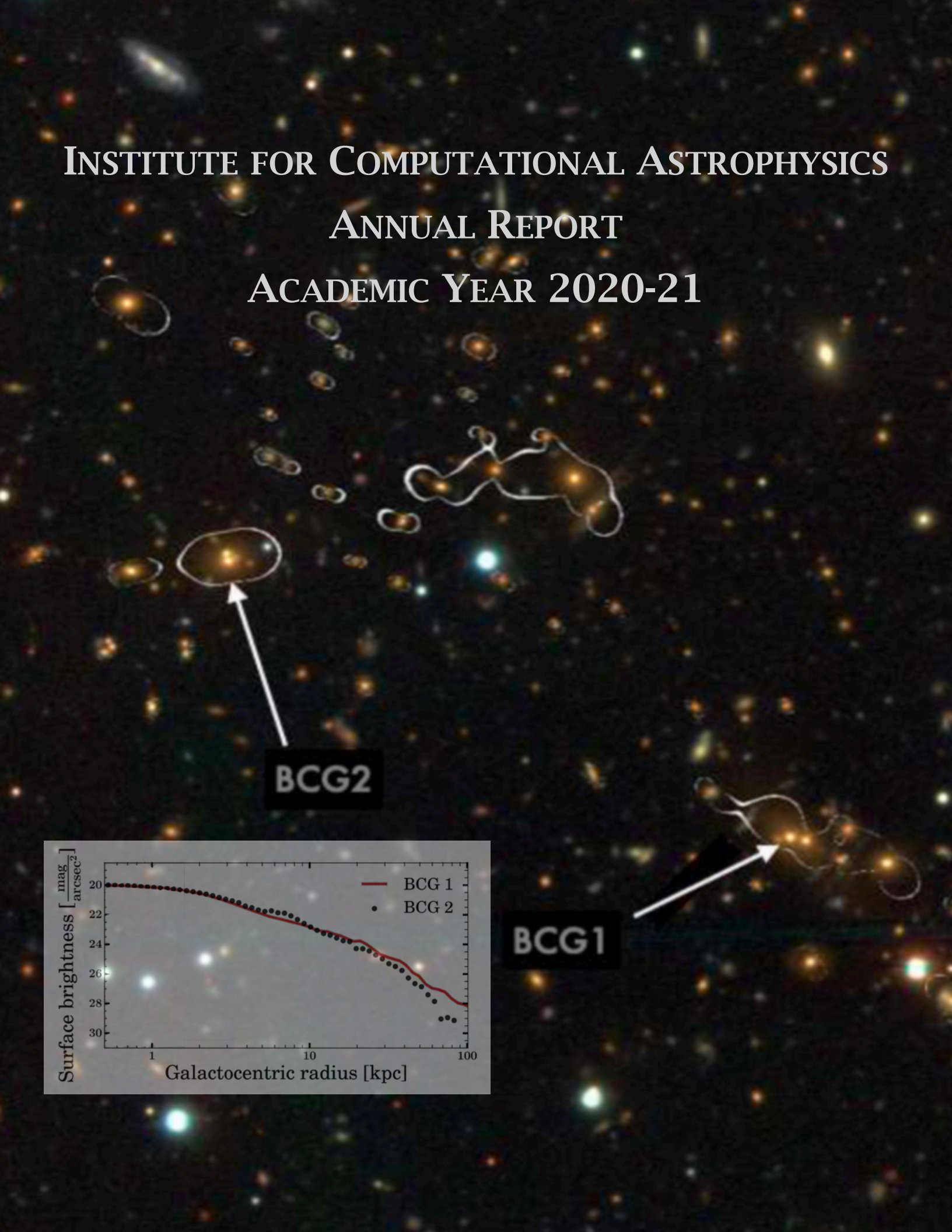
Institute for Computational Astrophysics
Annual Report
Academic Year 2020-21



ICA Annual report, compiled by Marcin Sawicki, Acting Director

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ON THE COVER

The cover image shows a distant cluster of galaxies observed with the Hyper Suprime-Cam (HSC) instrument on the Subaru Telescope in Hawai`i and used by ICA member Dr. Ivana Damjanov and her colleagues in their studies of the formation of some of the most massive galaxies in the Universe.

