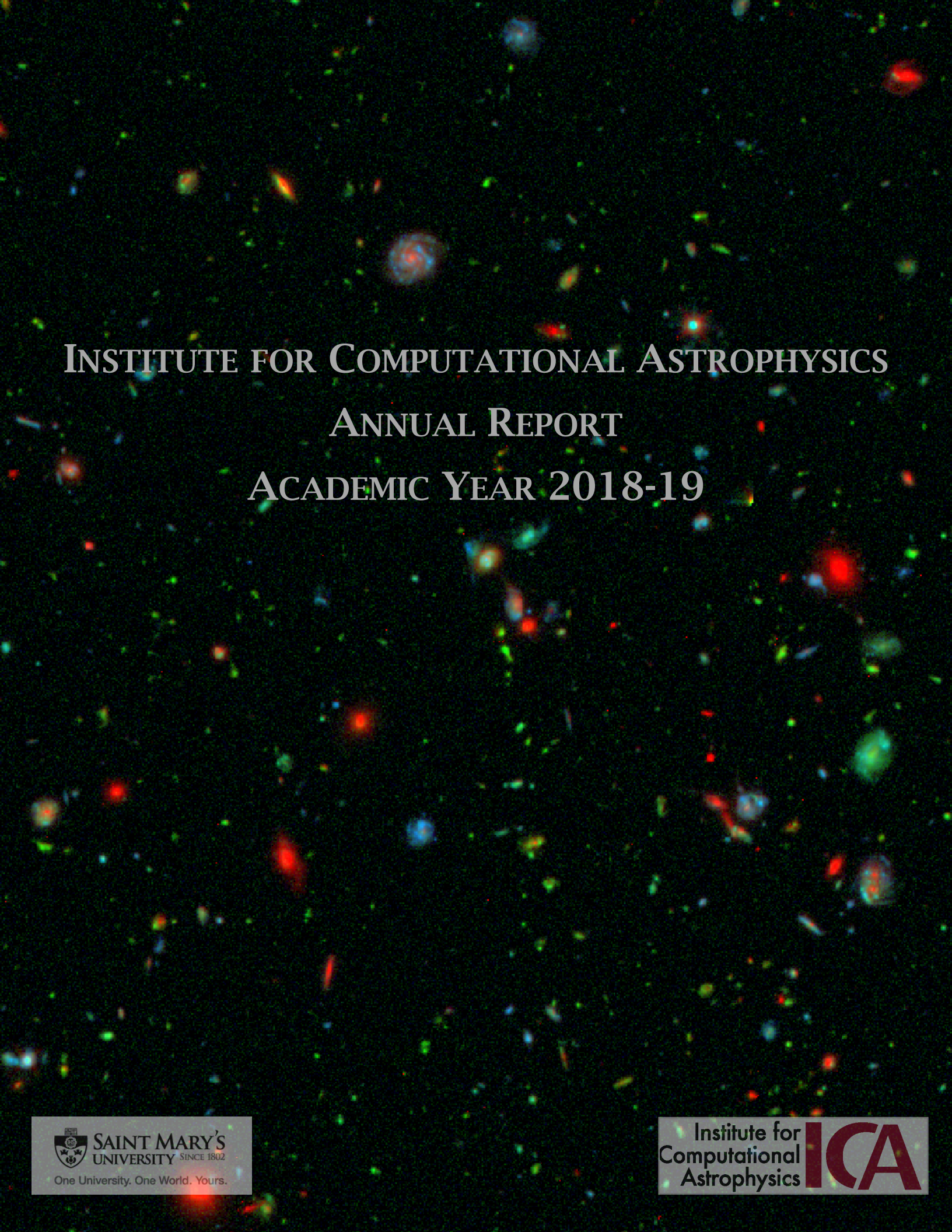

Institute for Computational Astrophysics
Annual Report
Academic Year 2018-19

Saint Mary's University Since 1802
One University. One World. Yours.

Institute for Computational Astrophysics ICA

On the cover

New advances of knowledge about the Universe will depend on the next generation of cutting edge instruments. During the 2018-19 academic year, several ICA members contributed to the development — sponsored by the Canadian Space Agency — of the proposed Canadian-led CASTOR international space telescope. As part of this effort, ICA undergraduate student Martin Hellmich used ACEnet / Compute Canada High Performance Computing (HPC) resources to produce simulations of what CASTOR and another planned space telescope — NASA's WFIRST — will be able to observe in combined survey projects.

