy Camera
Legacy Survey

U of T Astronomer	Institution
Dr. Dustin Lang	Lawrence Berkeley National Lab
Prof. Raymond Carlberg (DAA)	National Optical Astronomy Observatory

WIFIS
Wide Integral Field Infrared
Spectrograph

U of T Astronomer	Institution
Prof. Dae-Sik Moon	Korean Astronomy & Space Science Institute - KASI
Prof. Suresh Sivanandam	U Arizona
Elliot Meyer	U Florida
Siqi Liu	

POSSUM
Polarization Sky
Survey of the
Universe's Magnetism

U of T Astronomer	Institution
Prof. Bryan Gaensler	Australian National University
	CSIRO
	Dominion Radio Astrophysical Observatory, NRC
	Istituto Nazionale di Astrofisica
	U Calgary
	U Cape Town
	U Manchester
	U Minnesota
	U Sydney

ACTPol
Atacama Cosmology
Telescope

U of T Astronomer	Institution
Prof. Renée Hložek	Cardiff U
Dr. Laura Newburgh	Carnegie Mellon U
	CITA
	Columbia U
	Cornell U
	Florida State
	Haverford College
	INAOE
	Johns Hopkins U
	Kwazulu-Natal U
	NASA/GSFC
	NIST
	Oxford
	Pontifica Universidad
	Princeton U
	Rutgers U
	Stanford U
	Stony Brook U
	UC Berkeley
	UBC
	U of Illinois at Urbana-Champaign
	U. Michigan
	U Penn
	U Pittsburgh
	West Chester U

APOGEE
Apache Point Observatory
Galactic Evolution Experiment

U of T Astronomer	Institution
Prof. Jo Bovy	Apache Point Observatory
	Instituto de Astrofisica de Canarias
	Liverpool John Moores U
	Ohio State U
	New Mexico State U
	Texas Christian U
	U of Virginia

IRPWFS
InfraRed Pyramid
WaveFront Sensor

U of T Astronomer	Institution
Prof. Suresh Sivanandam	NRC Herzberg Institute of Astrophysics (NRC-HIA)
Dr. Shaojie Chen	U Arizona
Siqi Liu	

CHIME
Canadian Hydrogen Intensity
Mapping Experiment

U of T Astronomer	Institution
Prof. Keith Vanderlinde	Dominion Radio Astrophysical Observatory, NRC
Prof. Bryan Gaensler	McGill U
Prof. Ue-Li Pen	UBC
Prof. Richard Bond (CITA)	
Dr. Laura Newburgh	
Dr. Peter Klages (Dunlap; IBM Canada; CITA)	
Dr. Niels Oppermann (CITA)	
Andre Recnik (Dunlap)	
Philippe Berger (Physics)	
Ian Tretyakov (Physics)	
Liam Connor	
Nolan Denman	

Dragonfly

U of T Astronomer	Institution
Prof. Roberto Abraham	Yale U
Jielai Zhang	Harvard U

MSAMOS
Micro-Shutter Array Multi-Object Spectrograph

Prof. Dae-Sik Moon
Prof. Suresh Sivanandam
Dr. Shaojie Chen

NASA/Goddard
U of Maryland

GAS
Green Bank Ammonia Survey

Dr. Rachel Friesen
Prof. Peter Martin (CITA)
Prof. Chris Matzner (DAA)

Green Bank Telescope
Harvard-Smithsonian Center for Astrophysics
Max Planck Institute for Extraterrestrial Physics
NRC-Herzberg
U Alberta
U Arizona
U Massachusetts, Amherst
U Victoria
Yale U

VLASS
Very Large Array Sky Survey

Prof. Bryan Gaensler

Cornell University
U Alberta
U Manitoba
U Minnesota
US National Radio Astronomy Observatory

SPT-3G
South Pole Telescope-3rd Generation

Prof. Keith Vanderlinde
Dr. Tyler Natoli
Matthew Young

Argonne National Lab
Case-Western Reserve U
Fermilab
McGill U
Stanford U
U California, Berkeley
U Chicago
U Colorado, Boulder
U Illinois at Urbana-Champaign

