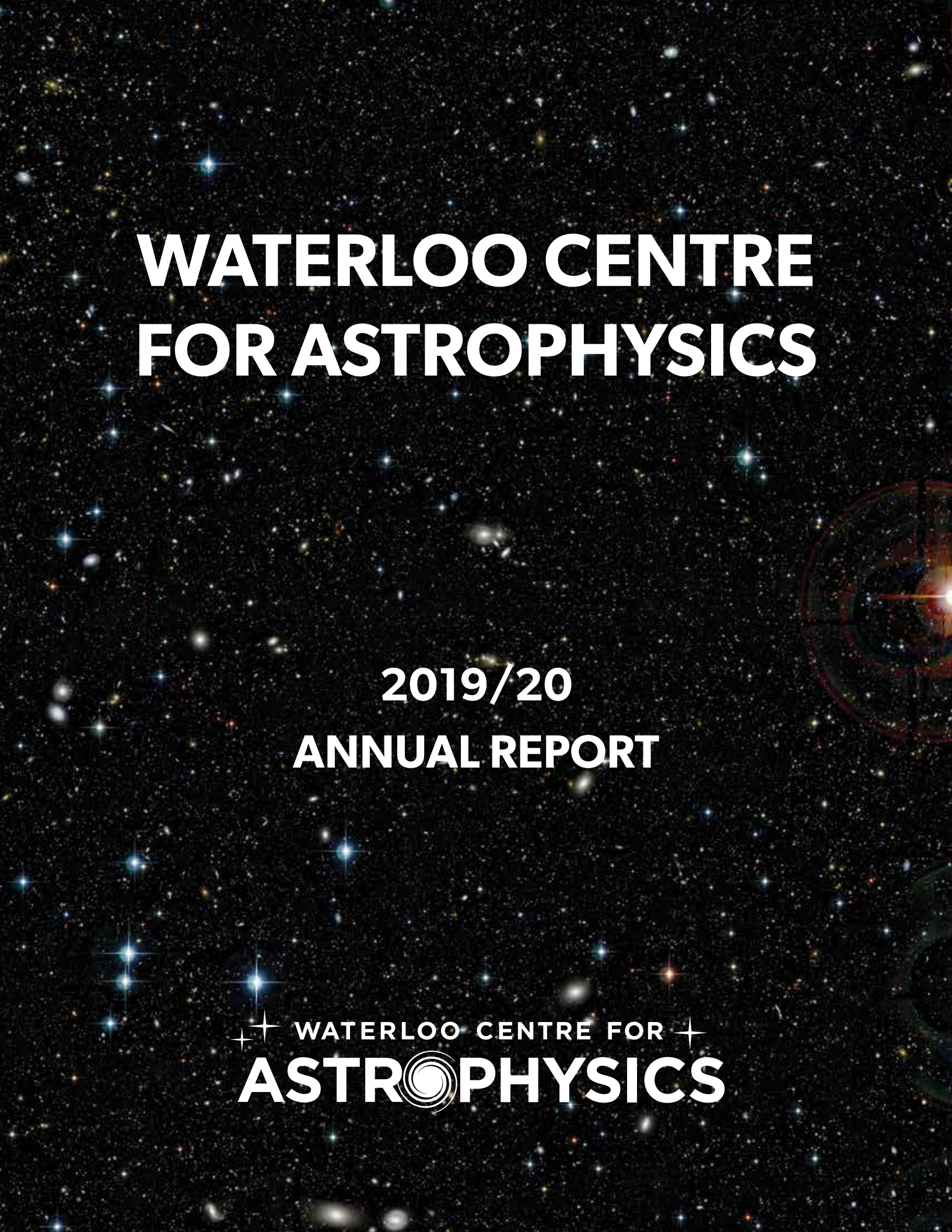
Background image credit: CFHT/Terapix/Jean-Charles Cuillandre

UNIVERSITY OF WATERLOO | WATERLOO CENTRE FOR ASTROPHYSICS



WATERLOO CENTRE FOR ASTROPHYSICS

2019/20
ANNUAL REPORT

WATERLOO CENTRE FOR
ASTROPHYSICS

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MESSAGE FROM THE CHAIR

Director Will Percival

The Waterloo Centre for Astrophysics (WCA) was formed to enable excellent research, with the idea of bringing together excellent scientists to create and test new theories. Unfortunately, thanks to the Covid-19 pandemic, bringing people together physically is precisely what we should not be doing at the moment. Instead we, like the rest of the world, have had to adapt to the new norm over the last year with project meetings, seminars, group interactions, and journal clubs all moving to an online format. We are very lucky that much of the core research activity supported by the WCA has been able to continue remotely, and we should remember that many are not in the same situation in other fields. That's not to say that we have not been affected. Many telescopes around the world were shut-down limiting the flow of data. Our hopes for refurbished office space dedicated for the WCA and for a new building in the more distant future have been put on hold. But these are minor problems within the big picture of the state of the world at the moment!

In spite of the problems that 2020 has brought, WCA members have continued to produce excellent science, to lead projects and publish results as later articles in this report show. Particular kudos to Niayesh for turning his modelling expertise towards Covid itself, helping with the collective global effort to understand and deal with the pandemic in the best way possible. I know some members of the WCA have struggled with stress at this time – I'm one of them – and I think that this is natural given the amount that's happening in the world. We're all only human and should do the best we can within those limitations – the WCA is here to support its members in whatever way we can – talk to me or someone else if you have concerns!

I would like to welcome our new members, Alex who is joining us on an AMTD fellowship, and Alexa on a WCA fellowship. Well done on making it across the border from the US, which I know was not straightforward! I hope that we can all soon meet in person to welcome you to the WCA.

Finally, as we move into the third year of the WCA let's take the lessons we've learned from this year, together with what we hope is a return to at least some of the previous normality, and push together to make the WCA stronger in the future. The future projects listed in this report show the promise of what's to come is very strong and I wish everyone a great 2021!

MISSION STATEMENT AND HISTORY

MISSION STATEMENT

The Waterloo Centre for Astrophysics looks to the cosmos to solve the greatest mysteries of the universe. World-class researchers and students come here in an atmosphere of curiosity, creativity and collaboration; exploring our cosmic origin to truly understand the physical processes at work in the Universe. From black holes to cosmology, we aim to understand what lies beyond the Earth. The possibilities for new discoveries are limitless.

HISTORY

The WCA is an initiative conceived by members of the faculty specialising in astrophysics to build upon the generous donation by Mike Lazaridis, which enabled a Distinguished Research Chair in Astrophysics, currently held by the inaugural WCA Director, Will Percival. The Waterloo Centre for Astrophysics was approved by the University of Waterloo Senate in November, 2018. One of the key roles of the WCA is to attract the brightest young scientists in the world to join us as postdoctoral researchers and work on cutting-edge astrophysical problems. The first two postdoctoral fellows joined the WCA in September 2019 and two more followed in October 2020.

CURRENT POSTDOCTORAL FELLOWS

ALEX KROLEWSKI

2020 ATMD Postdoctoral Fellow

Alex Krolewski earned his BA in Physics and Astrophysics from Harvard in 2015, and recently finished his PhD in Astrophysics at UC Berkeley in June 2020. His research focuses on testing cosmology and gravity from cross-correlations with current and upcoming galaxy surveys. Motivated by a variety of recent lensing measurements suggesting a lower amplitude of density fluctuations in the local universe than implied by the CMB, he has been working on measuring this amplitude and the universe's matter density using galaxies from the all-sky unWISE infrared imaging and Planck CMB lensing maps. He has also worked on clustering redshifts to determine the redshift distributions of photometric surveys, allowing their use in cosmological analyses even in the absence of photometric redshifts. Finally, he is planning for future cross-correlation efforts as a member of the CMB-S4, Simons Observatory, and DESI projects.

ALEXA VILLAUME

2020 WCA Postdoctoral Fellow

Alexa Villaume earned her PhD from the University of California Santa Cruz in 2020. She is now a WCA Fellow at the University of Waterloo. Her research focuses on developing and using precision stellar population synthesis models to understand star-formation and galaxy evolution processes using spatially resolved spectroscopy of distant galaxies and their globular cluster systems. She recently developed a statistical framework to model globular clusters systems around the most massive galaxies in the Universe. This model allows the globular clusters to be used to make more accurate inferences about the early star-formation in these galaxies and their subsequent assembly into the behemoths we see today.

