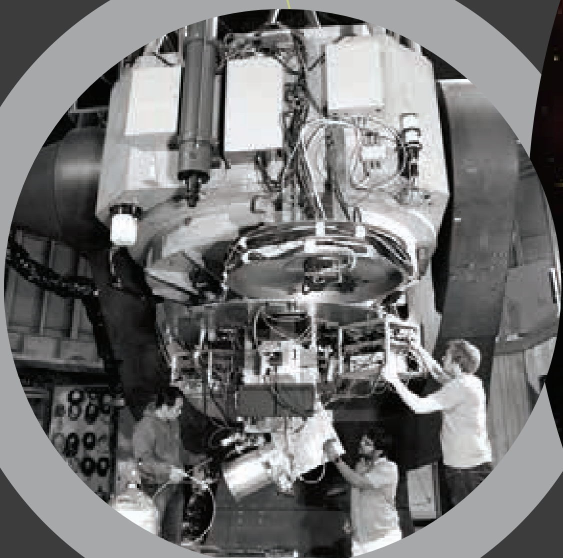
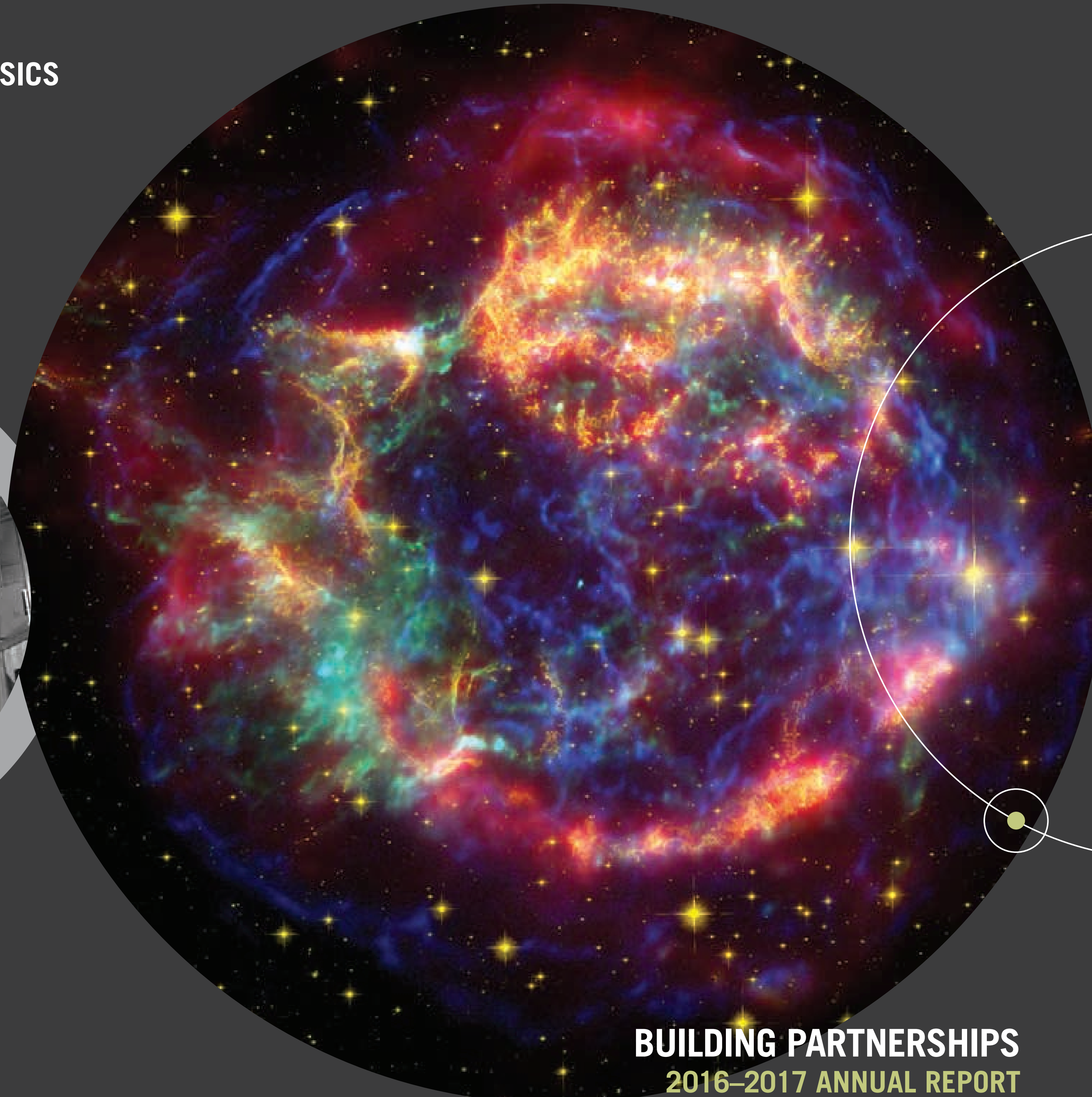
DUNLAP INSTITUTE *for* ASTRONOMY & ASTROPHYSICS





Dunlap Institute for Astronomy & Astrophysics
UNIVERSITY OF TORONTO

BUILDING PARTNERSHIPS

2016–2017 ANNUAL REPORT

Prof. Bryan Gaensler

Director's Message

Groundbreaking astronomy does not happen in isolation. As the Dunlap Institute continues to grow, we are increasingly being seen as a willing and capable partner on innovative new projects. This has manifest itself in many different ways over the last year.

