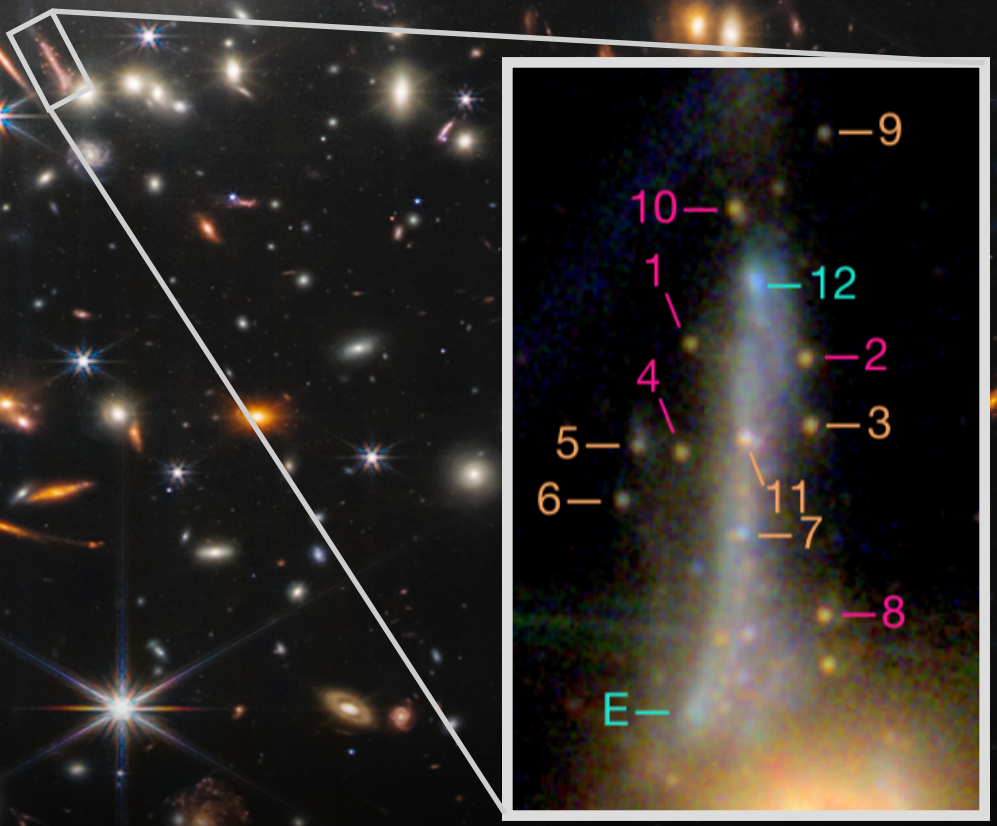
Institute for Computational Astrophysics
Annual Report
2021-22



ICA Annual report, compiled by Marcin Sawicki, Acting Director

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ON THE COVER

The full-page cover image shows the galaxy cluster SMACS 0723 recently observed by the James Webb Space Telescope (JWST). The inset image shows one of the distant galaxies located **behind** this cluster and dubbed The Sparkler because of the plethora of bright red 'sparkles' (tagged with ID numbers) that surround it. The Sparkler galaxy is 9 billion light years away from earth and is highly magnified by the general-relativistic bending of its light by the cluster SMACS 0723.

Especially interesting, however, are the red 'sparkles' that surround The Sparkler galaxy: they are **extremely** old - almost as old as the Universe itself - and appear to contain some of the very first stars to have formed after the Big Bang.

These results - published in the Astrophysical Journal Letters (paper 1 in Section 7 of this report) - show the amazing power of the Webb telescope to study the earliest phases of our cosmic history. The ICA members involved in The Sparkler study look forward to analyzing 5 more galaxy clusters such as SMACS 0723 and the distant galaxies behind them. These new Webb data will be taken over the current academic year 2022-23.

Image credit: NASA and the CANUCS 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 eighteen 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 sixteen 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.