SuperBIT
Super-pressure Balloon-borne Imaging Telescope

Prof. Barth Netterfield
Ivan Padilla
Leeav Lipton
Mathew Galloway (Physics)
John Hartley (Physics)
Javier Romualdez (A. Eng)
Steven Li (A. Eng)

Durham U
Jet Propulsion Laboratory
Princeton U

MWA
Murchison Widefield Array

Prof. Bryan Gaensler
Dr. Tessa Vernstrom

Arizona State U
Curtin U of Technology
Massachusetts Institute of Technology / Haystack Observatory
Massachusetts Institute of Technology / Kavli Institute
MIT
U Sydney
U Washington
U Wisconsin / Milwaukee
Victoria U Wellington

IRIS
InfraRed Imaging Spectrograph

Prof. Shelley Wright
Dr. Shaojie Chen
Dr. Jérôme Maire
Elliot Meyer

Caltech Optical Observatories
Dominion Astrophysical Observatory, National Research Council Canada
Herzberg Institute of Astrophysics, National Research Council Canada
Lawrence Livermore National Laboratory
Nanjing Institute of Astronomical Optics and Technology, Chinese Academy of Sciences
National Astronomical Observatory of Japan
Thirty Meter Telescope Observatory Corporation
U California, Los Angeles
U California Observatories, CfAO, University of California

LSST
Large Synoptic Survey Telescope (Canada)

Prof. Renée Hložek
Prof. Jo Bovy
Prof. Dae-Sik Moon

NIROSETI
Near InfraRed Optical Search for Extraterrestrial Intelligence

Prof. Shelley Wright
Dr. Jérôme Maire

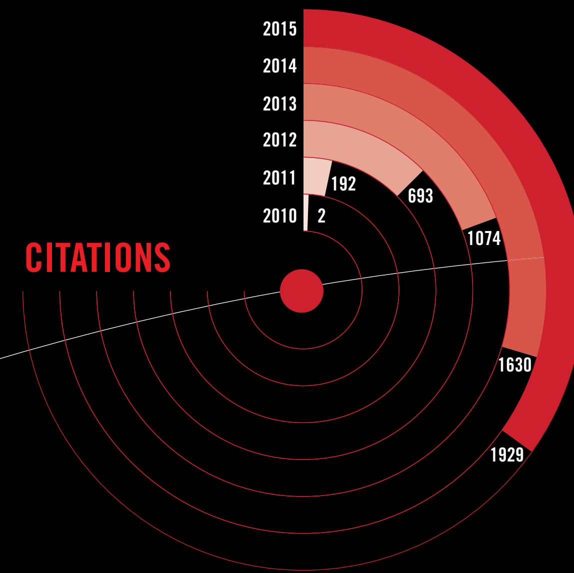
UC Berkeley
UC Observatories
UC San Diego
Starman Systems
SETI Institute