This galaxy cluster contains not one but two brightest cluster galaxies (BCGs), a sign that it recently merged with another cluster. The two BCGs and other galaxies in the cluster are embedded in massive haloes of invisible dark matter. Due to their mass, luminous and dark matter act as gravitational lenses: they bend the light coming from more distant galaxies, creating multiple distorted images and increasing their brightness. The white closed curves in the image show the regions of maximum magnification caused by this effect and indicate how dark matter is distributed within the cluster.

The inset graph shows the change in the amount of light coming from the two BCGs with the distance from their centres. Taken together, the observed distribution of light from the BCGs and the positions and shapes of lensed images around them can trace the assembly history of luminous and invisible component in some of the most massive galaxies we see in the Universe.

Image credit: Ivana Damjanov (ICA/SMU), Jubee Sohn (Harvard-Smithsonian CfA), Adi Zitrin (Ben Gurion University of the Negev), and the HSC SSP team.

1. Overview

The ICA's mission is to promote the study of complex astrophysical phenomena by numerical simulation, a remit which also includes 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. More recently, the ICA has also engaged in the processing and analysis of large astrophysical datasets and in the development of software in support of new astronomical instruments. A number of graduate students have been part of the ICA, and to date seventeen 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 fourteen postdoctoral fellows to date as well as numerous short- and long-term research visitors.

As of August 2021, the ICA has six full-time faculty members: Dr. David Clarke, Dr. Ivana Damjanov, Dr. Vincent Hénault-Brunet, Dr. Marcin Sawicki (Acting ICA Director), Dr. Ian Short, and Dr. Robert Thacker. Additionally, two emeritus faculty members, Dr. Robert Deupree and Dr. David Guenther, continue their affiliation with the ICA, while Dr. Ralph Pudritz (McMaster University) and Dr. Richard Henriksen (Queen's University) serve as external members of the Institute in which role they provide invaluable advice to the Institute.

There were eleven research students working with ICA faculty during AY 2020-21: five graduate students (Lingjian Chen, Angelo George, Kamalpreet Kaur, Paresh Mungara, Nolan Dickson) and six undergraduates (Ophélie Leste, Peter Smith, Devin Williams, Abigail Battson, Tasha Clowater, Tashveena Surdha). Three postdoctoral fellows (Drs. Gaël Noirot, Nick Martis, and Johannes Zabl) and a full-time research assistant (Mr. Harrison Souchereau) were affiliated with ICA faculty, while Among the three postdoctoral fellows, two (Dr. Martis and Dr. Zabl) joined the ICA in AY 2020-21, and a third (Dr. Vicente Estrada-Carpenter) is schedued to join in September 2021, highlighting the rebuilding of the research capacity in the ICA.

Ms. Shannon Rhode serves as the ICA Assistant, splitting her support duties between the ICA (30%) and the Department of Astronomy and Physics (70%). Finally, connected to the ICA are two ACEnet employees located at Saint Mary's: Mr. Phil Romkey and Dr. Sergiy Khan.

Of recent ICA alumni, former postdoctoral fellow, Dr. Thibaud Moutard is now in a postdoctoral position at the Laboratoire d'Astrophysique de Marseille, and research assistant Harrison Souchereau is starting his PhD studies at Yale University. Both continue their affiliation with the ICA.

At present, the ICA continues to be in its period of renewal that follows the retirements of two key members, Dr. Bob Deupree (inaugural ICA Director) and Dr. David Guenther (founding ICA member). The retirement of these two founding ICA members has resulted in the decrease of faculty-level ICA members to four in recent years, 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 SMU Science Outreach Centre Director, President of the Canadian Astronomical Society (CASCA), and SMUFU Chief Negotiator — have taken a further toll on research activity. However, two new faculty, Drs. Ivana Damjanov and Vincent Hénault-Brunet, joined the ICA at the end of AY 2019-20, and their presence is already rejuvenating the Institute and will continue to do so as the research programs and teams of these new faculty members grow over the coming years.

During AY 2019-20 the ICA carried out a self-study as part of the Senate-mandate periodic review. This activity has charted a new direction for the Institute, namely that of growing the ICA's activity in the direction of Astrophysical Data Analytics (for details, see the ICA's 2020 Self-study Report). This direction is closely aligned with, and indeed drives key elements of the strategic plan of the Department of Astronomy and Physics. In particular, in addition to the resulting expansion in research scope and activity (see Section 2), ICA faculty Drs. Damjanov

and Hénault-Brunet introduced course-based training in astrophysical data analytics for both undergraduate and graduate students at SMU. Additional ICA activities related to Astrophysical Data Analytics are under development and will be introduced in AY 2021-22.