GO OGIYA

2019 WCA Postdoctoral Fellow

The orbits of dark matter (DM) subhaloes moving in a larger DM host halo are essential in determining their spatial distribution and tidal evolution, key ingredients to unveil the nature of DM. Since Go Ogiya started the term in Waterloo last year, he has been developing a semi-analytical model to investigate the orbital evolution of subhaloes in a time-varying host halo potential. The analysis shows that the mass growth of the DM host halo shrinks subhalo orbits effectively. The model allows studying the spatial distribution of subhaloes within their host halo and provides implications for artificial subhalo disruptions in numerical simulations. The insight obtained from the analysis improves the theoretical scenario of tidal stripping describing the origin of the DM deficit galaxy that attracts plenty of scientists' attention. He studies the conditions to reproduce the observations with the tidal stripping scenario in detail.

ELENA MASSARA

2019 WCA Postdoctoral Fellow

Elena Massara earned her PhD from SISSA (Italy) in 2016 and she has previously held postdoctoral positions at the University of Berkeley (USA) and at the Flatiron Institute in New York (USA). Her research focuses on the study of the large-scale structure of the Universe with the aim of understanding the content and evolution of the Universe, and of studying the properties of neutrinos. Recently, she proposed a novel method — the marked power spectra — to extract cosmological information from the distribution of matter in the Universe. She showed that marked spectra with particular up-weighting schemes can improve the constraints on cosmological parameters by 2–3 times compared to standard analysis involving the power spectrum, and that marked spectra are particularly powerful in weighing neutrinos. She is now developing theory models for marked spectra and investigating the utility of this statistics in mock galaxy catalogs. She is also very interested in using cosmic voids — the emptier regions of the Universe — to study fundamental physics. She is developing a new method to measure the growth of structure using cosmic voids.

OUTREACH

NOTABLE EVENTS OF 2019/20

(copied from the WCA twitter feed @UWaterlooAstro)

October 4, 2019 – Public talk by Christine Jones Forman on "Black Holes, Dark Matter and Dark Energy: Exploring the Invisible Universe"

October 16, 2019 – Will Percival does podcast for UW daily bulletin

October 18, 2019 – Elena Massara sits on a Women in Science panel

October 30, 2019 – 5,000 fibre-optic "eyes" aimed at the night sky to capture the first images of galactic light

November 14, 2019 – Avery Broderick sits on a panel at CSPC2019 gala

November 18, 2019 – Ghazal Geshnizjani on CBC's Quirks and Quarks

November 27, 2019 – Go Ogiya gives guest lecture in Speech Communications class

December 2, 2019 – Elena Massara speaks at PhysiX: Girls Matter 2019

December 13, 2019 – Physics World names the first observation of a black hole as the top physics breakthrough of the year

January 2, 2020 – Black hole observation also named as one of UWaterloo's 10 Biggest Science Stories of the Decade

January 7, 2020 – Niayesh Afshordi awarded 2019 Buchalter Cosmology Award

January 14, 2020 – Richard Epp and Will Percival receive Outstanding Teaching Awards

January 21, 2020 – Niayesh Afshordi explains why gravitational wave echoes may confirm Stephen Hawking's hypothesis of quantum black holes. https://uwaterloo.ca/news/news/gravitational-wave-echoes-may-confirm-stephen-hawkings

January 24, 2020 – Go Ogiya interviewed for scientific article https://www.vice.com/en_uk/article/pkedvy/strange-dark-matter-findings-rewrite-universe-history

January 27, 2020 – The 2nd most cited #MNRAS paper of the decade was: Baryon acoustic oscillations in the Sloan Digital Sky Survey Data Release 7 galaxy sample by Will J. Percival et al. https://doi.org/10.1111/j.1365–2966.2009.15812.x… #SDSS #astronomy

March 5, 2020 – Brian McNamara awarded NASA's Group Achievement Award as a member of the Lynx Astrophysics Large Mission Study Team

March 9, 2020 – Michael Balogh awarded a CSA grant aimed at supporting analysis of data from Astrosat (which carries a Canadian Instrument, UVIT)

April 23, 2020 – Andrej Obuljen leads Galaxy Assembly Bias research

April 27, 2020 – Ghazal Geshnizjani is named Chair of Women in Math

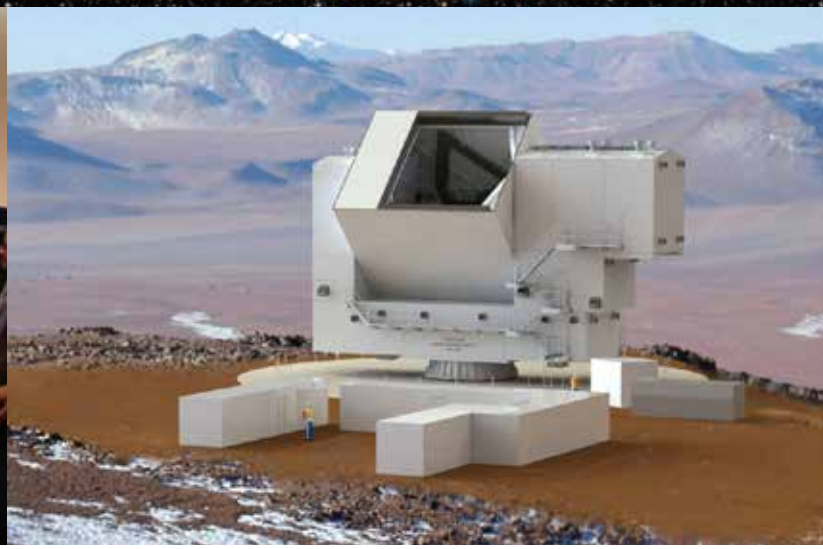
June 2, 2020 – Robert Mann and Mike Hudson both receive 2019 Outstanding Performance Awards

July 19, 2020 – Astrophysicists release largest 3D map of the universe ever created – Will Percival is a lead researcher on the work

July 28, 2020 – Niayesh Afshordi gives lectures at PI – "Managing the COVID19 Pandemic across Geography and Demography"

August 18, 2020 – Ghazal Geshnizjani is leading team and founding member of Supernova Foundation, a virtual mentoring programme in Physics

August 21, 2020 – Ghazal Geshnizjani and co-organizers were recently awarded $250,000 to run a Fields Institute program – as well as an additional $100,000 to support the participation of women and underrepresented groups



CONFERENCES HOSTED

CFU-WCA CONFERENCE

The inaugural meeting between the Perimeter Institute Centre for the Universe (CFU) and the Waterloo Centre for Astrophysics was held on February 21st, 2020. Theory talks were given at the University of Waterloo in the morning,with lunch provided, followed by observational talks at Perimeter in the afternoon and a joint dinner event. More talks were offered for this meeting than we could accept, and we had a difficult job cutting the talks down to fit within the allocated time. The meeting went well, with a series of excellent interesting talks, leading to significant discussion. The interactions led to a number of future collaborations between CFU and WCA members.

CCAT-PRIME COLLABORATION MEETING

The CCAT-prime telescope collaboration was scheduled to hold its first "Collaboration Meeting" April 7 and April 8, 2020. This meeting was to include participants from all of the partners, with a focus on the further development of the science program for this new facility. However the world shut down for the COVID-19 pandemic a few weeks before the meeting was scheduled to start.

The meeting team, led by Mike Fich (WCA), switched formats to a four-day, five hours/day format and were gratified by the huge increase in attendance: initially there were 41 people planning to attend the in-person meeting but by the end 103 people had joined the on-line meeting.

One of the main purposes of the meeting was to exchange the parameters of the various planned surveys. For example, one project that is planning a frequent mapping (every few days) of much of the sky to study the cosmic microwave background (CMB) was found to be very useful for another project searching for transients (things that change in brightness). The two teams found that a small change in the CMB survey – that had no negative effects on that survey – would enormously enhance the transients survey for essentially no additional science observing time. As such, this will significantly improve the efficiency of the telescope science program. Many other similar optimizations were found in comparisons of the proposed surveys.