Our cover image shows a part of Mr. Hellmich's simulation of the CASOR+WFIRST view of the distant Universe. In this image, realistic galaxies — based on Hubble Space Telescope observations that were earlier characterized by (now former) ICA graduate student Dr. Robert Sorba — were simulated in the CASTOR-U (blue) CASTOR-G (green) and WFIRST-IR (red) bands. Ing this three-colour composite image, WFIRST-IR (red) detects old, existing stars inside of galaxies, while CASTOR-U is particularly sensitive to star-forming regions where new stars are being born. These simulations illustrate the power and synergy of these planned future space observatories to study where and how stars form inside of galaxies in the distant Universe. It also highlights how HPC computing used by ICA researchers contributes to this effort to develop future international tools of discovery.

CONTENTS:

Overview

The ICA was created in 2002 to promote the study of complex astrophysical phenomena by numerical simulation, a remit which was broadened in 2014 to also include large-scale astrophysical data analytics. Throughout the past decade the ICA has acquired access, through ACEnet and Compute Canada (organizations in which several ICA members have played very significant roles), to significant high performance computing resources required for these simulations and analysis. A number of graduate students have been part of the ICA, and to date fourteen MSc degrees and eight PhD degrees were awarded to students supervised by ICA faculty members. In addition, the ICA has enriched the environment of the Department of Astronomy and Physics and of the University by hosting twelve postdoctoral fellows to date as well as numerous research visitors.

As of August 2019, the ICA has four full time faculty members, each of whom is also a faculty member in the Department of Astronomy and Physics: Dr. David Clarke, Dr. Marcin Sawicki (who became ICA's Acting Director in December 2018), Dr. Ian Short, and Dr. Robert Thacker. Two emeritus faculty members, Dr. Robert Deupree and Dr. David Guenther, continue their affiliation with the ICA. Additionally, in Academic Year (AY) 2018-19 ICA hosted a long-term sabbatical visitor, Dr. Ikuru Iwata, Associate Director of the giant Subaru Telescope of the National Astronomical Observatories of Japan (NAOJ), who chose Saint Mary's / ICA for his sabbatical location.

There were eleven research students working with ICA faculty during AY 2018-19: seven graduate students (Liz Arcila-Osejo, Lingjian Chen, Daniel Cunningham, Mitch Young, Tiffany Fields, Angelo George, Paresh Mungara) and four undergraduates (Savannah Cox, Martin Hellmich, Jason Bayer, and Harrison Soucherau). Two postdoctoral fellows, Dr. Thibaud Moutard and Dr. Gaël Noirot, were affiliated with ICA faculty. Ms. Florence Woolaver served as the ICA Assistant for a 12th year, splitting her support roles between the Department of Astronomy and Physics (70%) and the ICA (30%). Connected to the ICA are two ACEnet employees located at Saint Mary's: Mr. Phil Romkey and Mr. Sergiy Khan.

At present, the ICA is beginning a period of renewal that follows the retirements of two key members, Dr. Bob Deupree (inaugural ICA Director) and Dr. David Guenther (founding ICA member). Their retirement has resulted in a decreases of faculty-level ICA members to four, along with an associated decrease in research activity and in the number of students and post-doctoral fellows being supervised. Time-consuming administrative roles held by ICA faculty — e.g., Dr. Short is the Department Chair and Dr. Thacker the Science Outreach Centre Director — take a further toll on research activity. However, very recent faculty hires in the Department of Astronomy and Physics are aligned with the ICA mandate and we anticipate that these new researchers will be joining the Institute and will help expand its research activity.

Research Activity

The primary objective of the ICA is to engage in research activity, the key metric for which in our field is publication of research results in peer-reviewed journals. All of the ICA faculty members maintain active research programs involving graduate or undergraduate students and, in some cases, postdoctoral fellows. All faculty not only publish papers in high quality, high-impact refereed literature, but also serve as referees for many of these journals. These journals include Astrophysical Journal (ApJ, with Impact Factor, IF = 8.4), Astronomical Journal (AJ, IF = 5.5), Astronomy & Astrophysics (A&A, IF = 6.2), and Monthly Notices of the Royal Astronomical Society (MNRAS, IF = 5.2). Eleven peer-reviewed papers by ICA members were published during AY 2018-19 and several more are in press or undergoing peer review. A full list of these publications is given in a separate section of this report.