2. Research

ICA members engage in research in a number of areas of astrophysics using a range of techniques. These range from numerical modelling to the analysis of complex datasets and development of new instruments and techniques, and tackle topics from the atmospheres of stars to the formation of galaxies soon after the Big Bang.

2.1. Stellar atmospheres

During AY 2020-21, Dr. Ian Short has continued to develop and test novel codes for the computational modelling and visualization of stellar atmospheres and spectra, and exoplanet transit lightcurves, and related observables, in effectively platform-independent or web-oriented programming languages such as Python, Java, and Javascript (the Chroma+ suite).

Dr. Short continued to collaborate with Dr. Philip Bennett (Saint Mary's University and Dalhousie University) 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 integrating the Python port of Bennett's GAS procedure it into the Chroma+ codes so that they can now quickly compute the partial pressures of 105 chemical species self-consistently, including many diatomic and polyatomic molecules, for cool stellar atmospheres. During this reporting period we documented this work with a mathematically intensive paper that was accepted by PASP. Students in the graduate course in Stellar Atmospheres and Spectra will use the code in Fall 2021 to model stellar atmospheres and Spectra and to analyze the modelling results. See www.ap.smu.ca/OpenStars for additional information.

2.2. Magnetohydrodynamics of jets

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

When gases attain a high enough temperature (e.g., stellar coronae), their 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. Dr. Clarke continues to work on the development of AZEuS.

Finally, turning to related pedagogy, Dr. Clarke has submitted his textbook manuscript, "A First Course in Magnetohydrodynamics and Other Topics in Fluid Dynamics" to Cambridge University Press. This is a major work that includes ten chapters and

eight appendices, along with a 200-page document containing some 120 worked problems..

2.3. Star clusters

Dr. Hénault-Brunet's research programme uses a combination of dynamical models, statistical methods, and observations (spectroscopic, photometric, and astrometric) to tackle open questions about the dynamics of globular star clusters and related astrophysical implications, in particular: (1) the demographics of stellar- and intermediate-mass black holes in globular clusters and their contribution to observed rate of gravitational wave events, and (2) unveil the conditions under which globular clusters formed in the early Universe, in particular their initial stellar mass function, densities, and the possible role of dark matter in their formation/evolution.

Some of the research topics pursued during the reporting period include:

A survey of the stellar kinematics in the outer regions of globularc clusters. A series of collaborative workshops coordinated by Dr. Hénault-Brunet in previous years resulted in two successful observing proposals (using the 2dF/AAOmega instrument on the Anglo-Australian Telescope, and the FLAMES instrument on the VLT in Chile) to obtain spectroscopy of hundreds of stars in the outskirts of several Milky Way globular clusters. The kinematics of stars in these external regions of globular clusters can reveal crucial information about their interaction with the Milky Way, including possible traces of dark matter around clusters.

A first paper (led by PhD student Zhen Wan; University of Sydney) introducing the survey and presenting a detailed analysis of a first cluster (NGC 3201) was published earlier this year. The study analyzes the signature of stars escaping from the cluster and casts doubts on a recent suggestion that NGC 3201 is surrounded by a small dark matter halo. In the context of her honours thesis, SMU undergraduate student Tashveena Surdha studied the chemistry of stars in NGC 1851, a cluster for which VLT-FLAMES spectroscopy was obtained as part of this survey. She showed that the metallicity distribution of stars in the far outskirts of the cluster is very similar to that of stars close to the centre, placing useful constraints on formation scenarios for this system. These results will be combined with a similar analysis performed on other clusters and form the basis of a publication currently in preparation.

Dr. Hénault-Brunet's group continues to investigate ways to robustly infer the size of present-day black hole populations in Milky Way globular clusters by using observations of the velocities and spatial distribution of visible stars, which are affected by the presence of black holes. Undergraduate research assistant Peter Smith and graduate student Nolan Dickson have developed tools to explore how the precise timing of pulsars in the core of globular clusters (probing their acceleration in the cluster's gravitational potential) can improve these constraints. A paper led by undergraduate student Peter Smith, focusing on pulsars and black holes in 47 Tuc, is in preparation and expected to be submitted in the coming months. In a related ongoing project, MSc student Nolan Dickson is using similar models and comparing them to data from a larger sample of clusters to place constraints on their "dark" mass and by extension on their high-mass initial mass function. Building on exploratory work from undergraduate student Devin Williams, undergraduate summer research student Abigail Battson is performing a systematic search for high-velocity stars ejected from globular clusters, which are another indirect signature of the presence of "bully" black holes in globular cluster cores.