In September, 2020 the CCAT-prime telescope was renamed the Fred Young Submillimeter Telescope (FYST) in honour of a long-time supporter of the project. Young

has given over $16M(US) to the project and has been an active member of the team for almost twenty years. Young is a Cornell alum in engineering but has had a life-long interest in astronomy. Besides his financial contribution Young has constantly encouraged the CCAT Observatory team and participated in multiple visits to the telescope manufacturer in Germany and the observatory site in Chile. He even joins the weekly science meetings! It is safe to say that without Fred Young's involvement this project would not have happened.

GOGREEN DATA RELEASE AND SCIENCE WORKSHOP

In August, the WCA hosted the annual workshop of the GOGREEN collaboration, a consortium of more than 30 researchers around the world, led by WCA faculty member Michael Balogh. The GOGREEN survey is a spectroscopic and imaging survey of 21 overdense galaxy systems in the redshift range $1 < z < 1.5$, when the Universe was only a third of its present age. The overdensities span a wide range of mass, from groups of only a few galaxies up to the most massive clusters at those early epochs. The spectroscopic program was approved in the first round of Gemini Large and Long Programs in 2014, with an unprecedented allocation of 438 hours on Gemini North and South. Originally planned as a three-year survey, the observations ultimately ran over ten semesters and were completed in mid-2019.

This year's workshop coincided with the first major public data release of the survey. To announce and celebrate this milestone, the first two days of the conference were opened to people outside the collaboration. Over 80 people attended to hear these presentations, which included an overview of the survey, a technical description of the data release, and several talks on the published and forthcoming science results. These latter included many talks from students and postdocs, including WCA members Karen McNab (MSc), Andrew Reeves (PhD) and Kristi Webb (PhD). All presentations from this public session are available as both recordings and pdf, at https://uwaterloo.ca/astrophysics-centre/gogreengclass-data-release-and-workshop-agenda. For more information about the survey itself, see the GOGREEN website, and list of published papers.

With the data release and publication of the main results, the collaboration is looking forward to the next steps in this research. In particular, the results indicate that the galaxies in these clusters must have been subject to a formation mechanism that is distinct from that of most galaxies, at a much earlier time. The place to observe this physics is in protoclusters at even higher redshift. To this end, day three of the workshop was a protocluster symposium, where several leaders in that field were invited to help chart the way forward. The James Webb Space Telescope expected to launch in October 2021, will open up the high redshift Universe to detailed study with its vast array of instrument modes. Canadians have a significant share of time in this amazing facility, thanks

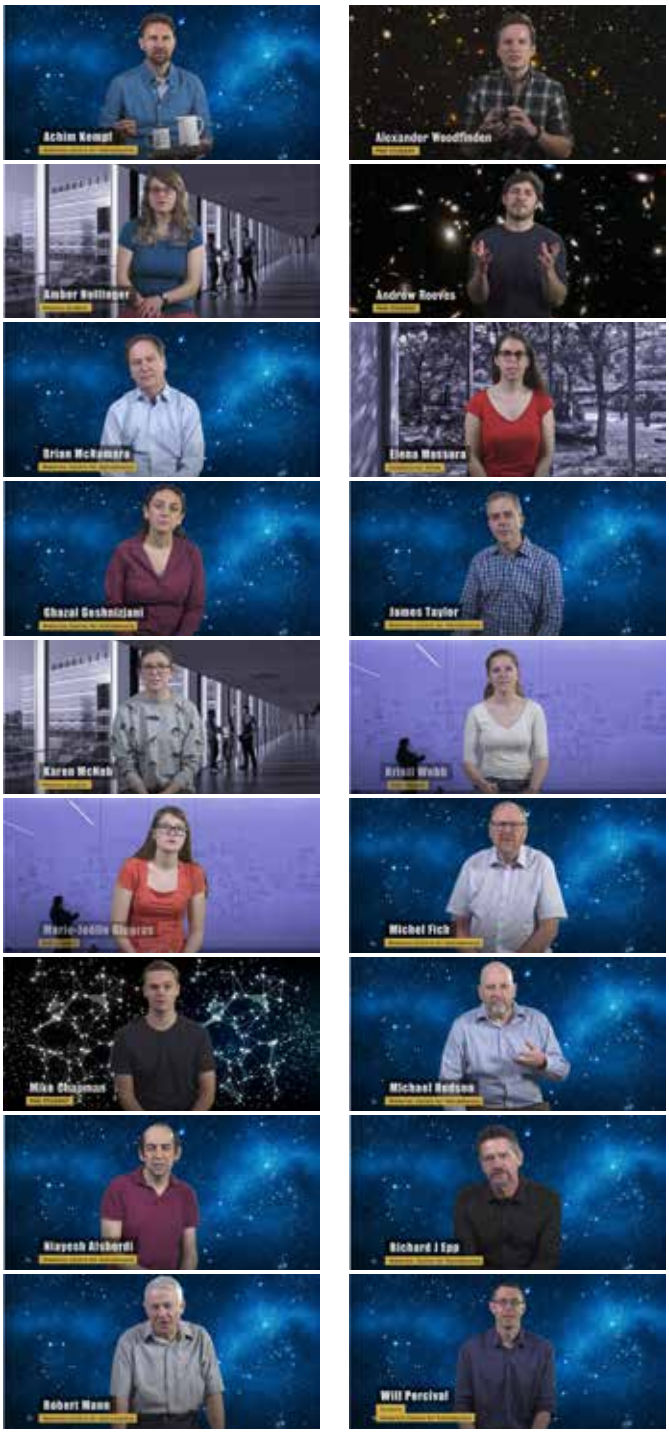
to their hardware contribution, and the GOGREEN collaboration and other WCA members are looking forward to using this telescope for a new era of discovery.

LAUNCH EVENT

The launch event for the WCA happened on the same day as our first Governing Board meeting (4 October 2019), and so it didn't make it into the last annual report, and therefore needs to be mentioned here! Our launch event consisted of three parts: a scientific meeting during the day and early afternoon, a formal inauguration including speeches by Will, the Dean of Science Bob Lemieux and the president of the University Feridun Hamdullahpur, and we finished with an excellent public talk by Christine Jones Forman in the early evening. We were planning that this would be the first of a series of public talks raising the profile of the WCA, but this was not possible due to the pandemic, and needs to be revised next year.

MEET OUR RESEARCHERS

One minute videos highlighting research areas



UPDATE ON FUTURE PROJECTS


CFIS

4MOST

The 4MOST Hemisphere Survey of the Nearby Universe (4HS) is a proposed ESO public survey to conduct a massive spectroscopic survey of the southern sky, obtaining spectroscopic redshifts up to 7.2 million galaxies, with very high (>95%) and unbiased completeness over 21 000 square degrees, and with a particular focus on the nearby Universe ($z < 0.15$). The review from the first proposal was very good, and a full proposal has been requested for Dec 15.WCA member Hudson is on the Proposal Planning and Review Team.

CFIS

Ultraviolet Near-Infrared Survey of the Northern Sky (UNIONS): is a large imaging survey of 5000 square degrees of the Northern Hemisphere, covering the sky in the 5 filters. This collaboration is a union of the Canada-France imaging Survey (CFIS), the Pan-STARRS and a Japanese-led collaboration (WISHES), which was recently awarded 40 nights to image in the z-band. WCA member Hudson leads the r-band component of CFIS, and is the lead of the weak lensing team. He, along with WCA member Balogh, are on the UNIONS Steering Group. In addition, Hudson led a successful 14-night Subaru Intensive Program Time proposal (via Gemini exchange) to acquire g-band data for UNIONS (and Euclid) from Subaru Hyper-Suprime Cam. The weak lensing team are in the final stages of releasing galaxy shape catalogues to the collaboration, with the first weak lensing papers expected in early 2021.