In the remainder of the present section we describe in detail the research activities undertaken by ICA faculty and those of the associated students, postdocs, and long-term visitors.

Dr. David Clarke's principal research interests include performing magnetohydrodynamical (MHD) simulations to investigate open problems in astrophysics, as well as maintaining and providing the astrophysical community with the widely-used MHD code ZEUS-3D. Dr. Clarke continues to work on the problem of stellar jets, a phenomenon associated with very early star formation. Jets are supersonic, narrow beams of magnetised gas that "proto-stars" launch along their rotation axes to very great distances

(several million times their own diameters). They have profound influence both on how the proto-star evolves to a "main-sequence star" (the bulk of those we see in the night sky), and the environment in which the young stars are formed. Without jets, for example, stars as we know them could not exist, and we would not be here to discuss them.

Based on several very extensive simulations of a rotating MHD gas under the influence of a central gravitational field, former ICA graduate student Dr. John Ramsey and Dr. Clarke have recently published a paper describing how a protostellar jet forms on length scales too small to see with the most powerful telescopes, and then propagates out to distances large enough to observe. These simulations were the first-of-their-kind in the world, and posed an extremely challenging computational problem since length scales with a dynamic range of nearly six orders of magnitude had to be accommodated within the same simulations.

When gases attain a high enough temperature (e.g., stellar coronae), the atoms become ionised and the fluid — now known as a plasma — becomes an ensemble of charged particles. As such, a plasma is capable of generating and sustaining a magnetic field that permeates the gas, and this same magnetic field confines the charged particles in a way that particles in an ordinary gas like our atmosphere are not. The prominences from our own sun are an excellent example of this phenomenon. Ambipolar diffusion (AD) is a process by which charged matter can escape the confines of a magnetic field, and can have profound implications in astrophysics. It can mitigate how stars form, and how stellar jets — Dr. Clarke's particular focus — evolve and influence their environment. Dr. Clarke's former Honours students — Michael Power and Chris MacMackin — made significant progress on the theoretical aspect of AD, and Dr. Clarke continues working on a manuscript to report these findings.

While ZEUS-3D is a mature code that can be downloaded from its own website (www.ap.smu.ca/~dclarke/zeus3d) complete with installation and user's manuals, a distributable version of its successor, AZEuS (with adaptive mesh refinement) is still under development. Undergraduate student Savannah Cox worked with Dr. Clarke on a project to develop what is known as tensor artificial viscosity for ZEUS-3D. This technique should help alleviate some minor outstanding numerical issues with the code and, if successful, will be incorporated into AZEuS.

Dr. Marcin Sawicki's research interests lie in the formation and evolution of galaxies, with a specific interest in their earlier evolution, the so-called "high redshift universe". This research allows us to look back in time to when the Universe and its content were only a fraction of their present age. Dr. Sawicki's specific interest is related to obtaining, processing, and analysing the large data sets ("Big Data") created in massive surveys of distant galaxies. Over the past several years much of his research time has been spent in relation to the CLAUDS survey (a major Canada-France-China observing collaboration that he leads) done with the Canada-France-Hawaii Telescope (CFHT), and its combination with the HyperSuprime-Cam Subaru Survey Program (HSC-SSP) being taken on Japan's national Subaru Telescope by a large team of Japanese, Taiwanese, and American astronomers. Together, these two surveys probe the distant Universe to an unprecedented combination of area and depth that will be unmatched until at least the next decade. The merged CLAUDS+GSC catalogs, which were recently finalized and validated, form or will form the foundation of a number of scientific investigations; they will also be released publicly world-wide, where they will enable many more investigations by the community. Indeed, many leading research teams from the US, Europe, and Japan have already contacted the CLAUDS team seeking early access to these data. For more information on the CLAUDS project see https://www.ap.smu.ca/~sawicki/sawicki/CLAUDS.html.