On the individual level, our researchers have made some unique discoveries by initiating unusual collaborations: John Antoniadis worked with an amateur astronomer from South Africa to identify "star spots" in the companion to a millisecond pulsar; while Dustin Lang mused about his data on Twitter, got an enthusiastic response from an astronomer in Germany, and ended up directly imaging the X-shaped structure at the centre of the Milky Way Galaxy.

More broadly, our key contributions to complex astronomical instruments are beginning to bear fruit. The Coronagraphic High Angular Resolution Imaging Spectrograph (CHARIS) has begun to search for and study extrasolar planets; the Murchison Widefield Array (MWA) has released its spectacular first maps of the radio sky; and the Wide Integral-Field Infrared Spectrograph (WIFIS) has now been shipped from our labs and will soon be providing new 3D views of stars and galaxies.

In the next year, more partnerships will flourish: the Canadian Hydrogen Intensity Mapping Experiment (CHIME) will begin its full science program on cosmology and fast radio bursts; we will be part of a new Canada-wide, NSERC-funded program aimed at training students in astronomical instrumentation; and we are eagerly awaiting the outcome of two Dunlap-led proposals submitted to the Canada Foundation for Innovation (CFI), through which we hope to lead ambitious new national hardware and software programs.

Looking ahead even further, in the coming years you can expect to hear quite a bit about our role in new facilities like the Simons Observatory, the Hydrogen Intensity and Real-time Analysis eXperiment (HIRAX), and the Large Synoptic Survey Telescope (LSST)—for all of which the Dunlap Institute is laying

Cover

Prof. Suresh Sivanandam, Prof. Dae-Sik Moon and Dunlap PhD student Elliot Meyer installing WIFIS on the 2.3-metre Bok telescope at the Steward Observatory in Arizona.

Credit: Prof. Suresh Sivanandam, Dunlap Institute

WIFIS will target objects like Cassiopeia A, a remnant of a supernova.

Credit: NASA/JPL-Caltech

"What makes the Dunlap Institute special is its people. I'm privileged to work alongside a fantastic team"

the groundwork for major new discoveries in the coming years.

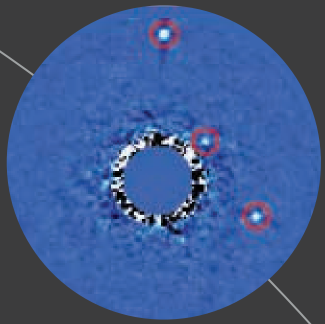
Our outreach program also continues to expand. This year we began an exciting new partnership with Toronto's Great Hall, which has let us host more than 500 people for each of our Astronomy On Tap T.O. events there. And our collaboration with Discover the Universe/À la découverte de l'univers now reaches over 1800 school teachers across Canada—in both English and French.

Our training program remains a core focus. Our instrumentation summer school, undergraduate research program, and Maunakea summer school target students from Canada and around the world, often giving them their first tastes of instrumentation and of research. Our Dunlap Fellows have maintained their outstanding record of scientific discovery and career success.

We have continued to expand our professional development activities, most notably through externally facilitated workshops on work-life balance and imposter syndrome. We'll soon be rolling out an internal mentoring scheme, in which members of the Dunlap Institute will each be the recipient of guidance from their elders, but in which each will also be expected to pass on their own thoughts and advice to those at earlier career stages. Overall, we're determined to make the Dunlap Institute a byword for excellence in training and expertise.

This was also the year in which we convened the first meeting of our full Dunlap Advisory Committee (DAC), chaired by Prof. Alyssa Goodman. The DAC has produced a detailed and wide-ranging set of recommendations, which we are now busy implementing. Expect a lot of changes and improvements at the Dunlap in response to the DAC's thoughtful input.

As always, what makes the Dunlap Institute special is its people. I'm privileged to work alongside a fantastic team, whose dedication, brilliance and professionalism make all our successes possible. I thank everyone in the Dunlap for their unswerving commitment to excellence over the last 12 months.



Prof. Bryan Gaensler on CBC News' The National explaining in August 2016 that, no, Russian astronomers haven't detected a signal from extraterrestrials just yet.

A CHARIS image shows three previously identified exoplanets (circled) around star HD 8799.

Credit: CHARIS/Princeton Team and NAOJ

Technology

01.