FYST

The Fred Young Submillimeter Telescope (FYST) (formally Cerro Chajnantor Atacama Telescope-prime (CCAT-p)) is a 6-meter aperture submillimeter wavelength telescope designed for very wide field observing. Construction began on November 1, 2018 and operations will start in 2023 (delayed from 2022 because of COVID-19). FYST will carry out several large-area surveys with a mapping speed unchallenged by any current or near-future facilities in the 150 to 1500 GHz telluric window. With FYST, we will be poised to make new discoveries and grow our emerging leadership in key areas of observational cosmology and fundamental physics as well as studies of the magnetic structure of our Milky Way galaxy. The rapid


FYST

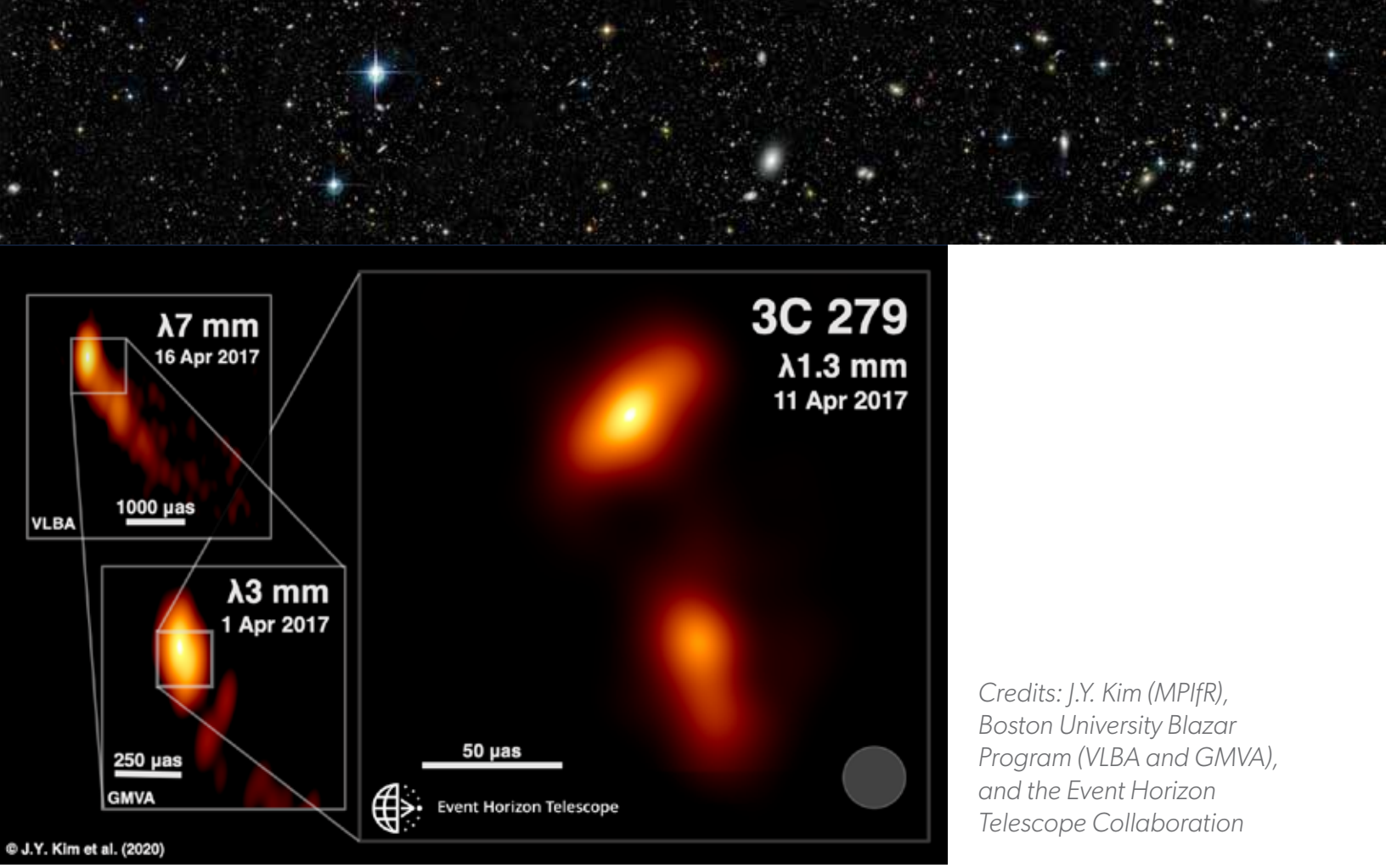

DESI

cadence surveys that were science goals since the start of this project will also permit a new, exciting, and unique science goal: a search for rapid submillimeter-wave transients.

The Canadian Team for FYST is led by WCA member Mike Fich and includes researchers at twelve other Canadian universities. An application has been submitted from UWaterloo to the Canada Foundation for Innovation (CFI) for an Innovation Fund 2020 grant to support the construction of FYST. This CFI grant, along with associated provincial grants, would be the main source of funding for the Canadian contribution to FYST construction. The total new Canadian funding requested is slightly over $9.4M. The largest expenditure required (slightly over $5M) will be for construction at the site of the observatory including assembly of the telescope, roads, power, and buildings. Other major expenses include a camera "module" for the main FYST instrument (prime-Cam) and software both for the observatory and for the instrument data reduction. Work to be done by WCA members includes project management, optics design work, and commissioning of the telescope and the prime-Cam instrument.

DESI

In October 2019, the installation of the Dark Energy Spectroscopic Instrument (DESI) on the Mayall telescope was completed, and commissioning began and has continued to date, albeit with a 6-month hiatus caused by the Covid-19 shutdown. Because of the complexity of the instrument, there are many components to test and to get working in harmony. Not least is getting the 5000 micro-motor based fiber positioners to place the fibers at the known locations of target galaxies in the focal plane (see photo above). Provided that the current phase of re-commissioning, which begins with the power-on of DESI on October 26 continues uninterrupted by Covid-19, we should see the next science-level observations mid-December, and DESI to start its survey proper in Spring of 2021. Ultimately, DESI will be able to cycle through a new set of 5,000 galaxies every 20 minutes, collecting a spectra for each. Will Percival serves as the Institutional Board representative for the at-large community (those scientists in DESI that are not from DESI institutes), and as a co-organiser of the Key Project creating the galaxy clustering catalogues. [Image: the focal place of DESI showing a subset of the 5000 positioners that move the ends of a fibre optic cables taking the light from target galaxies to the spectrographs].



Credits: J.Y. Kim (MPIfR), Boston University Blazar Program (VLBA and GMVA), and the Event Horizon Telescope Collaboration

EHT

WCA member Avery Broderick is a founding member of the Event Horizon Telescope (EHT) Collaboration, which is responsible for constructing, operating, and interpreting observations from a global array of high-frequency radio telescopes that together comprise the highest resolution telescope in history. Over the prior two decades, Avery laid much of the scientific groundwork for the historic observations. He now sits of the Board of the EHT and plays a central role in the science extraction.

This past year has seen the development of ground breaking advances in imaging techniques, retrospective studies of M87's "wobble" in light of the historic first image of a black hole horizon, and the surprising revelation that the quasar 3C 279 is much more complex than previously realized. Like M87, 3C 279 is home to a relativistic jet, a narrowly beamed collection of magnetic fields and plasma streaming away from a central supermassive black hole at very near lightspeed. Unlike M87, 3C 279 is much farther away and thus even the EHT cannot see the shadow cast by its horizon. Nevertheless, surprises abound.

In April 2019 the EHT published the first images of 3C 279 along with the first images of M87. In April 2020 the EHT published the first science results derived from the 3C 279 data. What all other instruments perceived as a sequence of bright blobs, the EHT resolved into two structure features, indicating conclusively that the journey of the luminous plasma was not nearly as straightforward as previously believed, and must "kink" along the way. Moreover, even over the single week of the EHT's observing campaign, 3C 279 moved, betraying motions that appear nearly 20 times that of light speed -- this is a trick of the light, an affect called "super-luminal motion" and closely related to the Doppler effect. Ultimately it demonstrates that on smaller scales the ever before probed in 3C 279 the jet must be moving at speed larger than 99.5% of light speed!