Finally, Dr. Hénault-Brunet is continuing to collaborate with other groups on projects to obtain increasingly precise velocity measurements for stars near the centre of globular clusters using adaptive optics-assisted observations. In AY 2020-21, this has lead to two successful observing proposals (using the Gemini-NIFS and VLT-MUSE instruments) and two peer-reviewed publications based on MUSE data.

2.4. The evolution of galaxies

Several ICA researchers study the evolution of galaxies, including faculty members Drs. Ivana Damjanov, Marcin Sawicki, and Rob Thacker, as well as post-doctoral fellows Drs. Gaël Noirot, Nick Martis, and Johannes, together with several graduate students.

Dr. Sawicki's research interests are 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 current focus in 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 Strategic 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+HSC-SSP catalogs of galaxies and stars, which were recently finalized and validated, 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.

A number of projects based on the merged CLAUDS and HSC-SSP datasets is now being led by ICA members (and many more by external collaborators). These including the study of massive galaxy environments led by PhD student Lingjian Chen and studies of galaxy morphologies led by PhD student Angelo George and research assistant (and former undergraduate) Harrison Souchereau; both these projects are described in more detail further down. A paper led by PhD student Anneya Golob that describes the machine learning code for distinguishing stars from galaxies in deep images has been published by MNRAS, while the results of a study on the cosmic evolution of the galaxy-galaxy merger rate led by former MSc student Nathalie Thibert were published in RNAAS. ICA members and students are also involved in several published or ongoing studies based on the CLAUDS data, including investigations of the ionizing radiation escaping from distant quasars (led by recent ICA sabbatical visitor Dr. Ikuru Iwata and Dr. Sawicki) and galaxies; the nature of distant quasars; and studies of galaxy luminosity functions and star-formation rate functions at extreme wavelengths. Altogether, 15 papers based on CLAUDS data have been published in the two years since the first one appeared in 2019, and many more are in preparation.

Building on the growing success of the CLAUDS survey, Dr. Sawicki now leads the Canadian component of the new Deep Euclid U-band Survey (DEUS) being carried out by a consortium of Canadian and French astronomers, including the ICA's Dr. Ivana Damjanov. DEUS paves the way for the exploitation of the upcoming deep data from the European flagship *Euclid* space telescope , and we look forward to using these combined data starting soon after *Euclid's* launch in 2023 to study how cosmic structure formed in the filamentary 'cosmic web' that pervades the Universe.

Post-doctoral fellow Dr. Gaël Noirot, as well as recent ICA alumnus Dr. Moutard (now at LAM-Marseille), have been working to understand the processes that result in the dramatic quenching of star formation in many galaxies. In ongoing work, Dr. Noirot, together with Drs. Sawicki and Moutard, is tackling the mysteries of the quenching process by investigating the properties of quenching galaxies using HST slit-less grim spectroscopy. In addition to yielding immediate scientific insights, this work is also developing techniques that these ICA researchers will use to analyze data from the upcoming Guaranteed Time Observer program on NASA's James Webb Space Telescope (JWST). This work is ramping up towards the upcoming launch of JWST in December 2021, and we look forward to using privileged Guaranteed Time Observer status to make major advances with NASA's new flagship telescope.

Postdoctoral fellow Dr. Johannes Zabl works with Dr. Sawicki on the development of the data reduction pipeline for the CFI-funded GIRMOS instrument, a major new facility being developed by a consortium of Canadian institutions (including SMU) for the Gemini International Observatory in Hawai`i. Dr. Zabl is an expert in the study of gas around distant galaxies and continues to work on this topic since arriving in Halifax in January 2021.

ICA faculty member Dr. Ivana Damjanov utilizes large-area imaging and spectroscopic surveys to study the evolution of galaxies in the last 7 billion

years, which corresponds to the second half of cosmic history. These studies provide crucially important constrains for the physical processes responsible for triggering, regulating, and halting star formation in galaxies and for the mechanisms that promote galaxy morphological transformation and growth after the cessation of star formation. Dr. Damjanov is actively involved in the HSC-SSP, CLAUDS, and DEUS imaging surveys mentioned earlier, as well as the HectoMap survey, which is a dense spectroscopic survey of 52 square degrees within the HSC-SSP footprint.