02.

The Year in Technology

**Prof.
Keith Vanderlinde**

The past year has been an eventful one for instrumentation at the Dunlap Institute. One instrument after another has reached maturity and been delivered from the lab to the field, ready to undergo commissioning and begin lives as productive scientific tools. This milestone is the high-water mark in the hectic life of an instrument builder—the chance to finally see years of R&D come to fruition.

The Canadian Hydrogen Intensity Mapping Experiment (CHIME) is rapidly nearing the end of its long construction period Dunlap members have spent the past four years designing, assembling and testing the digital brain of CHIME: the supercomputer "correlator" that allows the telescope to build images of the sky from the radio light striking it. The completed correlator was delivered to the Dominion Radio Astrophysical Observatory site in B.C. in early 2017. And, as subsystems come online, CHIME will slowly open its radio "eyes" and see an unprecedented radio view of both our Galaxy and the distant cosmos.

At shorter wavelengths, things have been even busier. Following several years of development and integration at the Dunlap, the Wide Integral Field Infrared Spectrograph (WIFIS) was shipped this spring to Arizona and installed on the 2.3-metre Bok telescope at the Steward Observatory. Commissioning is now largely complete, and regular observations are scheduled to begin soon, opening new windows on a wide range of processes within distant galaxies.

A number of existing instruments have also deployed major upgrades over the past year. The Dragonfly array doubled in size last summer, adding a second bank of 24 lenses for ever faster and deeper images of the ultra-low surface brightness Universe. Meanwhile, with the installation of additional detector tiles, the Murchison Widefield Array (MWA) officially entered Phase-II of its existence this year, adding capabilities for both lower noise and higher resolution operations.

The third-generation camera for the South Pole Telescope (SPT-3G) includes a huge new array of microwave detectors, which the Dunlap has been intimately involved in testing and characterizing. Over the 2016/17 Austral summer, these detectors made their way to the Antarctic, and a flurry of activity before the long South Pole winter saw everything installed and in-place. Initial observations are now underway.

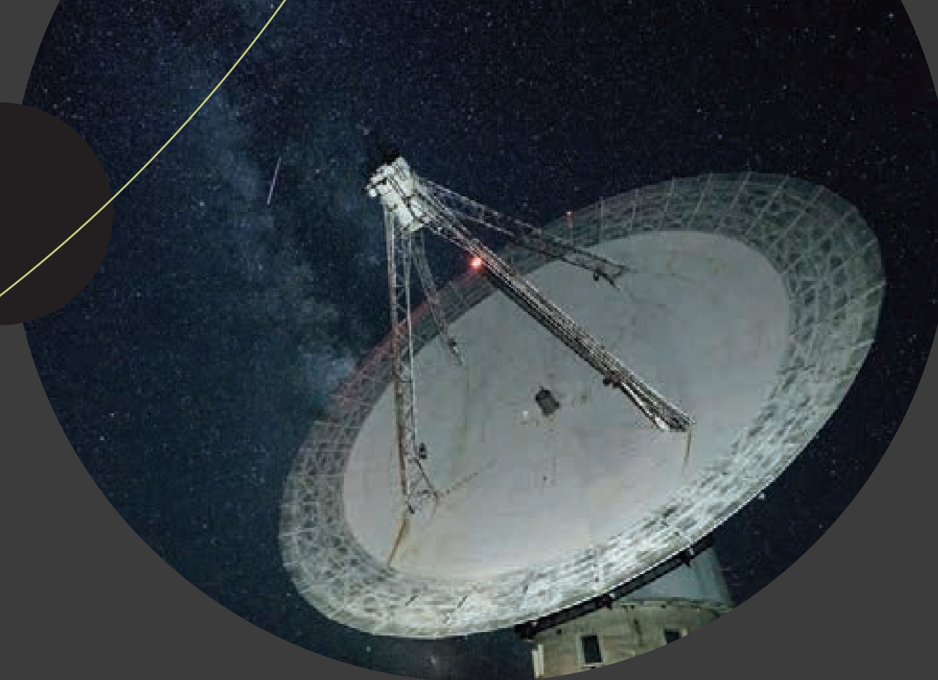
There's still much work to be done on these instruments before science operations get into full swing, but deployment marks a huge milestone and promises exciting results to come.

01. Prof. Roberto Abraham (l.), Department of Astronomy & Astrophysics, U of T; Prof. Pieter van Dokkum (r.), Yale University; and students on the Dragonfly team

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

02. The SPT-3G third-generation camera undergoing testing at Fermilab in Illinois prior to transporting it to the South Pole

Credit: Dr. Tyler Natoli, Dunlap Institute



Robert Main

Robert Main is a fourth-year PhD student. He received his BSc in Mathematical Physics and Masters in Physics from the University of Waterloo.

Algonquin Radio Observatory.