EUCLID


LSST

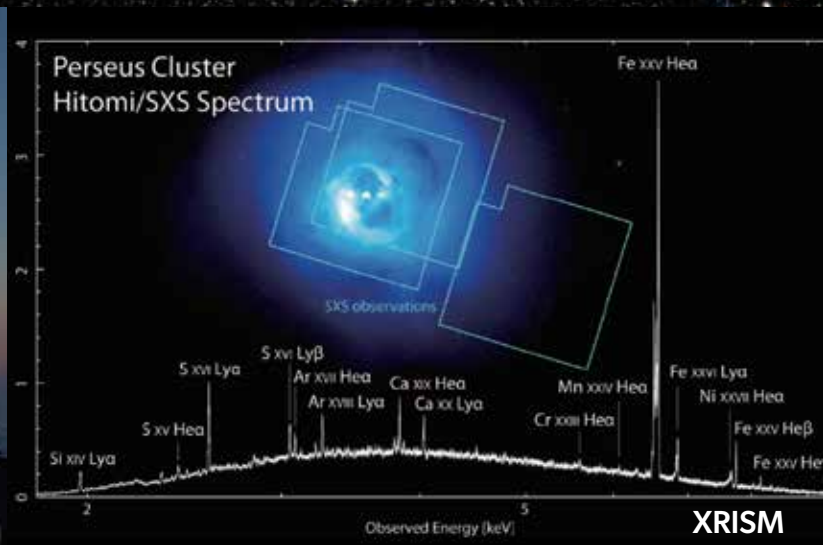
EUCLID

The cosmology-focussed satellite mission Euclid is set for launch on Sept 26, 2022 with potential delay due only to the ongoing Covid-19 crisis. The Payload module is being assembled with both VIS and NISP instruments now in place, and various Quality Assurance Reviews ongoing. As we countdown to launch, work within the scientific consortium intensifies, with calibration and survey reviews recently completed, and a number of software reviews scheduled for this year. The 15,000deg2 survey including visible and NIR imaging and spectroscopy to be provided by Euclid will be a game-changer in many fields of astronomy and will require careful and robust analyses. Within the Euclid consortium, Mike Hudson serves as the Canadian Euclid Consortium Board representative, and Will Percival serves as a co-lead of the Galaxy Clustering science working group, is one of four Science Coordinators for the consortium, with various other roles. Together with Euclid Consortium members Michael Balogh, and James Taylor they ensure that the WCA remains at the heart of the Euclid science. [Plot shows the integration of the Euclid telescope at Airbus.]

LSST

Construction of the Vera C. Rubin Observatory on Cerro Pachon, in Chile, is at an advanced stage, as shown in the accompanying image from August 2020. This US-led telescope (renamed since our last annual report), will conduct a ten year Legacy Survey of Space and Time (LSST). Revisiting each location on the sky multiple times over the course of the survey will provide not only very deep multicolour imaging of the entire Southern Sky, but also the ability to chart changing events on a range of timescales from days to years. This exploration of time domain astronomy opens up many opportunities for new discovery. Thanks in part to support from the University of Waterloo and the Faculty of Science, WCA members are participating in a CFI proposal, led out of the University of Toronto, to develop a data centre (CLASP) for integrating LSST data products with other survey data. If successful, this proposal will fund three Software Engineers and two LSST Science Fellows to reside at Waterloo and make technical and scientific contributions to the project. A decision about this proposal is expected soon. A parallel proposal is being prepared to offer CLASP as an in-kind contribution to the LSST survey, in return for membership and data access rights for Canadian researchers.

MSE



XRISM

MSE

The Maunakea Spectroscopic Explorer (MSE) is a Canadian-led initiative to transform the existing Canada France Hawaii Telescope into an 11-m wide field spectroscopic survey telescope. The 2020 Canadian Long Range Plan, made "unranked recommendations for MSE and the ngVLA: these two projects represent compelling future opportunities for Canada, which should be explicitly ranked once they have been fully developed". CFI ($24M) and Ontario Research Fund ($4M) proposals were submitted this year to support the preliminary design phase of this facility, with results expected mid-November. The CFI proposal included $780k of CFI envelope and $80k of institutional cash committed by Waterloo toward the project. These funds will go toward work on the software development, focusing on the data analysis pipeline. While MSE is the target, the design work will be generic and applicable to any 10-m class, highly multiplexed, fiber-fed spectroscopic facility. Percival co-leads the cosmology science working group for MSE and he, Balogh, and Hudson are members of the MSE science team. Current work by the team includes development of the Design Reference Survey, and work with various potential future stakeholders: for example, MSE submitted four Letters of Interest to the US Particle Physics Community Planning Exercise (a.k.a. "Snowmass"), including one co-led by Percival.

TMT

The top recommendation in the Draft Canadian 2020 Long Range Plan for Astronomy is that Canada "participate in a very large optical telescope (VLOT)… at a level that provides compelling opportunities for Canadian leadership in science, technology and instrumentation". Canada has been a major partner in the Thirty Meter Telescope since 2003, and received significant federal funding toward its construction in 2014. As one of only three planned VLOTs (the others are the European Extremely Large Telescope (ELT) and the Giant Magellan Telescope (GMT)), TMT promises decades of discovery, including the origins of galaxies, the growth of supermassive black holes, the nature of extrasolar planets, and the existence of extraterrestrial life. Construction has been delayed due in part to controversy over access to the preferred site, on Maunakea in Hawaii, and may not recommence (perhaps at an alternate site) until 2023 or later.

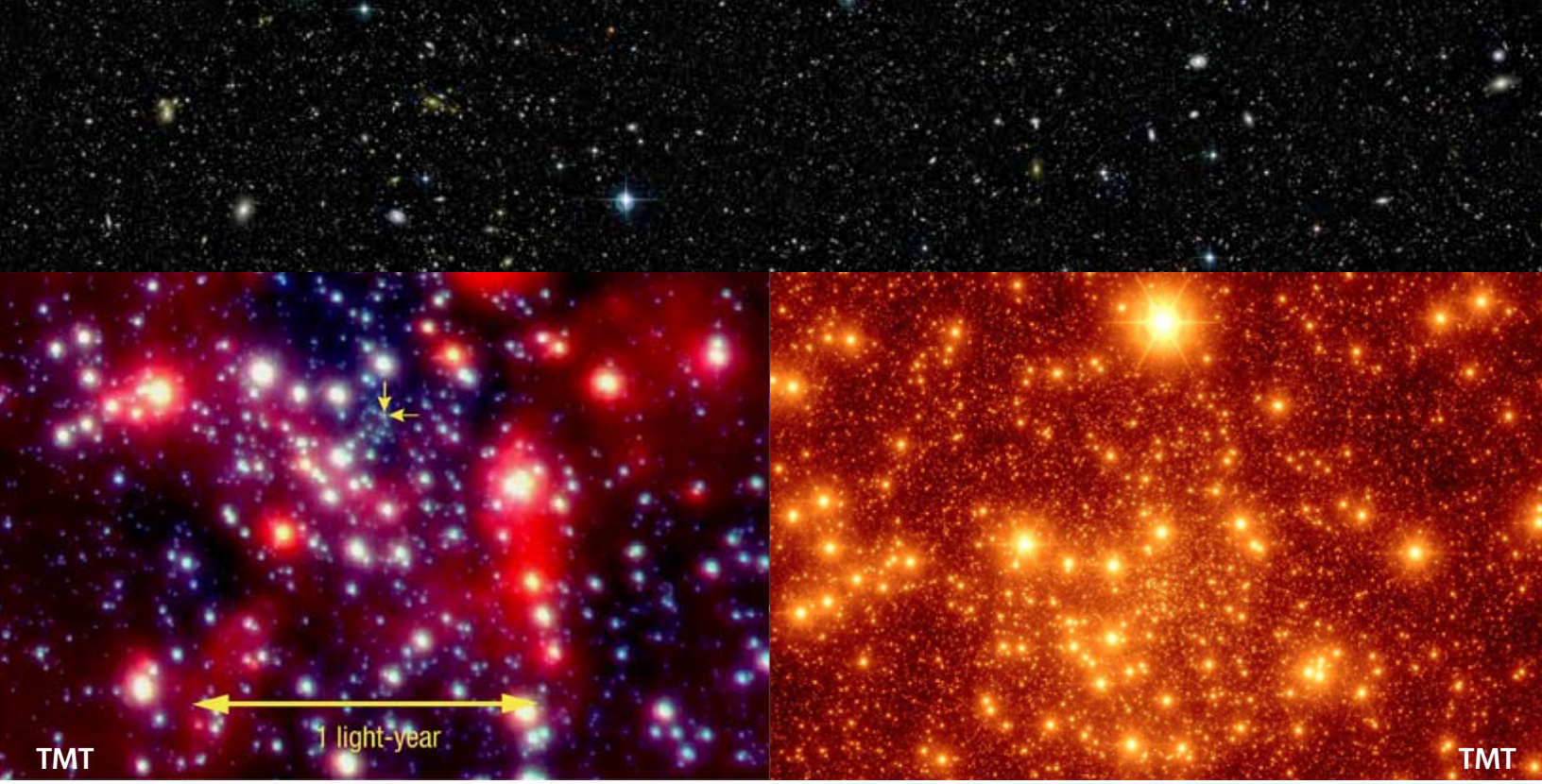


Image credits: Left – European Southern Observatory (ESO). Right – L. Meyer (UCLA)

Canadians have made critical technical contributions to the project, most notably in the design of the enclosure and the adaptive optics system (NFIRAOS). In particular, NFIRAOS is the facility that allows TMT to achieve the exquisite angular resolution afforded by a 30-m diameter mirror. As an example, the image shown here compares one of the best available views of the Galactic centre (left, from the 10-m class Very Large Telescope) with a simulation of the same field as it would be observed with TMT. Observations of stellar motions in this region resulted in the precise mass measurement of the supermassive black hole at the centre of the Milky Way, a discovery for which the 2020 Nobel Prize in Physics was recently awarded. TMT will detect and resolve more than 100,000 stars over the same area.