Dr. Damjanov is developing the optimal strategy for measuring sizes and shapes of galaxies in the CLAUDS+HSC-SSP using a combination of existing software and custom-built algorithm for the modelling of galaxy light profiles that is optimized for large-area high-quality images obtained with a ground-based telescope. Two student-led projects are underway as part of this effort: Working with Dr. Damjanov and Dr. Sawicki, PhD candidate Angelo George has been modeling the two-dimensional galaxy light profiles in the CLAUDS+HSC-SSP data, as well as galaxy light profiles in in the cores of clusters from the Hubble Space Telescope CLASH survey. Some of Mr. George's most intriguing results (published in his MSc thesis in August 2020) are (a) that the evolution in the relation between the size and mass of galaxies depends on galaxy mass, and (b) that the most massive galaxies in cluster cores are smaller in size than their massive counterparts in the “field”. Starting as a summer undergraduate research assistant in 2018, Harrison Souchereau has been developing a versatile algorithm for the extraction of one-dimensional radial profiles of galaxies in the CLAUDS+HSC-SSP fields. After completing the undergraduate degree in April 2020 (with honours thesis project overseen by Dr. Damjanov), Mr. Souchereau continued to collaborate with Drs. Damjanov and Sawicki, completing the code and documentation on the radial profile extraction software and the suite of simulations for the evaluation of its performance. Devin Williams, who joined the Extragalactic Group in May 2021 as a summer research assistant (and is now enrolled in the MSc Program in Astronomy under the supervision of Drs. Damjanov and Sawicki), is using the software to measure radial profiles of several million CLAUDS+HSC SSP galaxies and examine the change in their outer regions as a function of galaxy mass, distance, star formation activity, and environment.

As a senior participant in the 2019 Kavli Summer Program in Astrophysics at the University of California Santa Cruz, Dr. Damjanov became a research advisor for the project to investigate the performance of machine learning algorithms in the identification and classification of galaxy tidal features in the HSC-SSP imaging survey, led by a PhD student Connor Bottrell (University of Victoria) and postdoctoral fellow Dr. Helena Domínguez Sánchez (Institute of Space Sciences, Barcelona). These features in otherwise undisturbed galaxy light profiles point towards major merging events in the assembly history of host galaxies. Although their frequency is not well understood, merging events are considered to be one of the main mechanisms that drive the observed evolution in properties of individual galaxies and their populations. This collaboration on machine learning approaches to galaxy properties and their evolution continues through the project DILEMA (Deep Imaging and deep LEarning for galaxy Mass Assembly), with Dr. Domínguez Sánchez as the Principal Investigator and Dr. Damjanov as one of co-investigators. DILEMA is now fully funded by the Spanish Government for a 3-year period starting from September 2021.

In related work, undergraduate student Ophélie Karishma Leste has been working with Dr. Damjanov on the classification of galaxies with tidal features in deep imaging surveys such as HSC-SSP, first improving previous classifications and creating the optimal galaxy samples for training machine learning algorithms and then data mining the Sloan Digital Sky Survey (SDSS) spectroscopic database and comparing spectroscopic measurements (average stellar population age, metallicity, dynamics, stellar mass) of galaxies harbouring tidal features with the general galaxy population. Ms. Leste completed her undergraduate honours thesis on this topic in April 2021. During the following summer she continued collaborating with Dr. Damjanov and Dr. Domínguez Sánchez on the spatially resolves spectroscopic properties of one target with prominent tidal features that was also part of the Mapping Nearby Galaxies at APO (MaNGA) sample.

Taking advantage of the volume covered by Hectomap and the number of objects with measured

spectroscopic redshifts (~100,000), Dr Damjanov uses galaxy size and shape measurements to examine in detail the connections between the observed morphological transformations of galaxies and their internal spectroscopic properties and environments, tracing the evolutionary trends in these relations over 7 billion years of cosmic time. The HectoMap survey includes several hundred galaxy clusters. The most massive clusters in the survey display arcs surrounding the most massive galaxies in them. These arcs are light profiles of background galaxies (i.e., galaxies more distant than the cluster) which are bent (lensed) due to the effect that the gravity of both luminous and dark matter along the line of sight has on the light as it travels from observed distant galaxy. By measuring the shapes of and distances to the lensed galaxies it is possible to model the distribution of dark matter within these massive galaxy clusters. Dr. Damjanov has established a collaboration with staff astronomers at the W. M. Keck Observatory which hosts the largest-mirror telescopes on Earth. The first target in the sample of massive lensing clusters in HectoMap, a spectacular supercluster that showcases two brightest cluster galaxies surrounded by a number of strong lensing arcs, was observed in June 2020. The incoming graduate student George Ridgeway will analyze obtained data to follow the evolution of the most massive galaxies residing in the cores of these clusters.