Credit: Andre Renard, Dunlap Institute

HOW DID YOU FIRST BECOME INTERESTED IN ASTRONOMY?

I first became interested in astronomy as a teenager, when I started reading popular science books like *A Brief History of Time* and *Coming of Age in the Milky Way*. I had always liked math and physics, but I was particularly drawn to astronomy by the sense of exploration and discovery it evoked. Once I took my first astronomy course as an elective in my undergrad, I realized that astronomy wasn't just a passing interest, but was what I actively wanted to do.

WHAT IS YOUR KEY SCIENTIFIC INTEREST?

Pulsars—rapidly rotating neutron stars that emit a beam of radiation. Pulsars have been studied in detail in the 50 years since their discovery, yet there are still many questions to be answered, such as how they emit radiation, and how massive a pulsar can be before it collapses into a black hole. I'm interested in answering these questions using novel techniques to analyze data from radio telescopes.

HOW ARE YOU CONDUCTING YOUR RESEARCH?

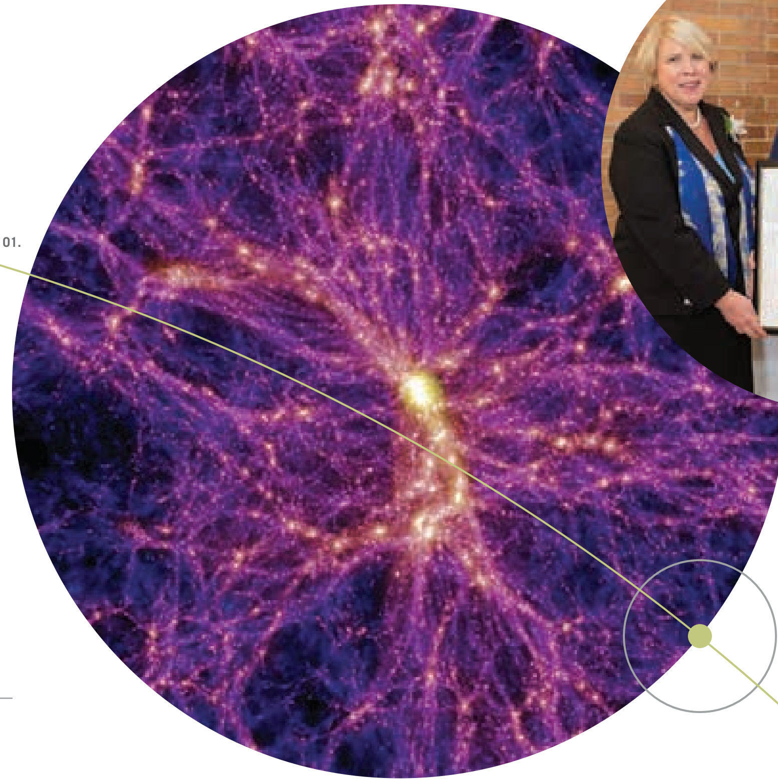
I observe at the Algonquin Radio Observatory in Algonquin Park in northern Ontario and combine those observations with observations made from other radio telescopes around the world. With a technique called Very Long Baseline Interferometry (VLBI), we can combine the radio signals from different telescopes to achieve the resolving power of a telescope the size of the Earth. Similarly, we can combine light from a single pulsar that has taken different paths through space to reach us. This gives us the resolving power of a radio telescope roughly the size of our Solar System. My research is to use this information to map where in the pulsar's magnetosphere the emission comes from, which will help answer how a pulsar emits its light.

WHAT'S MOST EXCITING ABOUT YOUR WORK?

One of the most exciting aspects of the work is the remarkable precision we can achieve. We can see a feature roughly 10 kilometres in size from several light-years away—that's roughly equivalent to seeing a human hair on Jupiter! Plus, it's been very rewarding to be involved in the coordination of VLBI observations. It takes a remarkable amount of cooperation with many other scientists to do simultaneous observations from different sites across the Earth.

The Year in Research

Observational Research

01.


02.


Prof. Suresh Sivanandam

This year, the Dunlap Institute continued to make a significant impact across diverse fields in observational astronomy ranging from exoplanets, neutron stars, the Milky Way Galaxy, to cosmic magnetism.

Our Dunlap postdoctoral fellows have been at the forefront of these fields. Of note, Dunlap Fellow John Antoniadis won the prestigious and highly competitive Polanyi Prize in physics for using pulsars—rapidly rotating neutron stars that emit a beam of radiation—to tackle fundamental problems such as testing Einstein's theory of gravity and the detection of Gravitational Waves.