XRISM

The X-Ray Imaging and Spectroscopy Mission (XRISM) is an earth-orbiting X-ray observatory developed jointly by JAXA, NASA, ESA, and the Canadian Space Agency. Its prime camera, Resolve, provides non-dispersive spectroscopy with approximately 5 eV energy resolution in the 0.3-12 keV bandpass. XRISM is the successor to Hitomi, which yielded an unprecedented study of the dynamics of the X-ray atmosphere of the Perseus cluster. XRISM will study the X-ray atmospheres of galaxy clusters, young stars, and the gaseous environments of accreting black holes after it is launched in 2022.

McNamara serves on NASA's Resolve Instrument Team and is principal investigator for the agreement between NASA and the Canadian Space Agency entitled, X-ray Calibration for the NASA Resolve Instrument at the Canadian Light Source Synchrotron (CLS) Facility. This program supported facility upgrades and operation of the Canadian Light Source. Led by scientists from Goddard Space Flight Center and Lawrence Livermore National Laboratory, McNamara's team is performing Resolve filter transmission studies to calibrate the instrument. McNamara serves on the XRISM Science Team. McNamara's research team will use Resolve to perform detailed spectroscopic studies of the hot atmospheres of galaxies, clusters of galaxies, and accreting black holes.

RESEARCH HIGHLIGHTS

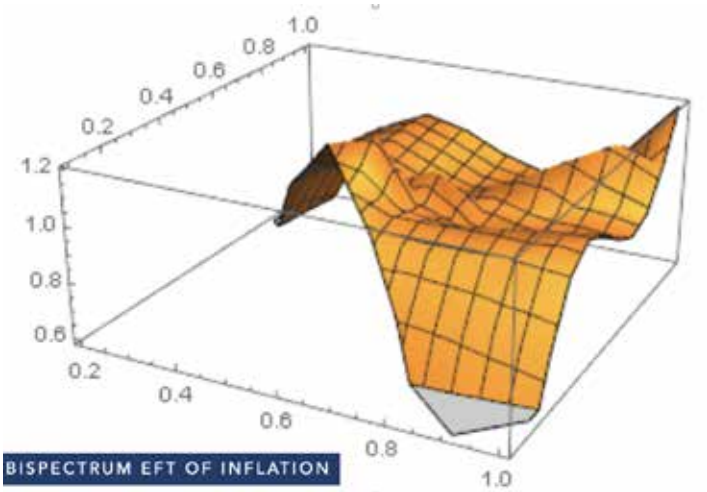
FACULTY HIGHLIGHT – GHAZAL GESHNIZJANI

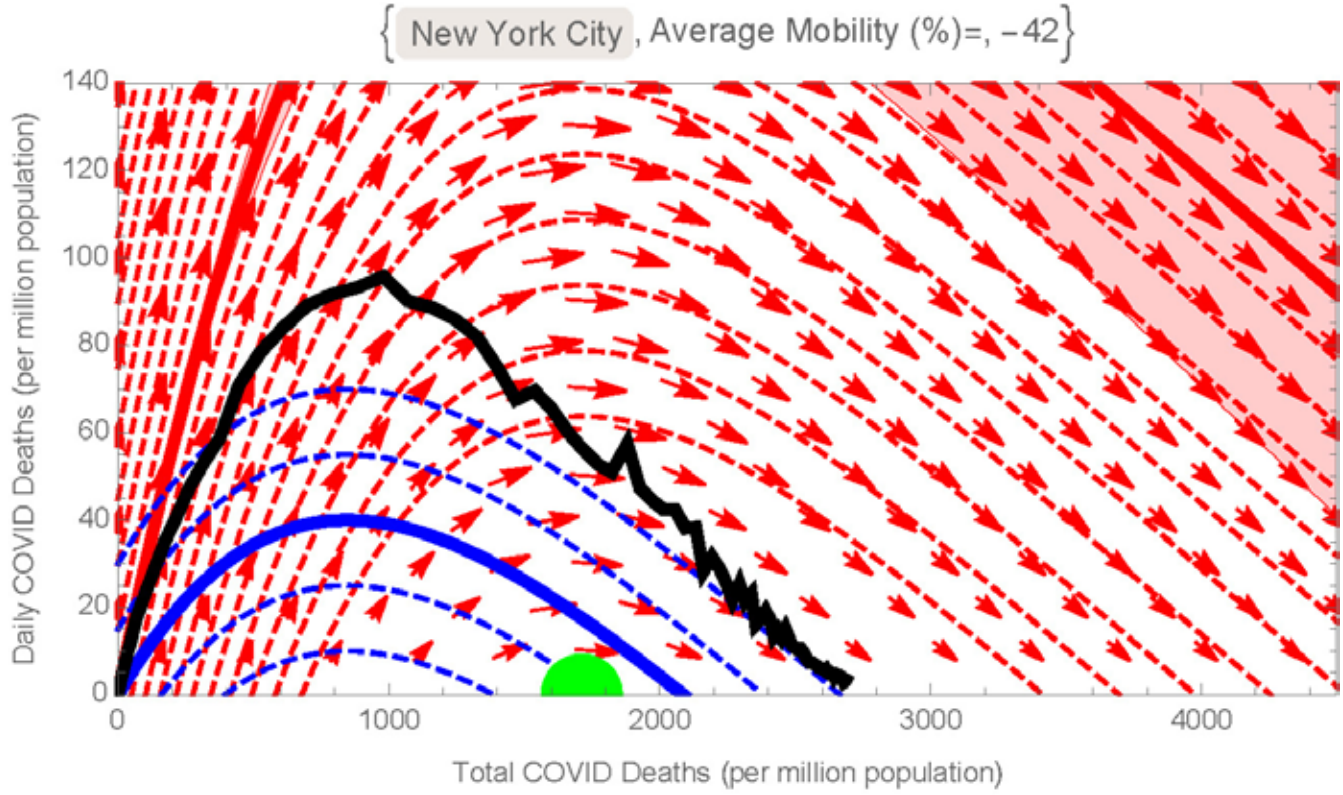
Professor Ghazal Geshnizjani is a member of the WCA with a cross-appointment in Applied Mathematics. Ghazal is currently the Chair of Women in Math and is also a leading team and founding member of Supernova Foundation, a virtual mentoring programme in Physics. She has supervised three graduate students and four undergraduate students this year with two more to come in the Winter term. Prof. Geshnizjani was awarded $250,000 CAD from the Fields Institute for Research in Mathematical Sciences. She and her co-organizers will run the program with an additional $100,000 CAD to support the participation of women and underrepresented groups. Ghazal also has a substantial Discovery Grant from the Natural Sciences and Engineering Research Council of Canada (NSERC).

Prof. Geshnizjani's main research program over the past year has been aiming at addressing two different but equally important puzzles in present day cosmology.

The first puzzle explores the beginning of the universe. The physics of the early universe is what determines how our cosmos looks like today. In the last couple of decades, the inflationary paradigm has gradually become the widely accepted theory to describe the initial conditions of the Universe. However, taking everything into account from theory to observations, one could argue that its compatibility within a larger theoretical high energy physics framework is far from certain. So, on one hand she has been trying to test the validity of the effective field theory and semi-classical gravity assumptions that are used in inflation and their consistency with current theoretical candidates to describe quantum gravity (Babic et al. 2020 as well as past and ongoing project with Hyungjin Kim) and on the other hand investigate whether an alternative model of the Early Universe can avoid these shortcomings and/or be less contrived. In particular, she has found a bounce solution within a modified theory of gravity called cuscuton that can potentially resolve the Big Bang singularity problem. Just recently, with her student Leo Kim, they showed that in a cuscuton bounce scenario scale-invariant entropy modes can be generated (Kim and GG 2020). As far as they are aware this is the first time that such a self consistent mathematical solution has been found.