Working towards a MSc degree under Dr. Damjanov's supervision, Kamalpreet Kaur selected and characterized the population of post-starbursts galaxies (PSBs), a key link between galaxies that actively form stars and systems in which the star formation ceased more than a billion years before they are observed. She used the large-area spectroscopic galaxy sample (SHELS) to measure the properties of emission and absorption lines in galaxy spectra and construct the PSB sample. In addition, Ms. Kaur created maps of galaxy stellar mass density in the field and investigated the position of PSBs in them. With a number of these rare systems in hand, she took the advantage of deep HSC imaging available for SHELS galaxies to explore the structure of light profiles in PSB systems and trace the relation between their structural properties and environments. The main result of this study, that in the last six billion years large fraction of PSB galaxies have been forming in relative isolation rather than in dense cluster environments, is presented in a MSc thesis that Ms. Kaur defended in August 2021.

On the theoretical side, Dr. Rob Thacker and graduate student Paresh Mungara have been working on understanding the role of chaos in simulations of galaxy formation. Perhaps more commonly known as the "Butterfly effect", simulations of galaxy formation show sensitivity to small changes in their initial conditions, but determining the exact level of this sensitivity is important to understanding how robust results are from simulation work. Results derived with previous graduate student Tiffany Fields (MSc, 2019) have shown that a precise methodology for classifying the level of chaos is not possible within current simulation frameworks essentially because the simulations simply run out of resolution in many regions within the simulation volume. Consequently, simulations conducted with Mr. Mungara have focused on trying to quantify whether these variations can be related back to physical quantities in the simulations. The simplest idea along these lines is whether density, which largely determines how many time-steps a simulation requires in a given region, is related to the local variations observed in solution variances. This research is challenging conceptually since while variations in solutions are described in a global context, specifically in terms of their "phase space" evolution, the issues that lead to these variations arise in a local context. Consequently, this research is targeted at trying to build a bridge between these scales to help better understand robustness of simulation work. One can do this by relating how the local variations contribute to the global differences by analyzing the complete distribution of variations across all regions. The implications of these studies are significant because we are not yet fully able to describe how the variations in quantities calculated from simulations are the result of physical effects versus numerical ones. Furthermore, with enormous surveys of galaxies coming in the next few years, the precise nature of statistical variances will become increasingly important, rendering understanding this in simulations increasingly valuable.

2.5. Development of new research tools

ICA astronomers Drs. Zabl and Sawicki are leading the development of software tools for the CFI-

funded GIRMOS instrument which is now under construction by a consortium of Canadian institutions and is to be deployed on the 8-metre Gemini North Telescope later this decade. When coupled with Gemini's new NSF-funded Adaptive Optics (AO) system now under construction, GIRMOS will enable detailed spectroscopic studies of distant objects and will be complementary in that regard to the soon-to-be-launched JWST. Furthermore, Drs. Damjanov, Hénault-Brunet, Sawicki, and Zabl are all members of the GIRMOS Science Team.

Postdoctoral fellows Dr. Gaël Noirot, Dr. Nick Martis, and Dr. Johannes Zabl, and faculty member Dr. Sawicki are preparing software tools that will be used world-wide in the analysis of slit-less grim spectroscopy that will come from the James Webb Space Telescope (JWST), Hubble's much more capable successor and NASA's new flagship telescope. In addition to (and as part of) this work, Dr. Noirot has been analyzing archival Hubble Space Telescope (HST) grism spectra of z>1 galaxies that are in the process of quenching their star-formation activity — work that sets the baseline for what will be possible with JWST once it launches in December 2021.

3. Service

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.

3.1. Saint Mary's

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 (more on which below), 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 18th annual undergraduate summer research mini-symposium in September 2019; 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 2020 Atlantic Universities Physics and Astronomy Conference. Additionally, Drs. Damjanov, Sawicki and Short contributed to implementing program changes following the Department's Astronomy Graduate Program Review, and all regular ICA faculty contributed to developing and implementing changes to the Department's Undergraduate Program follow that Program's recent review.