Over the last year, we have made significant progress in the detection and analysis of exoplanets—planets orbiting stars other than the Sun. Dunlap Fellow Jeffery Chilcote recently published an extensive characterization of the atmosphere of a giant planet around a nearby star, Beta Pictoris, which helps answer questions related to planet formation. He has also been a pivotal member in the development of a powerful exoplanet imaging instrument, the Coronagraphic High Angular Resolution Imaging Spectrograph (CHARIS)—recently commissioned at the 8.2-metre Subaru telescope in Maunakea, Hawaii. CHARIS will carry out a search for exoplanets around stars in the northern sky through direct imaging. It will complement the southern sky survey currently being carried out by the Gemini Planet Imager.

Another Dunlap Fellow, Jason Hunt (pg. 5), has been leading efforts to understand the structure of the Milky Way Galaxy through the innovative use of new data from the GAIA space mission. In recent work, he has tackled the nature of the spiral arms within the Galaxy and predicts that they will disappear eventually and be replaced with new ones.

Our membership in the Murchison Widefield Array (MWA) collaboration is also beginning to pay off. For example, Dunlap postdoctoral fellow Tessa Vernstrom and Dunlap Director Prof. Bryan Gaensler recently published the results of the first real search for the radio cosmic web using MWA data. The cosmic web is very difficult to detect as it consists of filaments of rarefied gas connecting large structures within our Universe. This work is a step forward in measuring the large-scale magnetic field in the Universe, which is only possible with survey telescopes like MWA and, in the future, the Square Kilometre Array.

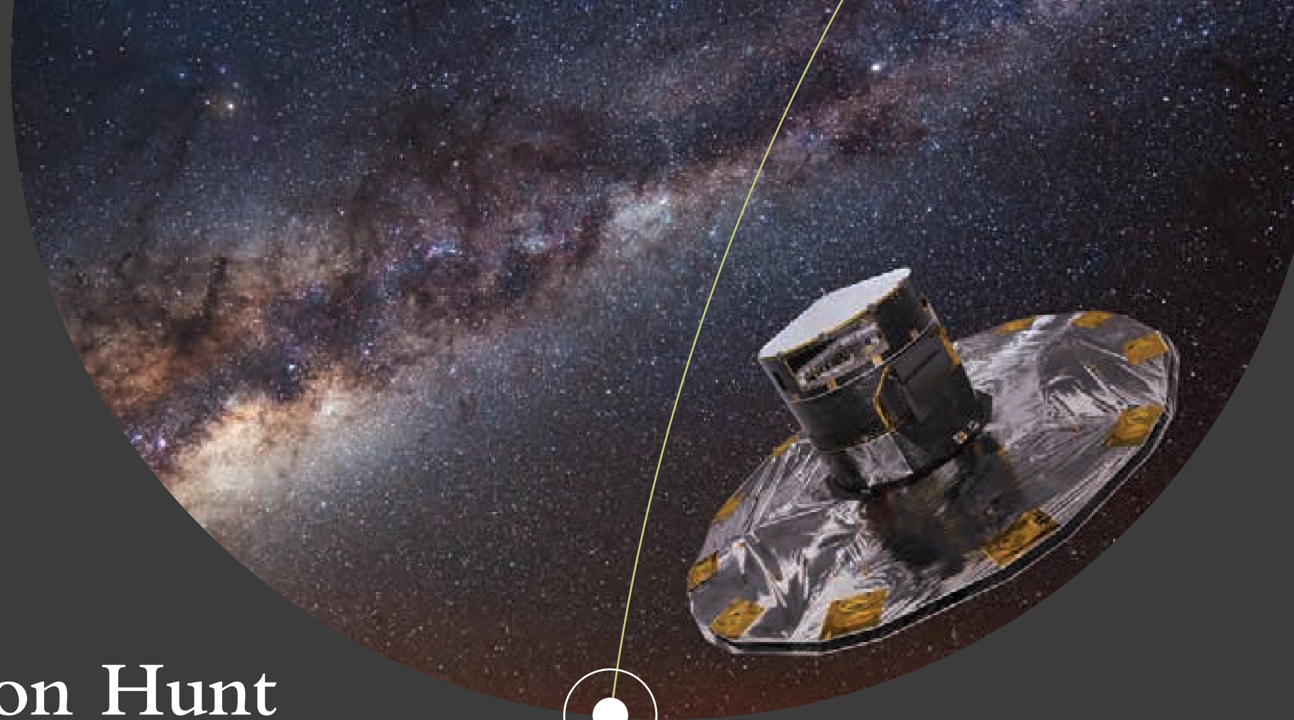
Over the next year, we expect survey experiments such as the Canadian Hydrogen Intensity Mapping Experiment (CHIME) and the Wide Integral-Field Infrared Spectrograph (WIFIS) to bear fruit by tackling fundamental questions in the fields of galaxy evolution and cosmology.

01. A simulated visualization of the Universe showing galaxies and dark matter organized into the cosmic web.

Credit: V.Springel, Max-Planck Institut für Astrophysik, Garching bei München

02. Dunlap Fellow, John Antoniadis receiving a 2016 John C. Polanyi Prize from John Polanyi and Deb Matthews, Minister of Advanced Education and Skills Development.