Working with Dr. Sawicki, PhD candidate Anneya Golob continued her thesis research on the CLAUDS project part-time as she works full-time as Data Scientist at RubiCloud. She has submitted to MNRAS a paper that describes the machine learning code for distinguishing stars from galaxies in deep images, and is finalizing her research on the evolution of the galaxy stellar mass function in the CLAUDS+HSC-SSP dataset.

Lingjian Chen has defended his MSc thesis working under the supervision of Dr. Sawicki. This work, subsequently submitted for publication to MNRAS, investigates the radial distribution of satellite galaxies around massive central galaxies using data from the CLAUDS+HSC-SSP database.

Dr. Thibaud Moutard, under the supervision of Dr. Sawicki, has been working on producing the most detailed to date study of the evolution of the galaxy UV luminosity function using the CLAUDS+HSC-SSP dataset. This work has been submitted to

MNRAS in the fall of 2019. Dr. Moutard has also been studying the mechanism responsible for the slow quenching of massive galaxies by examining the x-ray hardness ratios in the so-called green valley — a transitional region of parameter space that galaxies cross as they quench their star formation; this work shows that galaxy-galaxy mergers are a symptom (rather than cause — as is thought by some) of the quenching process.

Dr. Gaël Noirot has started his postdoctoral appointment in January 2019 working under the supervision of Dr. Sawicki on preparing the software tools that will be needed for the analysis of slit-less grim spectroscopy that will come from the James Webb Space Telescope, Hubble's much more capable successor. In addition to (and as part of) this work, he has began the analysis of archival Hubble Space Telescope (HST) grism spectra of z>1 galaxies that are in the process of quenching. In the meantime, he is also continuing his research on the properties of distant galaxy clusters using HST data.

Dr. Liz Arcila-Osejo has published in MNRAS the first paper from her PhD thesis done under the supervision of Dr. Sawicki. This paper concerns the number density of massive quiescent galaxies at "cosmic noon" — the epoch of peak cosmic star formation. A follow-on paper led by another recent ICA graduate, Ms. Gurpreet Kaur Cheema, has been submitted to MNRAS; this investigates the clustering of the ultra-massive galaxies' from Dr. Arcila-Osejo's sample and finds that these massive z~1.6 monsters are associated with the most massive dark matter concentrations known at these early epochs and that are destined to evolve into massive present-day galaxy clusters such as Virgo and Coma. A third paper in the series, led by Dr. Sawicki and to be submitted to MNRAS in 2019, investigates the environments of these ultra-massive galaxies and finds that they have likely grown through major galaxy-galaxy mergers at early times and will continue to grow only through minor mergers into the future.

Dr. Ikuru Iwata, ICA sabbatical visitor from the National Astronomical Observatory of Japan, has been investigating the escape of ionizing radiation from distant galaxies and Active Galactic Nucleii (AGN), publishing two papers on this topic during his visit to the ICA. A further paper. He has also contributed to the data calibration of the CLAUDS survey, interacting with ICA students and postdocs, and he and Dr. Sawicki (along with several co-authors) have been working on a measurement of the escape of ionizing radiation from distant AGN in the CLAUDS+HSC survey.

MSc student Angelo George and undergraduate student Harrison Souchereau were supervised jointly by Dr. Ivana Damjanov and Dr. Sawicki and were working on the morphological analyses of galaxy images in both CLAUDS+HSC-SSP data and other datasets using ACEnet computing resources. Mr. George is performing parametric morphological fits using the GALFIT software, while Mr. Souchereau extracts non-parametric light profiles using ellipse-fitting algorithms. The results of these measurements will form the foundations of both students' theses to be completed in the 2019-20 academic year.

Dr. Short has continued to develop novel codes for the computational modelling and visualization of stellar atmospheres and spectra, and related observables, in effectively platform-independent or web-oriented programming languages such as Python, Java, and Javascript (the Chroma+ suite). In 2019 he collaborated with Honours student Jason Bayer (now an MSc student at UWO) to improve the Chroma+ suite in three ways: (1) The treatment of how partition functions are approximated; these allow the code to quickly calculate the fraction of many chemical elements that are in each ionization stage, and are necessary to compute the strength of spectral lines in stellar spectra. (2) The treatment of spectral lines based on species-wise model atoms rather than the traditional line list – this allows for a more complete inclusion of the physical mechanisms that broaden spectral lines. (3) The ability to compute limb darkening curves that describe the variation of brightness across the resolved projected disk of a star through a variety of photometric filters. This is an important first step toward generating transit light curves of extra-solar planets for arbitrary star/planet combinations.