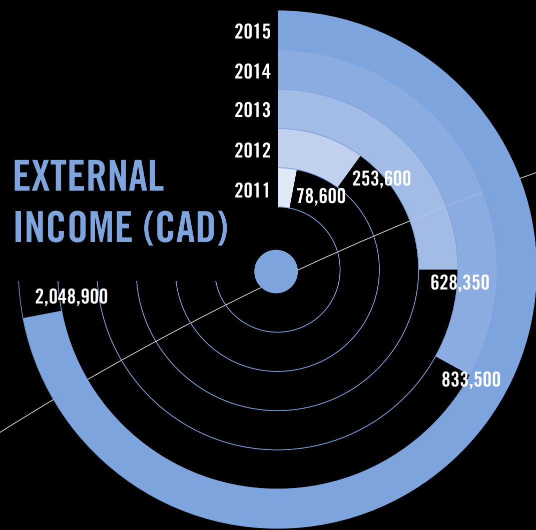
GPI
Gemini Planet Imager

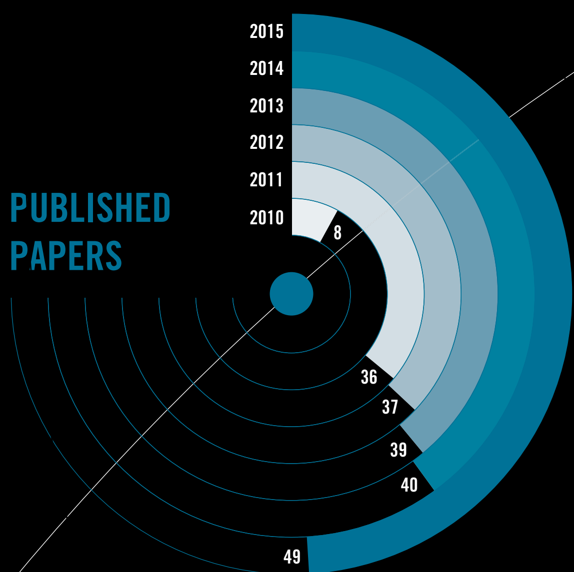
Dr. Jérôme Maire
Dr. Jeffrey Chilcote
Max Millar-Blanchaer

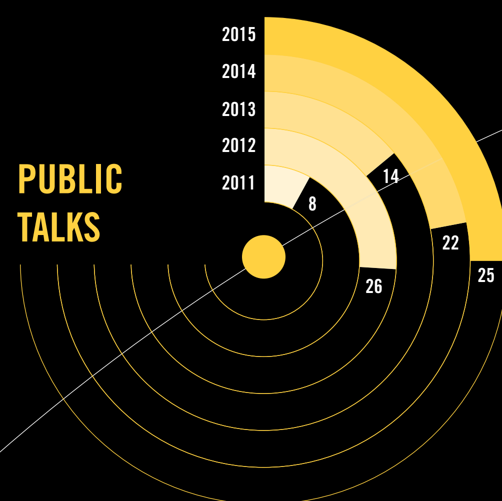
American Museum of Natural History
Arizona State U
Gemini Observatory
Herzberg Institute of Astrophysics
Jet Propulsion Laboratory
Lawrence Livermore National Laboratory
NASA Ames
SETI Institute
Stanford
Space Telescope Science Institute
U California, Berkeley
U California, Los Angeles
U California, Santa Cruz
U Georgia
U de Montréal

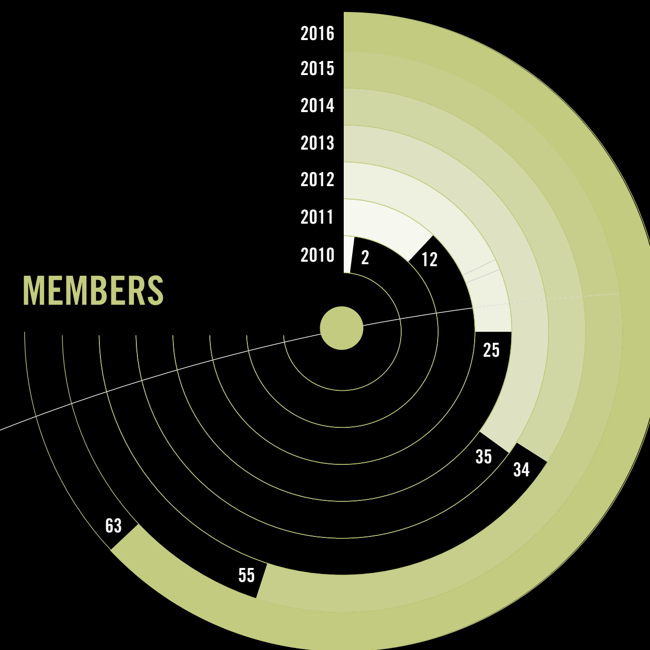
Accelerating Growth











* All figures unofficial

Dunlap Members 2015 - 2016

FACULTY

Prof. Bryan Gaensler
Prof. Renée Hložek
Prof. Michael Reid
Prof. Suresh Sivanandam
Prof. Keith Vanderlinde

ASSOCIATES

Prof. Roberto Abraham
Prof. Jo Bovy
Prof. Dae-Sik Moon
Prof. Barth Netterfield
Prof. Ue-Li Pen
Prof. John Percy
Dr. Niels Oppermann
Julie Bolduc-Duval, *Discover the Universe*