Credit: Property of the Government of Ontario; Barry Roden



Gaia spacecraft.

Credit: ESA/ATG medialab; background image: ESO/S. Brunier

Dr. Jason Hunt

Jason Hunt is a Dunlap Fellow. He received his PhD from Mullard Space Science Laboratory, University College London, and joined the Dunlap Institute in September 2016.

HOW DID YOU FIRST BECOME INTERESTED IN ASTRONOMY?

I became interested in astronomy because my parents would often watch space documentaries or science fiction shows when I was a kid, and used to take me to dark sky sites on holidays. I remember seeing the old Russian space station Mir in the night sky, and I remember thinking how cool it was that humans had put that up there. Then at university, I enjoyed my astronomy courses more than the rest of my studies, and decided to pursue it further.

WHAT IS YOUR MAIN SCIENTIFIC INTEREST?

I'm interested in learning more about the Milky Way Galaxy. Because we're inside it, we actually know a lot less about some of its fundamental properties than about those of other galaxies. For example, we know we live in a spiral galaxy, but the number of spiral arms, why they form, and how they change with time are still subjects of considerable debate.

WHAT IS GAIA AND WHAT GAIA-RELATED RESEARCH ARE YOU DOING?

Gaia is a European Space Agency satellite launched in 2013. Its primary mission is to map the positions and velocities of about one billion stars in the Milky Way Galaxy. This will give us distances to hundreds of millions more stars than we've ever had before. But even the one billion stars which Gaia will see is still only around one percent of the total number of stars in our Galaxy. So, I'm using the data from Gaia to try and reveal the structure of our Galaxy where Gaia can't see. I spend a lot of my time making computational models of our Galaxy and then seeing how well they match the observations from Gaia.

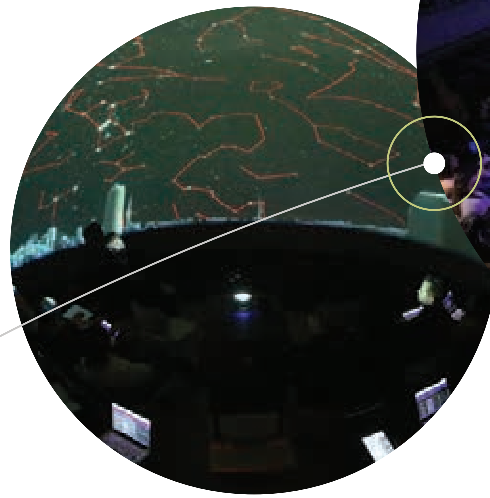
WHAT'S BEEN THE MOST REWARDING ASPECT OF YOUR CAREER?

The fact that with Gaia, we'll detect stars we've never seen before and see more of the Galaxy than ever before. And that we're working on things that have never been done before and solving new problems. Expanding that bubble of human knowledge—even a little bit—is something I'm excited to be doing.

Public Outreach

The Year in Outreach

02.



01.

Prof.
Michael Reid

One of our main goals at the Dunlap Institute is to make astronomy accessible to everyone. Astronomy has a special power to create curiosity about the natural world, so we want everyone to have access to it.

Over the past year, we have had unprecedented success in achieving this with our Astronomy on Tap T.O. events. "Tap" is all about bringing science to people who would rather chat over a pint at a pub than listen to a lecture in a hall on campus. We've run Tap successfully for several years in a venue designed for about 100 people. In November 2016, we moved to the 500-seat capacity Great Hall, a beautiful historic venue in Toronto's West Queen West neighbourhood. We've been very happy with the warm response, filling the venue to capacity twice.

Another priority at the Dunlap is to help teachers develop their capacity to teach astronomy. A recent survey found that only 43 percent of K-6 teachers in Québec actually teach astronomy in their classrooms—and this is likely typical of the country as a whole. Teachers report lack of expertise as one of the main reasons they don't cover the astronomy curriculum.

Through our partnership with Discover the Universe, the Dunlap released two bilingual astronomy teaching modules in 2016. Our first module, called *Looking Up!*, contains eight activities teachers can do with their students to help them engage with the sky and learn some of its cycles. The second module, *The Solar Cycle*, provides an inquiry-based activity for secondary school teachers, showing students how they can use real astronomical data from space telescopes to explore the twenty-two year cycle of solar activity. We will be releasing more of these modules in the coming years.

This year, the university made major upgrades to the planetarium, installing an improved sound system and a 4K digital projection system. Now, the Dunlap can bring the cosmos to audiences in greater detail than ever before. We are also working with the university on plans for a new, much larger planetarium, which will be open to the public. In the meantime, we are training graduate students and postdoctoral fellows to create and deliver even more shows in our current facility.

These are just a few of the many public outreach initiatives that kept us busy this year. In the coming year, we're looking forward to a whole lot more—starting with a solar eclipse event at the Canadian National Exhibition in August.