As Director of the SMU Science Outreach Centre, Dr. Thacker coordinated Faculty open houses, student visits to the Faculty of Science, MacLennan lecture etc, and Chaired of Faculty of Science Community Engagement & Outreach Committee. He conducted numerous outreach events – 103 in total, including above two lectures; 46 episodes of Science Files on the Rick Howe Show (News 95.7); 39 episodes of Ottawa Today (1310 News); 6 CTV anchor interviews; 9 other various interviews, plus one presentation to a group of mixed students visiting SMU (grades 5-9). Finally, a large fraction of Dr. Thacker's time over the summer has been devoted to issues related to being SMUFU Chief Negotiator due to COVID-19 financial situation.

3.2. National

On the national scene, Dr. Thacker served as President of the Canadian Astronomical Society (CASCA) — completing his term in June 2020 — 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 and is CASCA's representative to NDRIO. The pandemic transition also required he lead the organization of the 2020 (online) CASCA AGM and conference. 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 served on the ACEnet Research Directorate until May 2020, at which point the role was taken on by Dr. Hénault-Brunet. Dr. Hénault-Brunet also serves on the CASCA Sustainability Committee, on NSERC's selection committee for the Vanier Scholarship, on the Evaluation committee for the "Research Support for New Academics" program in natural sciences, mathematics and engineering, Fonds de recherche

du Québec – Nature et technologies (FRQNT), and on the panel reviewing "JWST Early Release Science (ERS) and General Observers (GO) cycle 1" funding proposals for the Canadian Space Agency. Dr. Damjanov is a member of CASCA's Board of Directors and serves on several CASCA committees. She also serves on the Canadian Time Allocation Committee (CanTAC), the body appointed to assess Canadian observing-time proposals for the CFHT and Gemini telescopes, as the chair of the Extragalactic Panel. Dr. Damjanov has also been a member of the multidisciplinary review panel for the application stage of the Frontier Fields in Research Fund since its inaugural competition in 2019. 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. In the summer of 2021 he joined NSERC Discovery Grant evaluation committee.

3.3. International

On the international level, Dr. Sawicki served 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.

4. Upcoming Activities

The Institute has recently undergone a strategic planning exercise and submitted its result to the SMU Senate. We are now proceeding with implementing the our new strategic plan, which focuses on increasing our strength in the area of astrophysical data analytics. We will be providing a separate report on this activity to the Senate later this year.

5. Financial Statement

There was no spending in the ICA budget in AY 2020-21 as operations were all done remotely under global pandemic restrictions. At the start of September 2021, the ICA fund contains $12,223.

Research at the ICA is supported through grants from NSERC, Canada Foundation for Innovation (CFI), Research Nova Scotia Trust (RNST), and the Canadian Space Agency. As of the end of the present reporting period, the total amount of research funding for which ICA members are lead grand-holders is ~C$1.5M.

6. Publications

ICA members publish papers in high quality, high-impact refereed journals, including 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). Papers published by ICA and associated students and post-docs in AY 2020-21 are listed below.

Papers published in peer-reviewed journals by ICA members and associated students and post-docs during AY 2019-20 are listed below. Names of ICA faculty and associated personnel are highlighted in boldface.

1. *Molecular Gas in a Gravitationally Lensed Galaxy Group at z = 2.9* Shen, J., Man, A. W. S., **Zabl, J.**, Zhang, Z.-Y., Stockmann, M., Brammer, G., Whitaker, K. E., & Richard, J. (2021), The Astrophysical Journal, 917, 79.

2. *A giant central red disk galaxy at redshift z = 0.76: Challenge to theories of galaxy formation* Xu, K., Liu, C., Jing, Y., **Sawicki, M.**, & Gwyn, S. (2021), Science China Physics, Mechanics, and Astronomy, 64, 279811.

3. *MusE GAs FLOw and Wind (MEGAFLOW) VIII. Discovery of a Mg II emission halo probed by a quasar sightline* **Zabl, J.**, Bouché, N. F., Wisotzki, L., Schaye, J., Leclercq, F., Garel, T., Wendt, M., Schroetter, I., Muzahid, S., Cantalupo, S., Contini, T., Bacon, R., Brinchmann, J., & Richard, J. (2021), Monthly Notices of the Royal Astronomical Society,.

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