DUNLAP FELLOWS

Dr. John Antoniadis
Dr. Jeffery Chilcote
Dr. Nicolas Crouzet
Dr. Rachel Friesen
Dr. Chelsea Huang†
Dr. Jérôme Maire
Dr. Tyler Natoli
Dr. Laura Newburgh

POSTDOCTORAL FELLOWS

Dr. Shaojie Chen
Dr. Peter Klages
Dr. Etsuko Mieda
Dr. Tessa Vernstrom

RESEARCH ASSOCIATE

Dr. Dustin Lang

STAFF

Angela Choi, *Department Manager* ⋆
Alice Chow, *Business Officer*
Roberto Figueiredo, *IT Technologist*
Carol Gordon, *Office Assistant*
Zoë Jaremus, *Events and Communications Officer*
Alysa Obertas, *Outreach Support Scientist*
Gautam Patel, *Finance Officer* ⋆
Ondrej Recnik, *CHIME Computing Specialist*
Chris Sasaki, *Communications Coordinator*
Hugh Zhao, *Computing Manager* ⋆

GRADUATE STUDENTS

Liam Connor
Nolan Thomas Denman
Matthew Galloway
John Hartley
Siqi Liu
Deborah Lokhorst
Elliot Meyer
Maxwell Millar-Blanchaer
Ivan Padilla
Javier Romualdez
Dana Simard
Ian Tretyakov
Heidi White
Matthew Young
Jielai Zhang

UNDERGRADUATE STUDENTS

Ariel Amaral

⋆ jointly with the Department of Astronomy & Astrophysics, U of T
† jointly with the Centre for Planetary Science, U of T

Awards & Honours

Dr. John Antoniadis

John Charles Polanyi Prize in Physics, Council of Ontario Universities, 2016

Prof. Bryan Gaensler

Thomson Reuters Citation and Innovation Award;Canada Research Chair in Radio Astronomy; Whitford Lecture

Outreach Talks & Media Appearances

Dr. Nicolas Crouzet

Feb 10, 2016, *The Hunt for Planets Beyond the Solar System*, Royal Astronomical Society of Canada (RASC) Toronto Centre

Prof. Bryan Gaensler

Ongoing radio appearance on astrophysics, ABC Sydney

May 22, 2015, *How The Cosmos Will Kill You*, Royal Astronomical Society of Canada Mississauga

June 13, 2015, *The Dunlap Institute for Astronomy and Astrophysics: Past, Present and Future*, David Dunlap Observatory 80th anniversary celebration

Aug 2015, *An Expat Life*, Qantas Inflight Magazine

Nov 3, 2015, *Italy Inspires Canada*, Department of Italian Studies, U of T

Jan 24, 2016, *The Dishes, The Desert and The Dawn of the Universe*, Royal Canadian Institute

Jan 27, 2016, *How The Cosmos Will Kill You*, Brentwood Public Library

Feb 11, 2016, *Scientists hours away from proving last piece of Einstein's general theory of relativity*, ABC Radio

Feb 12, 2016, *What are Gravitational Waves*, ABC News Radio

Feb 25, 2016, *The World Records of the Universe*, Astronomy and Space Exploration Society, U of T

Mar 22, 2016, *The World Records of the Universe*, U of T Alumni Talk

Apr 2016, *Magnets, Aliens and Why Your Dog Poops in Circles*, UofT Planet ArtSci

Prof. Michael Reid

Ongoing radio appearances on astronomy, 102.1 The Edge

May 4, 2015, *Energy and Aliens*, Let's Talk Science All Science Challenge

May 13, 2015, *The Lifecycle of Stars*, Don Mills Library

June 13, 2015, *Universe: A Cinematic Triumph*, David Dunlap Observatory 80th anniversary celebration

Sept 28, 2015, *Discovery of liquid water on Mars*, CBC News Network

Sept 29, 2015, *Discovery of liquid water on Mars*, CBC Radio Ontario Morning

Nov 15, 2015, *Water on Mars*, Astronomy on Tap T.O.