01. Michael Reid in the planetarium, training students and postdocs to present shows.

02. Over 500 people packed the Great Hall in November 2016 for Astronomy on Tap T.O.

Julie Bolduc-Duval

Julie Bolduc-Duval is a physics and astronomy educator and has been the director of Discover the Universe (DU) since its launch in 2011.

Julie Bolduc-Duval explaining an astronomical concept to teachers during a Discover the Universe webinar.

WHEN DID YOU FIRST BECOME INTERESTED IN ASTRONOMY?

I've always been curious about the world around me but my interest in physics and astronomy really started as a teenager. I read a few books, including Stephen Hawking's *A Brief History of Time*, and I wanted to understand the big questions about the Universe, its beginning and its evolution. That's why I decided to study physics and astronomy in university.

TELL US ABOUT YOUR ASTRONOMICAL AND TEACHING BACKGROUND.

I've been working in astronomy education and public outreach for over 15 years. As an undergraduate student at the University of Victoria, I had the chance to work as a research assistant and public outreach coordinator for the Dominion Astrophysical Observatory. While I found research very interesting, I quickly realized I preferred sharing my passion with the public. Since then, I've provided public programming for all kinds of audiences and trained thousands of teachers and educators. I also taught physics and astronomy at the college level (Cégep) in Québec.

WHY IS IT IMPORTANT FOR YOUNG PEOPLE TO LEARN ABOUT ASTRONOMY?

There are many reasons. Most kids are fascinated by space and learning about it can be a gateway into the world of science and technology. It also helps them understand phenomena which affect their daily lives—like night and day, lunar phases, the seasons. But I think the most important aspect is how astronomy teaches us about our place in the Universe and gives us a sense of global citizenship.

WHAT'S THE MOST REWARDING ASPECT OF YOUR WORK?

Knowing I've had an impact in science teaching in classrooms across Canada and worldwide. Since most of the training I offer is done online, I don't get to interact much with the participants. Therefore, it feels extra special when people take the time to write an email thanking me and telling me how much I helped. And the best part? When I get to meet them at conferences. When they recognize me and tell me howmuch they like what Discover the Universe offers—it makes my day!

Training

The Year in Training

01.

02.

Prof. Renée Hložek

At the Dunlap, training is at the forefront of everything we do. And so, the past year has been one of continuing with strong existing programs, and planning and creating a vision for the future.

It's been exciting imagining new opportunities to supplement our current programs for both an internal audience of Dunlap members, as well as for participants from outside the Dunlap and beyond the University of Toronto.

We are planning additional conferences and workshops devoted to professional development, where we can meet, foster and empower students and young scientists.

We have already started extending training programs locally with sessions on Impostor Syndrome; skills sessions on astronomical software; and a "Hack Day" session planned for the upcoming 2017 Dunlap Retreat. In these sessions, we'll learn about the research interests and skills of our colleagues. They also serve an additional goal: to empower students, postdoctoral fellows and faculty alike to think about the skills they need to become more efficient, competent and successful.

While we envision the future of training at the Dunlap, our existing programs are growing from strength to strength.

The 2016 Introduction to Astronomical Instrumentation Summer School was incredibly successful, with 42 students visiting us from 21 countries. The school featured a new X-ray lab, and included lectures and labs on radio interferometry, wave-front sensing and optics. Our students were pleasantly surprised that the hands-on components challenged them to test and investigate the concepts they had learned in lectures. Over the course of one short week, we saw the students grow in confidence and develop a flair for astronomical instrumentation and technology.

The past year saw the start of an ambitious new training partnership between the Dunlap Institute and Queen's University: the Dunlap Maunakea Summer School in Hawaii. Participants were selected from the pool of the previous year's instrumentation summer school who were enrolled at a Canadian institution.

This included students from the University of Toronto, Queen's University and the University of Victoria, and in May 2016, they visited the Canada France Hawaii Telescope (CFHT), the Gemini Observatory, and other Maunakea observatories. The students received instrumentation training, as well as training in astronomical observation and data-processing; they even made their own observations with the Gemini telescope. The school was an incredible success and is continuing in 2017.

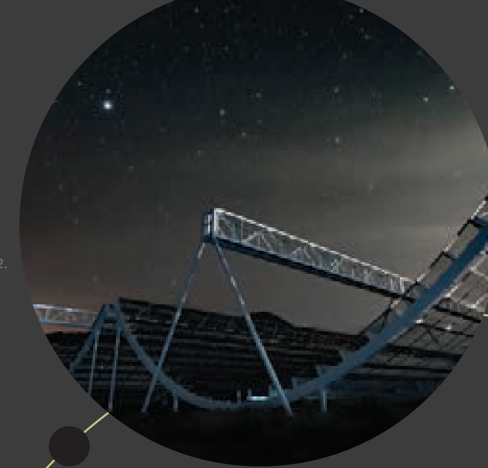
With current strengths and a new vision, we are excited about training at the Dunlap Institute and the rewards it brings for the next generation of astronomers.