Working with ICA faculty during AY2021-22 were 23 early-career researchers:

- Six postdoctoral fellows: Dr. Guillaume Desprez, Dr. Vince Estrada-Carpenter, Dr. Nick Martis, Dr. Gaël Noirot, Dr. Robert Sorba, and Dr. Johannes Zabl
- Nine graduate students (7 in Astronomy and 2 in the Computing and Data Analytics): Lingjian Chen, Maigan Devries, Nolan Dickson, Angelo George, Tanmaya Murthy, George Ridgeway, Fraser Smith, Devin Williams and Hongbo Zhao
- Eight undergraduates: Abigail Battson, Starling Cox, Lukas Donovan, Rebecca Hamel, Katherine Myers, Colby O'Keefe, Joya Smit, and Peter Smith.

The ICA also has three external members: Dr. Ralph Pudritz (McMaster University) Dr. Richard Henriksen (Queen's University), and Harrison Souchereau (Yale University).

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, affiliated to the ICA are two ACEnet employees located at Saint Mary's: Mr. Phil Romkey and Dr. Sergiy Khan.

During AY 2019-20 the ICA carried out a self-study which 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 new direction is closely aligned with 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. In AY2021-22 the Institute has also started hosting online ICA Data Analytics seminar series (see Section 3 of this report), with three seminars held that year, and several already scheduled for AY2022-23.

In parallel, the research capacity of the ICA has been rebuilding so that in AY2021-22 the Institute had six SMU-based faculty (compared to four in 2017-18) and six post-doctoral fellows (compared to just one one in 2017-18). This ramp-up coincides with expanding involvement of Institute staff in key roles within leading national and international astronomy projects of the present (exemplified by the recently-launched Webb Space Telescope) and the future (see Section 2.5).

The ICA's website, refreshed in 2022, provides up-to-date information about the Institute.

2. Research

Astrophysical research is the primary goal of the ICA and Institute 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; they tackle a broad spectrum of topics from the atmospheres of stars to the formation of galaxies soon after the Big Bang. These are described in the following sections (Sec. 2.1-2.5), with a focus on progress in AY2021-22. Notably, this research has resulted in 31 papers published or submitted to journals in AY2021-22 (see Section 6).

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). The latest significant improvement to the treatment of the equation-of-state, chemical equilibrium, and ionization equilibrium solution was published in 2021 (Short, C. Ian and Bennett, Philip D., 2021, "Chroma+Gas: An Expedited Solution of the Chemical Equilibrium for Cool Star Atmospheres", Publications of the Astronomical Society of the Pacific, 133, 064501). Students in the graduate course in Stellar Atmospheres and Spectra used 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. During this academic year, while on sabbatical, Dr. Clarke made significant progress on the code, which is now nearly in beta version.

Finally and during his sabbatical, Dr. Clarke submitted his textbook manuscript, "A First Course in Magnetohydrodynamics and Other Topics in Fluid Dynamics" to Cambridge University Press who have agreed to publish it. 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 black hole content of globular clusters and their contribution to rate of gravitational wave events, (2) the evolution of the stellar mass function of globular clusters and constraints on their initial mass function, (3) the

dynamical interaction between globular clusters and the Milky Way and how this informs scenarios for the formation and evolution of these systems.

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

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) 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 second paper from this survey (led by PhD student Zhen Wan; University of Sydney) was recently submitted for publication. The study analyzes the kinematics and dynamics in the outskirts of four globular clusters, and by comparison with *N*-body simulations concludes that the observations can entirely be explained by tidal interaction with the Milky Way, with no need for dark matter around these four clusters.