Dec 7, 2015, *Misconceptions about the Big Bang*, Cawthra Park Secondary School

Dec 10, 2015, *Supermoon Total Lunar Eclipse Viewing Party*, U of T Bulletin

Feb 12, 2016, *Life in the Cosmos*, Rotherglen Academy

Feb 16, 2016, *The Sky Tonight*, Gerrard-Ashdale Library

Feb 24, 2016, *Finding Our Place in the Cosmos*, U for U

Mar 23, 2016, *Misconceptions about the Big Bang*, Don Mills Library

Apr 18, 2016, *Life in the Cosmos*, Discover the Universe webinar

Apr 20, 2016, *Life in the Cosmos*, Richland

Apr 26, 2016, *Life in the Cosmos*, North York Central Library

Prof. Suresh Sivanandam

May 21, 2015, Astronomy on Tap T.O.

Nov, 2015, *Seeing Beyond Red with Cool Technology*, Astronomy and Space Exploration Society Star Talk

Apr, 2016, Star-gazing with Beavers and Cubs

Apr, 2016, Titanium Physicists Podcast Guest

Prof. Keith Vanderlinde

May 26, 2015, Toronto Public Libraries "Thought Exchange" Lecture, *Cosmology, Cell Phones and Video Games*, St. Lawrence Library, May 26, 2015

May 30, 2015, University of Toronto Spring Reunion 2015, *Science at the South Pole*, Toronto,.

Sept 22, 2015, Toronto Public Libraries "Thought Exchange" Lecture, *Cosmology, Cell Phones and Video Games*, Agincourt Library

Sept 24, 2015, *The Canadian Hydrogen Intensity Mapping Experiment*, Astronomy and Space eXploration Society (ASX) Star Talk

Sept 26, 2015, *Contact*, Science Literacy Week

Nov 18, 2015, *Science at the South Pole*, University Lecture Series, U of T

Nov 18, 2015, *A Long Winter's Night*, Astronomy on Tap T.O.

Feb 29, 2016, *Science at the South Pole*, Brentwood Library

Peer Reviewed Publications

The 154 MHz radio sky observed by the Murchison Widefield Array: noise, confusion and first source count analyses; Franzen, T.M.O.,… **Gaensler, B. M.**, et al.; Monthly Notices of the Royal Astronomical Society; 04/2016

Providing Stringent Star Formation Rate Limits of z~2 QSO Host Galaxies at High Angular Resolution; **Vayner, Andrey**, et al.; The Astrophysical Journal, Volume 821, Issue 1; 04/2016

Erratum: *"Broadband Radio Polarimetry and Faraday Rotation of 563 Extragalactic Radio Sources"* (ApJ, 815, 1, 49); Anderson, C.S.; **Gaensler, B. M**., et al.; The Astrophysical Journal, Volume 820, Issue 2; 04/2016

Point Source Polarimetry with the Gemini Planet Imager: Sensitivity Characterization with T5.5 Dwarf Companion HD 19467 B; Jensen-Clem, Rebecca; **Millar-Blanchaer, Max**, et al.; The Astrophysical Journal, Volume 820, Issue 2; 04/2016

Radio Polarization Observations of the Snail: A Crushed Pulsar Wind Nebula in G327.1-1.1 with a Highly Ordered Magnetic Field; Ma, Y. K.,… **Gaensler, B. M.**, et al.; The Astrophysical Journal, Volume 820, Issue 2; 04/2016

High-energy sources at low radio frequency: the Murchison Widefield Array view of Fermi blazars; Giroletti, M.,… **Gaensler, B. M**., et al.; Astronomy & Astrophysics, Volume 588; 04/2016

Dust emissivity in the star-forming filament OMC 2/3; Sadavoy, S. I.,… **Friesen, R. K.**, et al.; Astronomy & Astrophysics, Volume 588; 04/2016

Advanced ACTPol Cryogenic Detector Arrays and Readout; Henderson, S. W.,… **Hložek, R**.; Newburgh, L., et al.; Journal of Low Temperature Physics, Online First; 03/2016

Contraction Signatures toward Dense Cores in the Perseus Molecular Cloud; Campbell, J. L.; **Friesen, R. K**., et al.; The Astrophysical Journal, Volume 819; 03/2016