In addition to contemplating on topics concerning the beginning of the universe, she has also been working on some exciting aspects of the recent cosmological history of our universe. With the remarkable and ongoing detection of gravitational waves since 2015, for the first time in the history of humankind, we now can make astrophysical observations independent of electromagnetic waves. With some of her other students, they are developing statistical inference models that can combine astrophysical electromagnetic surveys and data from the next generation





of gravitational wave experiments, in order to extract cosmological parameters. They have made some interesting progress over the past few months in this regard and Prof. Geshnizjani is expecting to publish some of their results in the next couple of months.

A NOVEL PREDICTIVE FRAMEWORK FOR THE NOVEL CORONAVIRUS

It would be hard to exaggerate the impact that COVID-19 pandemic outbreak, caused by the rapid spread of the SARS–CoV-2 coronavirus, has had on human civilization. Cascading effects from the impact of the pandemic on national healthcare systems, as well as the shutdown of a large fraction of global socioeconomic activity can further impact the health and livelihood of the world population and lead to secondary fatalities, as well as shortening and/or deterioration of lives. Therefore, it is of paramount importance to understand the true dynamics and efficiency of mitigation strategies, so that a proper, transparent, and balanced response can be designed and adopted by local governments across the world. Afshordi and his collaborators offer a new data-driven way of attacking this problem via a dynamical causal model informed by their unusual array of backgrounds in cosmology, quantum mechanics, and mathematical modeling. They have developed a physical model for the growth of the disease based on the collision of infected and susceptible populations in a community, with a cross-section+stochastic incubation of the virus. They then calibrate the cross-section and incubation, in terms of population demographics of the county, its Google social mobility, search trends, and weather, by comparing the model to the actual growth rates of COVID in all US counties. This leads to a powerful model that can be used to predict the growth/decay of pandemic in all local communities, through their online dashboard: https://wolfr.am/COVID19Dash . They hope this framework can be scaled up to more regions/data, and be used to inform smart region-specific policies to suppress and/or mitigate the pandemic and its adverse effects, and ultimately, save lives.

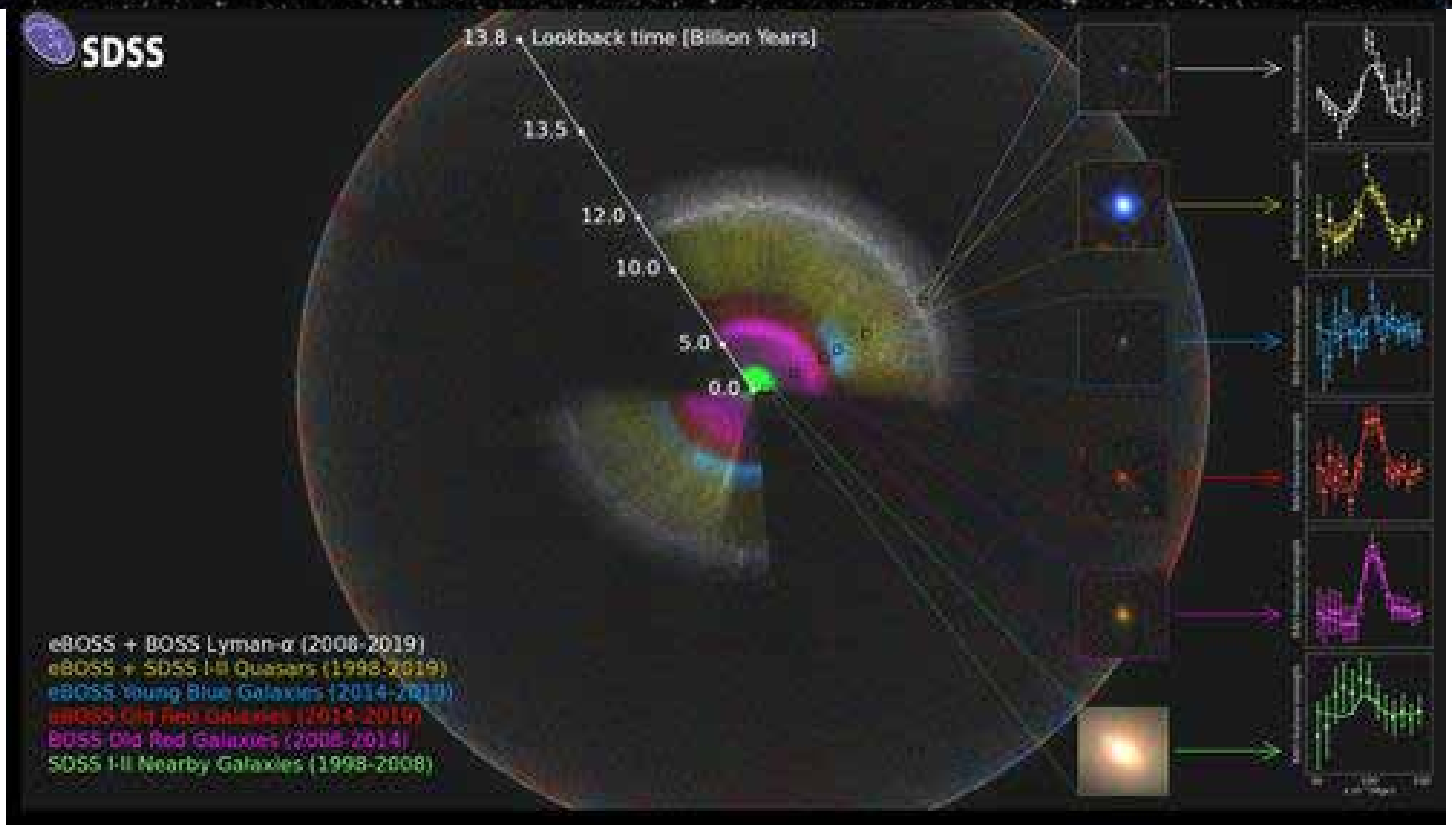


*Image credit: Anand Raichoor (EPFL), Ashley Ross (Ohio State University) and the SDSS Collaboration**

ASTROPHYSICISTS RELEASE LARGEST 3D MAP OF THE UNIVERSE EVER CREATED

In July this year, the eBOSS (extended Baryon Oscillation Spectroscopic Survey) team formally announced its final measurements, labelled Data Release 16. eBOSS is the last dedicated galaxy redshift survey to be produced as part of the Sloan Digital Sky Survey (SDSS), and represents the culmination of 20 years of effort, that has produced a series of galaxy surveys that now span a period of 11 billion years of cosmic history. Combining observations from eBOSS with studies of the universe in its infancy from the CMB reveals cracks in the standard cosmological model. In particular, the eBOSS team's measurement of the current rate of expansion of the universe (the "Hubble Constant") is about 10 percent lower than the value found from distances to nearby galaxies. The high precision of the eBOSS data means that it is highly unlikely that this mismatch is due to chance, and the rich variety of eBOSS data allows for multiple independent ways to draw the same conclusion. There is no broadly accepted explanation for this discrepancy in measured expansion rates, but one exciting possibility is that a previously unknown form of matter or energy from the early universe might have left a trace on our history.

Within the eBOSS team, individual groups at universities around the world focused on different aspects of the analysis. To create the part of the map dating back six billion years, the team used large, red galaxies. Farther

out, they used younger, blue galaxies. Finally, to map the universe eleven billion years in the past and more, they used quasars, which are bright galaxies lit up by material falling onto a central supermassive black hole. Each of these samples required careful analysis in order to remove contaminants and reveal the patterns of the universe. Faizan Mohammad, a postdoctoral researcher at the Waterloo Centre for Astrophysics at the University of Waterloo and an associate member of the Perimeter Institute, led one such analysis. "The hardware used to make the observations itself leaves an imprint on the map," said Mohammad. "It has been a lot of hard work to understand this imprint and remove it from the data, enabling robust measurements to be made about the universe." eBOSS, and SDSS more generally, leaves the puzzle of dark energy, and the mismatch of local and early universe expansion rate, as a legacy to future projects – such as the Dark Energy Spectroscopic Instrument (DESI) and EUCLID, a European Space Agency satellite mission.