Dr. Short also collaborated with Dr. Philip Bennett (Saint Mary's University, Dalhousie University, and Eureka Scientific) to implement a major improvement to how the Chroma+ suite computes the chemical and ionization equilibrium, and the equation of state relating the gas pressure, density, and temperature, throughout a stellar atmosphere. This involved porting a FORTRAN code (GAS) developed by Dr. Bennett, and related linear algebra library (BLAS and LINPACK) routines to Python, Java, and Javascript, and integrating it into the Chroma+ codes. The spectacular result is that these codes can now quickly compute the partial pressures of 105 chemical species self-consistently, including many diatomic and

polyatomic molecules, for cool stellar atmospheres. Users of ChromaStar and ChromaStarServer can very quickly visualize these partial pressures versus depth in a web browser on demand. A related improvement was to increase the number of TiO bands included in the computed spectra – these are the most important bands determining the appearance of the stellar spectra of late-types stars (red dwarfs and giants) in the visible band. See www.ap.smu.ca/OpenStars for additional information.

MSc student Tiffany Fields and Dr. Robert Thacker examined the relationship between local instability and global chaos in galactic disks. The goal of this research was to see whether local measures, such as the balance between local gravity vs processes that counteract gravity, like gas pressure, can serve to prevent the build-up of chaotic dynamics in the interstellar medium. This research is comparatively novel and relies upon techniques that were first used in atmospheric dynamics. In the end it was shown that the precise methodology needed did not work well in gas that has exceptionally large density contrasts like the interstellar medium. MSc student Mr. Parash Mungara is continuing this work with Dr. Thacker but in a different vein: they are looking to measure how atomic cooling processes can contribute to stochasticity in structure formation at various mass scales.

Finally, the ICA has also contributed to the development of future astronomy research infrastructure. A number of ICA members, as well as two non-ICA Departmental faculty, have contributed to a CSA-funded science maturation study for the proposed Canadian-led CASTOR space telescope. These include Dr. Sawicki, Dr. Moutard, Dr. Iwata and honours thesis student Mr. Martin Hellmich, as well as Dr. Damjanov and Dr. Luigi Gallo from the Department. In particular, Mr. Hellmich, working under the supervision of Dr. Sawicki, has produced realistic simulations of CASTOR (and WFIRST) deep imaging; this work has resulted in Mr Hellmich's honours BSc thesis (and features on the cover page of this Report). Meanwhile, Dr. Iwata assessed the promise of CASTOR for studies of Lyman Continuum escape from high-redshift galaxies, and Dr. Moutard investigated its usefulness for studying the mysterious blue bump in galaxy spectra. Additionally, in another instrumentation-related project, Dr. Sawicki is participating in the development of the Gemini Infra-Red Multi-Object Spectrograph (GIRMOS) — a major future instrument being built for the Gemini Observatory in Hawaii. In this role, Dr. Sawicki is leading the design of the instrument's data reduction pipeline and observation planning tools — tools that will form a crucial component of this major new instrument.

Service Activity by ICA Members

Members of the ICA play significant roles in service to the University and the community on local, national, and international levels. Some of these activities are summarized here.

Dr. Short has served as Department Chair for the Department of Astronomy & Physics. Dr. Thacker served as Director of the Saint Mary's Science Outreach Centre, as Acting Dean of Science for Student Affairs, and on the University Pension Committee (where he Chairs the Investment Subcommittee). Dr. Clarke has chaired the Department's 15th annual undergraduate summer research mini-symposium in September 2018, served as the science representative to the University's Copyright Committee; served as the Department's Science Atlantic representative; organized the Department's student participation in the 2019 Atlantic Universities Physics and Astronomy Conference held in Wolfville, NS; and participated in the Science Majors Day. Additionally, Drs. Clarke, Sawicki, and Short served on the Departmen's tenure-track faculty search committees this year, Drs. Sawicki and Short contributed to the Department's Graduate Program Review, and all four regular ICA faculty contributed to developing and implementing changes to the Department's Undergraduate Program that follow that Program's review.