Cool white dwarf companions to four millisecond pulsars; Bassa, C. G.; **Antoniadis, J**., et al.; Monthly Notices of the Royal Astronomical Society; 02/2016

The PDS 66 Circumstellar Disk as Seen in Polarized Light with the Gemini Planet; Wolff, Schuyler G.,… **Millar-Blanchaer, Maxwell A.; Chilcote, Jeffrey**, et al.; The Astrophysical Journal Letters; 02/2016

The JCMT Gould Belt Survey: A First Look at Dense Cores in Orion B; Kirk, H.,… **Friesen, R**., et al.; The Astrophysical Journal; 02/2016

WISE Photometry for 400 Million SDSS Sources; **Lang, Dustin**, et al.; The Astronomical Journal; 02/2016

Probing star formation in the dense environments of z ~ 1 lensing haloes aligned with dusty star-forming galaxies detected with the South Pole Telescope; Welikala, N.,… **Vanderlinde, K**., et al.; Monthly Notices of the Royal Astronomical Society; 01/2016

First Scattered-light Image of the Debris Disk around HD 131835 with the Gemini Planet Imager; Hung, Li-Wei,… **Maire, Jérôme; Millar-Blanchaer, Maxwell A.; Chilcote, Jeffrey K**., et al.; The Astrophysical Journal Letters; 12/2015

Broadband Radio Polarimetry and Faraday Rotation of 563 Extragalactic Radio Sources; Anderson, C. S.; **Gaensler, B. M**., et al.; The Astrophysical Journal; 12/2015

A Search for Fast Radio Bursts at Low Frequencies with Murchison Widefield Array High Time Resolution Imaging; Tingay, S. J.,… **Gaensler, B. M**., et al.; The Astronomical Journal; 12/2015

Quantifying ionospheric effects on time-domain astrophysics with the Murchison Widefield Array; Loi, Shyeh Tjing,… **Gaensler, B. M**., et al.; Monthly Notices of the Royal Astronomical Society; 11/2015

Astrometric Confirmation and Preliminary Orbital Parameters of the Young Exoplanet 51 Eridani b with the Gemini Planet Imager; De Rosa, Robert J.,… **Chilcote, Jeffrey K.; Maire, Jérôme; Millar-Blanchaer, Maxwell A**., et al.; The Astrophysical Journal Letters; 11/2015

Direct Imaging of an Asymmetric Debris Disk in the HD 106906 Planetary System; Kalas, Paul G.,… **Millar-Blanchaer, Maxwell A.; Chilcote, Jeffrey; Maire, Jérôme**, et al.; The Astrophysical Journal; 11/2015

Physical Conditions of the Earliest Phases of Massive Star Formation: Single-dish and Interferometric Observations of Ammonia and CCS in Infrared Dark Clouds; Dirienzo, William J.,… **Friesen, Rachel K**., et al.; The Astronomical Journal; 11/2015

Abundances, Stellar Parameters, and Spectra from the SDSS-III/APOGEE Survey; Holtzman, Jon A.,… **Bovy, Jo; Nguyen, Duy Cuong**, et al.; The Astronomical Journal; 11/2015

Discovery and spectroscopy of the young jovian planet 51 Eri b with the Gemini Planet Imager; Macintosh, B.,… **Chilcote, J. K.; Maire, J.; Millar-Blanchaer, M. A**., et al.; Science; 10/2015

Gemini Planet Imager Observations of the AU Microscopii Debris Disk: Asymmetries within One Arcsecond; Wang, Jason J.,… **Millar-Blanchaer, Max; Maire, Jerome**, et al.; The Astrophysical Journal Letters; 10/2015

The Q/U Imaging Experiment: Polarization Measurements of the Galactic Plane at 43 and 95 GHz; Ruud, T. M.,… **Newburgh, L. B**., et al.; The Astrophysical Journal; 10/2015

Fabrication of large dual-polarized multichroic TES bolometer arrays for CMB measurements with the SPT-3G camera; Posada, C. M.,… **Natoli, T**., et al.; Superconductor Science and Technology; 09/2015