23 papers were published on arXiv together on July 20, and a press release was sent out describing the work aimed at news outlets across the world. As Survey Scientist for the latest SDSS survey Will Percival played a big part in the coordination of these results, and the press interest that followed. In particular, he gave three interviews on prime-time Canadian TV networks (including the CBC National) describing the research, and a similar number of radio interviews. The press release was picked up by many news outlets (CNN, CBC, …) across the world and news articles were written about this work. In addition, four YouTube videos were released describing the work and providing a "fly-through" of the Universe, including two produced by the Perimeter Institute. Collective views currently stand at 880,000 for these videos.

BUDGET

	2018 – 2019	2019 – 2020	2020 – 2021	2021 – 2022	2022 – 2023	2023 – 2024	2024 – 2025
Admin salary	23.1	77	80	83	86	89	92
Postdoc salaries	1.2	146	219	365	365	292	146
Postdoc travel/ Moving	1.5	6	30	50	50	40	20
Visitors program	2.8	2.8	5	30	30	30	30
Operating	6.7	13	15	30	15	15	15
Total outgoings	35.3	244.8	349	558	546	466	303
TOTAL INCOME	504.2	550	550	550	550		
CUMULATIVE TOTAL	468.9	774.1	975.1	967.1	971.1	505.1	202.1

The table above reflects the WCA's actual spending in 2018–19 and 2019–20 with anticipated spending in the years to follow. For the first 5 years of the Centre, the income is $50k/annum from the Faculty of Science and $500k/annum from the Research stipend of the Director. In 2019, two 3-year postdoctoral fellows were hired. Two additional fellows were hired in 2020 but only one is funded by the WCA. The estimated budget will allow for two further 3-year fellows to be hired in each of the following two hiring cycles (2021–2022 and 2022–2023). The final two years show that the postdocs in the program would be able to complete their 3-year term without any additional income. Although we hope to continue this program through the acquisition of further funding.

If the LSST CFI grant is successful, we have agreed to host two LSST Institutional Fellows working 50% on LSST infrastructure supported by the CFI grant, with 50% supported by the WCA. In this case, we will reduce the number of WCA fellows supported by one. Obviously, we will look at other ways to extend the reach of the WCA money

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JAMES TAYLOR

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FACULTY MEMBERS, STUDENT AND POSTDOC REPRESENTATIVES

WILL PERCIVAL, DIRECTOR

Professor Percival's research interests focus on the properties of the Universe on the largest scales. Surveys of three-dimensional galaxy positions provide a wealth of data both on the physics just after the Big-Bang when the seed fluctuations that will grow through gravity to become galaxies were created, and on the physics driving the evolution of the Universe today.

NIAYESH AFSHORDI

Dr. Afshordi dabbles in Astrophysics, Cosmology, and Physics of gravity and is obsessed with observational hints that could help address problems in fundamental physics.

MICHAEL BALOGH

Professor Balogh's research uses the world's largest telescopes to study the physical properties of distant galaxies. Through spectroscopy we can learn about the distances, ages, chemical composition and star formation histories of these galaxies. As the light we observe from more distant objects originated at earlier times, by observing ever more distant systems we can reconstruct the changes that occur over time to populations of galaxies. His particular expertise lies in trying to understand the source of the puzzling link between galaxy growth rates and surrounding large-scale structure, many orders of magnitude larger than the galaxies themselves.

AVERY BRODERICK

Dr. Broderick works to explain the fundamental physics of black holes and their observable characteristics. Black holes are sites where strong gravity dominates everything, from the dynamics of orbiting material to the shape of spacetime itself. As a result, they are the engines that power some of the brightest objects in the universe. Broderick works on scales spanning from the horizon to the cosmos, tied together by the unique physical conditions near black hole horizons.

RICHARD EPP

Current research interests: Geometrical, quasilocal frame approach to the problem of motion in general relativity. Ultimately, application to gravitational waveform prediction from compact, dynamic sources.

MICHEL FICH

Dr. Fich is an astronomer specializing in studies of star formation, the interstellar medium, and the structure of galaxies. His recent research activities have focused on "small scale" formation studies of low and intermediate mass stars, circumstellar disks, and the formation of proto-solar systems.

GHAZAL GESHNIZJANI

Prof. Geshnizjani's research has so far included tackling different aspects of theoretical cosmology such as investigating inflationary and bouncing scenarios, models of dark energy, modifications of general relativity, backreaction of metric perturbations, cosmic strings in extra dimensions and initial conditions for quantum fluctuations. While mathematically intertwined, these research topics aim at understanding the theoretical puzzles about our cosmos in different phases of its evolution.

MICHAEL HUDSON

Broadly speaking, Professor Hudson's research is in observational and theoretical cosmology, particularly Galaxy Formation, and measuring the properties of dark matter and dark energy through Gravitational Lensing, Cosmic Flows and Large-scale Structure.

ACHIM KEMPF

Prof. Kempf is currently particularly interested in opportunities for using cosmological observations to test theories that try to unite quantum theory and general relativity. The approach is based on the current understanding that, according to inflationary cosmology, all structure in the universe ultimately originated in tiny quantum fluctuations that were stretched to cosmological size during the initial very rapidly accelerated expansion of the universe. These virtual quantum fluctuations are thought to have become definite classical fluctuations when they were still almost as small as the Planck scale, which is where the laws of physics are dominated by quantum gravity effects. This provides opportunities to test quantum gravity theories by predicting and measuring possible modulations in the distribution of structure in the universe, included in the cosmic microwave background.

ROBERT MANN

Professor Mann works on gravitation, quantum physics, and the overlap between these two subjects. He is interested in questions that provide us with information about the foundations of physics, particularly those that could be tested by experiment.

EDUARDO MARTIN-MARTINEZ

Prof. Martin-Martinez's research combines the fields of quantum information science, quantum field theory and general relativity; studying quantum effects induced by gravity from the perspective of quantum information to gain information about the spacetime structure. This approach has a wide range of potential outcomes and applications from quantum computing technology to the basic physics of the question of how the spacetime curvature and quantum theory impact the flow and the processing of information and cosmology.

BRIAN MCNAMARA

Giant black holes weighing upwards of one billion times the mass of the Sun are thought to lurk at the centers of all massive galaxies. Energy released by spin breaking and infalling matter onto such supermassive black holes may be regulating the growth of galaxies and clusters of galaxies.

ANDREJ OBULJEN

Andrej Obuljen is a postdoctoral fellow at the University of Waterloo working with Prof. Will Percival. He has earned his PhD degree at SISSA (Italy). His main research interest is studying the Large-scale Structure of our Universe using either future 21cm Intensity Mapping or upcoming spectroscopic galaxy surveys (e.g. DESI) in order to better constrain main cosmological parameters. Andrej is the postdoc representative for the Waterloo Centre for Astrophysics.

JAMES TAYLOR

Dr. Taylor is using whatever tools he can, including numerical simulations, astrophysical theory and observational data, to try to figure what dark matter is, where it is, and how it behaves. His research includes gravitational lensing and dynamical studies of galaxy clusters, the properties of the smallest galaxies in the local universe, and the theory behind dark matter halos around galaxies and clusters.

STEVE WEINSTEIN

Prof. Weinstein's research is primarily in the foundations of physics, with special interests in the nature of time and the interpretation of quantum mechanics.

KRISTI WEBB

Kristi is a second year PhD student at the University of Waterloo working with Dr. Michael Balogh. She is the graduate student representative for the Waterloo Centre for Astrophysics. Kristi earned her bachelor's degree from the University of Victoria. Her research interests are in galaxy evolution, and her project focuses on observations of galaxies in different environments.

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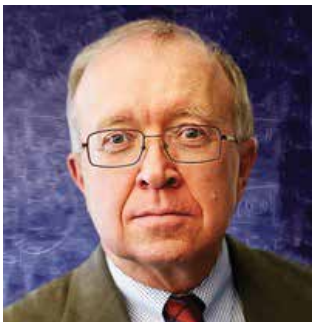

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