On the national scene, Dr. Thacker served as President of the Canadian Astronomical Society, which entailed an extensive amount of travel and consultation with government and industry; in this role he also co-Chaired the Coalition for Canadian Astronomy and served on the Longer Range Plan Implementation Committee for Canadian astronomy, on the CASCA-ACURA Thirty Metre Telescope (TMT) Advisory Committee, and on the CASCA-Canadian Space Agency's Joint Committee on Space Astronomy. Dr. Thacker is also a Board member of the Association of Canadian Universities for Research in Astronomy (ACURA) and the SMU institutional representative to the ACURA Council. Finally, Dr. Thacker is a Director of the Royal Astronomical Society of Canada, the premier amateur association in

the country. Also at the national level, Dr. Sawicki serves on the Science Management Committee of the Canadian Advanced Network for Astronomy Research (CANFAR) and on the Management Committee of the CFI-funded GIRMOS instrument project.

On the international level, Dr. Sawicki serves on the Board of Director's of the Gemini Observatory, one of the premier world observatories with 8-metre-class telescopes located in Chile and Hawaii.

Upcoming ICA Activities

The current ICA complement is in a low state following the retirement of two key ICA faculty, Drs. Robert Deupree and David Guenther. Consequently, the Institute is looking towards a period of renewal in its staff and research portfolio. In this regard, the Department has recently recruited two new astrophysics faculty to fill vacancies left by the retirement of Drs. Deupree and Guenther. These new hires are Dr. Ivana Damjanov and Dr. Vincent Henault-Brunet. Both Dr. Damjanov and Dr. Hanault-Brunet have indicated that they are interested in becoming ICA members and we hope that they will be joining the Institute in the near future. This injection of "new blood" will re-invigorate the ICA, and will allow the Institute to expand further in the direction of big data analytics that also forms the backbone of the Department's recently-adopted Strategic Plan for 2019–2024.

ICA Financial Statement

There was no spending in the ICA budget in AY 2018-19. At the start of September 2019, the ICA fund contains $12,223.

Peer-reviewed Publications by ICA members

Names of ICA faculty and associated students and post-docs are highlighted in **boldface**.

Papers published in peer-reviewed journals during AY 2018-19:

Arcila-Osejo, L., Sawicki, M., Arnouts, S., **Golob, A.**, **Moutard, T.**, Sorba, R. *LARgE Survey. I. Dead Monsters: The Massive End of the Quiescent Galaxy Mass Function at z~1.6*, MNRAS, 486, 4880

Basset, R., Ryan-Weber, E.V., Cooke, J., Diaz, C.G., Nanayakkara, T., Yuan, T.-T., Spitler, L.R., Meštrić, U., Garel, T., **Sawicki, M.**, Gwyn, S., **Golob, A.** *On the Lack of Correlation between [OIII]/[OII] and Lyman Continuum Escape Fraction,* MNRAS, 483, 5223

Hayashino, T., Inoue, A. K., Kousai, K., Kashikawa, N., Mawatari, K., Matsuda, Y., Tejos, N., Prochaska, J. X., **Iwata, I.**, Noll, S., Burgarella, D., Yamada, T., Akiyama, M. *Enhancement of H I absorption associated with the z = 3.1 large-scale proto-cluster and characteristic structures with AGNs sculptured over Gpc scale in the SSA22 field,* MNRAS, 484, 5868

Iwata, I., Inoue, A.K., Micheva, G., Matsuda, Y., Yamada, T., *Subaru narrow-band imaging search for Lyman continuum from galaxies at z > 3 in the GOODS-N field*, MNRAS, 488, 5671

Kiehbadroudinezhad, S., Bousquet, J-F., Cada, M., **Short, C.I.**, Shahabi, A., Kiehbadroudinezhad, S., *Expansion of a Y-Shaped Antenna Array and Optimization of the Future Antenna Array in Malaysia for Astronomical Applications* Journal of Modern Physics, 10, 888

Kiehbadroudinezhad, S., Cada, M., Chen, Z., Shahabi, A., **Short, I.**, Abidin, Z.Z., and Kiehbadroudinezhad, S., *Concentric Circles and Spiral Configurations for Large Correlation Arrays in Radio Astronomy*, AJ, 156, 177