01. Students in the radio lab during the instrumentation summer school.

02. Dunlap Maunakea Summer School students, instructors and observatory personnel at the Gemini Observatory.

01.

02.



03.

04.

01. At Astronomy on Tap T.O., Dunlap Fellow Rachel Friesen explains why astronomers build observatories in far-flung locations.

02. CHIME awaits the start of science in 2017.

Credit: Andre Renard, Dunlap Institute; CHIME

03. Amateur astronomer André van Staden, who collaborated with Dunlap Fellow John Antoniadis, in his home observatory in South Africa

Credit: André van Staden

04. Students attending the annual instrumentation summer school visit the David Dunlap Observatory.

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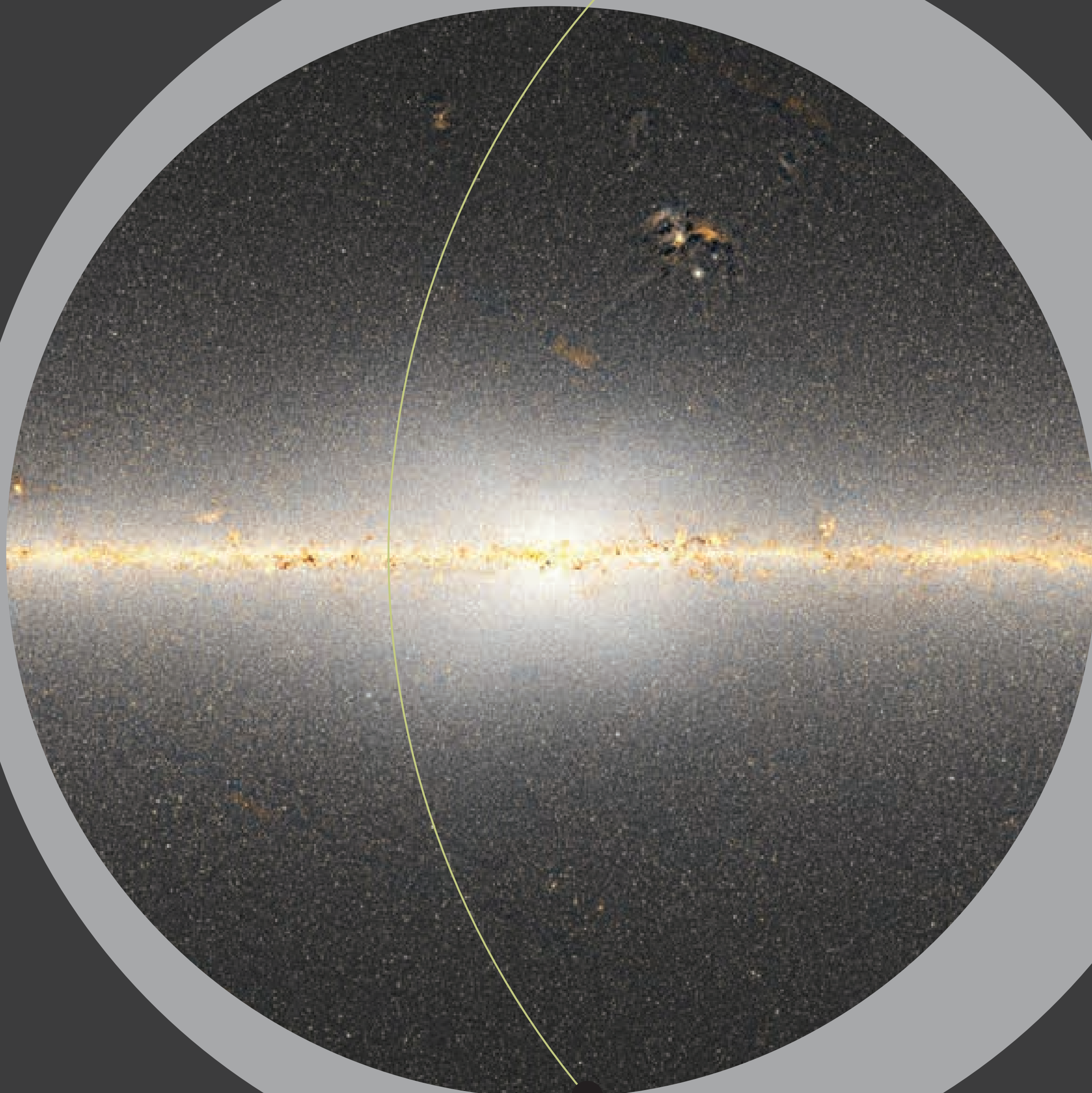

Dunlap Research Associate Dustin Lang's image of the Milky Way Galaxy. The Galaxy's centre is at the centre of the image.

Credit: D. Lang, Dunlap Institute

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