Faraday Tomography of the North Polar Spur: Constraints on the Distance to the Spur and on the Magnetic Field of the Galaxy; Sun, X. H.,… **Gaensler, B. M**., et al.; The Astrophysical Journal; 09/2015

Beta Pictoris' Inner Disk in Polarized Light and New Orbital Parameters for Beta Pictoris b; **Millar-Blanchaer, Maxwell A.,…; Moon, Dae-Sik; Chilcote, Jeffrey; Maire, Jérôme**, et al.; The Astrophysical Journal; 09/2015

A Measurement of the Cosmic Microwave Background Gravitational Lensing Potential from 100 Square Degrees of SPTpol Data; Story, K. T.,… **Natoli, T.; Vanderlinde, K**., et al.; The Astrophysical Journal; 09/2015

Thermalizing a telescope in Antarctica - analysis of ASTEP observations; Guillot, T.,… **Crouzet, N.**, et al.; Astronomische Nachrichten; 09/2015

A compression scheme for radio data in high performance computing; Masui, K.,… **Connor, L.; Newburgh, L. B.; Vanderlinde, K**., et al.; Astronomy and Computing; 09/2015

Constraints on the distribution and energetics of fast radio bursts using cosmological hydrodynamic simulations; Dolag, K.; **Gaensler, B. M**., et al.; Monthly Notices of the Royal Astronomical Society; 08/2015

Murchison Widefield Array Observations of Anomalous Variability: A Serendipitous Night-time Detection of Interplanetary Scintillation; Kaplan, D. L.,… **Gaensler, B. M**., et al.; The Astrophysical Journal Letters; 08/2015

Broadband Spectral Modeling of the Extreme Gigahertz-peaked Spectrum Radio Source PKS B0008-421; Callingham, J. R.; **Gaensler, B. M**., et al.; The Astrophysical Journal; 08/2015

P*ower spectrum analysis of ionospheric fluctuations with the Murchison Widefield Array;* Loi, Shyeh Tjing,… *Gaensler, B. M.*, et al.; Radio Science; 07/2015

The Atacama Cosmology Telescope: measuring radio galaxy bias through cross-correlation with lensing; Allison, Rupert,… **Hložek, Renée; Newburgh, Laura**, et al.; Monthly Notices of the Royal Astronomical Society; 07/2015

The Eleventh and Twelfth Data Releases of the Sloan Digital Sky Survey: Final Data from SDSS-III; Alam, Shadab,… **Bovy, Jo; Lang, Dustin; Nguyen, Duy Cuong**, et al.; The Astrophysical Journal Supplement Series; 07/2015

The Atacama Cosmology Telescope: Lensing of CMB Temperature and Polarization Derived from Cosmic Infrared Background Cross-correlation; van Engelen, Alexander,… **Hložek, Renée; Newburgh, Laura**, et al.; The Astrophysical Journal; 07/2015

Observing Strategy for the SDSS-IV/MaNGA IFU Galaxy Survey; Law, David R.,… **Cherinka, Brian**; The Astronomical Journal; 07/2015

GLEAM: The GaLactic and Extragalactic All-Sky MWA Survey; Wayth, R. B.,… **Gaensler, B**., et al.; Publications of the Astronomical Society of Australia; 06/2015

The JCMT Gould Belt Survey: first results from the SCUBA-2 observations of the Ophiuchus molecular cloud and a virial analysis of its prestellar core population; Pattle, K.,… **Friesen, R.**, et al.; Monthly Notices of the Royal Astronomical Society; 06/2015

A Measurement of Gravitational Lensing of the Cosmic Microwave Background by Galaxy Clusters Using Data from the South Pole Telescope; Baxter, E. J.,… **Vanderlinde, K**., et al.; The Astrophysical Journal; 06/2015

The Q/U Imaging Experiment: Polarization Measurements of Radio Sources at 43 and 95 GHz; Huffenberger, K. M.,… **Newburgh, L. B**., et al.; The Astrophysical Journal; 06/2015

The Magnetic Field and Polarization Properties of Radio Galaxies in Different Accretion States; O'Sullivan, S. P.; **Gaensler, B. M.**, et al.; The Astrophysical Journal; 06/2015