Lacaille, K.M., Chapman, I. Smail, C.C. Steidel, S.C., Blain, A.W., Geach, J., **Golob, A.**, Gurwell, M., Ivison, R.J., Reddy, N., **Sawicki, M.** *A SCUBA-2 Survey for Luminous Far-Infrared Galaxies in Protoclusters at z>2,* MNRAS, 488, 1790

Moutard, T., Sawicki, M., Arnouts, S., **Golob, A.**, Adami, C., Coupon, J., Ilbert, O., & Malavasi, N. *On the fast quenching of young low-mass galaxies to z~0.6: new spotlight on the lead role of environment,* MNRAS, 479, 2147

Ramsey, J.P., and **Clarke, D.A.**
MHD simulations of the formation and propagation of protostellar jets to observational length-scales
MNRAS, 484, 2364

Simpson, J.M, ... **Sawicki, M.,** et al.
The East Asian Observatory SCUBA-2 Survey of the COSMOS Field: Unveiling 1147 Bright Sub-Millimetre Sources Across 2.6 Square Degrees,
AJ, 880, 43

Siwak, M, Winiarski, M, Ogłoza, W, Dróżdż, M, Zoła, S, Moffat, A.F.J., Stachowski, G, Rucinski, S.M., Cameron, C., Matthews, J.M., Weiss, W.W., Kuschnig, R, Rowe, J.F., **Guenther, D.B.**, Sasselov, D. *Insights into the inner regions of the FU Orionis disc,* A&A 618, A79

Papers Submitted or in Press:

An, F.X., ..., **Sawicki, M.**, et al. *Multi-Wavelength Properties of Radio And Machine-Learning Identified Counterparts of Submillimeter Sources From S2COSMOS*, ApJ, submitted

Cheema, G., Sawicki, M., **Arcila-Osejo, L., Golob, A., Moutard, T.**, Arnouts, S., & Coupon, J.
LARgE Survey. II. Dark Matter Halos of Ultra-Massive Quiescent Galaxies at Cosmic Noon
MNRAS, submitted

Golob, A., Sawicki, M., Goulding, A., & Coupon, J.
Classifying Stars, Galaxies, and AGN with Gradient Boosted Trees, MNRAS, submitted

Helavi, G., Greene, J., Goulding, A., Coupon, J., **Golob, A.,** Gwyn, S., Johnson, S.D., **Moutard, T., Sawicki, M.**, Suh, H., Toba, Y., *HSC-XD 52: A low-mass X-ray detected AGN at z~0.56*, ApJL, submitted

Lim, C.-F., ..., **Sawicki, M.**, et al.
SCUBA-2 Ultra Deep Imaging EAO Survey (STUDIES) III: Source catalog, multi-wavelength properties, and luminosity functions of 450-μm-selected galaxies, ApJ, submitted

Moutard, T., Malavasi, N., **Sawicki, M.**, Arnouts, S., & Tripathi, S. *On the slow quenching of M* galaxies: heavily-obscured AGN clarify the picture*, MNRAS, submitted

Sawicki, M., Arnouts, S., Huang, J., Foucaud, S., Coupon, J., **Golob, A.**, Gwyn, S., **Moutard, T.,** **Iwata, I.**, **Chen, L.**, Harikane, Y., Liu, C., Ono, Y., **Thibert, N.**, et al. *CFHT Large Area U-band Deep Survey (CLAUDS),* MNRAS, in press

Sulis, S., Dragomir, D., Lendl, M., Bourrier, V., Demory, B. O., Fossati, L., Cubillos, P. E., **Guenther, D. B.**, Kane, S. R., Kuschnig, R., Matthews, J. M., Moffat, A. F. J., Rowe, J. F., Sasselov, D., Weiss, W. W., Winn, J. N. *Multi-season optical modulation phased with the orbit of the super-Earth 55 Cnc*
A&A, in press

Young, M.E., Short, C.I. *NLTE Stellar Population Synthesis of Globular Clusters using Synthetic Integrated Light Spectra III: Optical Sensitivity and Observed Galactic Globular Cluster Analysis*, submitted