An Ammonia Spectral Map of the L1495-B218 Filaments in the Taurus Molecular Cloud. I. Physical Properties of Filaments and Dense Cores; Seo, Young Min,… **Friesen, Rachel**, et al.; The Astrophysical Journal; 06/2015

The JCMT Gould Belt Survey: SCUBA-2 observations of circumstellar discs in L 1495; Buckle, J. V.,… **Friesen, R.**, et al.; Monthly Notices of the Royal Astronomical Society; 05/2015

The JCMT Gould Belt Survey: constraints on prestellar core properties in Orion A North; Salji, C. J.,… **Friesen, R**., et al.; Monthly Notices of the Royal Astronomical Society; 05/2015

P-MaNGA: full spectral fitting and stellar population maps from prototype observations; Wilkinson, David M.,… **Cherinka, Brian**, et al.; Monthly Notices of the Royal Astronomical Society; 05/2015

Real-time imaging of density ducts between the plasmasphere and ionosphere; Loi, Shyeh Tjing ,… **Gaensler, B. M.**, et al.; Geophysical Research Letters; 05/2015

Measurements of E-Mode Polarization and Temperature-E-Mode Correlation in the Cosmic Microwave Background from 100 Square Degrees of SPTpol Data; Crites, A. T.,… **Natoli, T.; Vanderlinde, K.**, et al.; The Astrophysical Journal; 05/2015

Spectroscopic confirmation of the existence of large, diffuse galaxies in the Coma cluster; van Dokkum, P. G.,… **Abraham, R.; Zhang, J.**, et al.; Astrophysical Journal; 05/2015

P-MaNGA: Gradients in Recent Star Formation Histories as Diagnostics for Galaxy Growth and Death; Li, Cheng,… **Cherinka, Brian,** et al.; The Astrophysical Journal; 05/2015

01

02

03

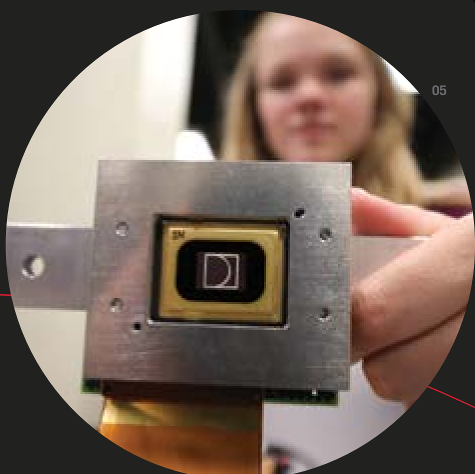
01. Students at the annual West Africa International Summer School for Young Astronomers where, for the second year, instructors included astronomers from the Dunlap Institute and the Department of Astronomy & Astrophysics.

Credit: Dr. Duy Cuong Nguyen

02. The Dunlap's Public Outreach Coordinator, Michael Reid, showing an excited passer-by the May 9th transit of Mercury at a special U of T Sidewalk Astronomy session.

03. Prof. Bryan Gaensler hosting the Dunlap's annual holiday party.

04



05

06

07

Editorial, original photography & production:
Chris Sasaki

Original photography & production:
Zoë Jaremus

Design & production:
Sovereign State

1 May 2015 – 30 April 2016

Unless otherwise noted, all photographs:
Dunlap Institute for Astronomy & Astrophysics

04. Dunlap membership has its privileges: new t-shirts.

05. The Dunlap icon displayed using the 786,432 micro-mirrors of a micro-mirror array, each of which can be controlled separately.

06. In December 2015, the Dunlap Institute hosted the Murchison Widefield Array Project Meeting and the Canada and the Square Kilometre Array Meeting.

07. Crowds continue to enjoy a night of talks, games, prizes and pints at Astronomy on Tap T.O.

Canada is one of ten member countries building the Square Kilometre Array which, when completed in the mid-2020s, will be the largest radio telescope ever constructed. Dunlap Institute director Bryan Gaensler is the Canadian SKA Science Director and Chair of the ACURA Advisory Council on the SKA.

Credit: SKA Organisation

www.dunlap.utoronto.ca
www.universe.utoronto.ca
www.dunlapobservations.wordpress.com