Dr. Hénault-Brunet's group also continues to work on dynamical modelling of globular clusters to provide new constraints on the dark remnant content of globular clusters (including black holes) and their (initial) stellar mass function. Graduate student Nolan Dickson successfully defended his MSc thesis in which he fitted multi-component equilibrium mass models (recently developed and tested by Hénault-Brunet and collaborators) to a wide range of data, for a selected sample of ~40 Milky Way GCs. This work found that the IMF of globular clusters above 1 $M_\odot$ is consistent with the canonical Salpeter or Kroupa slope, arguing against suggestions of a top-heavy IMF proposed in the literature for metal-poor clusters. This research also provides improved and independent constraints on the size of BH populations in a significant sample of clusters, and is the subject of a paper in preparation (Dickson, Hénault-Brunet et al., to be submitted). In a companion study (Baumgardt, Sollima, Hénault-Brunet, Dickson et al., to be submitted), new constraints on the global present-day stellar mass function within globular clusters are used to show that the IMF of globular clusters below of 1 $M_\odot$ was likely more bottom-light (i.e. lacking low-mass stars) than the commonly assumed canonical Kroupa or Chabrier IMF. For his honours thesis research, undergraduate student Peter Smith worked on dynamical modelling of the globular cluster 47 Tuc using pulsar timing to probe the gravitational potential of the cluster and self-consistently including the effect of binary stars. This work led to improved constraints on the black hole population in this cluster and is the subject of a publication in preparation (Smith, Hénault-Brunet et al., to be submitted). MSc student Maigan Devries is developing a hierarchical Bayesian method to take into account observational biases and infer the orbital period distribution of binary stars in globular clusters based on incomplete multi-epoch radial velocity surveys. This will open up opportunities to constrain the initial density of globular clusters based on how this initial density affects the present-day period distribution of binaries.

Undergraduate summer research student Abigail Battson has performed a systematic search for high-velocity stars ejected from globular clusters (with new data from Gaia Data Release 3), which can be another indirect signature of the presence of black holes and other stellar remnants in globular cluster cores. Undergraduate summer student Joya Smit worked on Monte Carlo simulations to interpret these observations of high-velocity star candidates.

Dr. Hénault-Brunet is involved in collaborations using the FLAMES and MUSE spectrographs on the VLT to obtain multi-epoch radial velocity observations of massive stars and massive star clusters. In 2021-2022, this work has led to two publications which were also featured in ESO press releases: the discovery of an X-ray-quiet black hole born with a negligible kick in a massive binary within the LMC (Shenar et al. 2022), and the discovery of a black hole candidate in the young massive cluster NGC 1850 in the LMC (Saracino et al. 2022).

2.4. The evolution of galaxies

Several ICA researchers study the evolution of galaxies. These are faculty members Drs. Ivana Damjanov, Marcin Sawicki, and Rob Thacker, as well as post-doctoral fellows Drs. Guillaume Desprez, Vince Estrada-Carpenter, Gaël Noirot,

Nick Martis, Robert Sorba, Johannes Zabl, 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 recent focus has been 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; the paper that describes them has been submitted for publication, and the catalogs themselves will be made public as soon as it is accepted by the journal. 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 the CLAUDS Project Website.

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 galaxy stellar mass functions and massive galaxy environments led by PhD student Lingjian Chen and studies of galaxy morphologies led by PhD student Angelo George and MSc student Devin Williams; both these projects are described in more detail further down. A paper on the escape of hydrogen-ionizing radiation from Active Galactic Nuclei led by recent ICA sabbatical visitor Dr. Ikuru Iwata and by Dr. Sawicki) and galaxies; the nature of distant quasars; and studies of galaxy luminosity functions and star-formation rate functions at extreme wavelengths. Altogether, 20 papers based on CLAUDS data have been published in the ~three 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 faculty Dr. Ivana Damjanov, postdocs Drs. Desprez, Estrada-Carpenter, Noirot, and Zabl, and students Chen, George, and Williams. 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 (expected in 2023-2024) to study how cosmic structure formed in the filamentary 'cosmic web' that's made of dark matter and 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. A recent paper led by Dr. Noirot has tackled 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 recently-launched Guaranteed Time Observer program on NASA's James Webb Space Telescope (JWST).

With the successful lauch of JWST in December 2022, the research focus of many ICA researchers, led by Dr. Sawicki and including Drs. Desprez, Martis, Noirot, and Zabl as well as undergraduates Katherine Myers and Lukas Donovan, has shifted towards working with upcoming JWST data. This will benefit from the 200 JWST observing hours that thee researchers have access to as leading members of the CANUCS collaboration to use Webb's made-in-Canada NIRISS instrument to study very distant galaxies behind five gravitationally-lensing clusters. These data will start flowing in late 2022, and the team is preparing to process and analyze their scientific content. A preview of the kind of research that these upcoming observations will enable, based on publicly-released JWST observations of "The Sparkler" galaxy

behind the cluster SMACS 0723, has recently been accepted for publication by Astrophysical Journal Letters (see cover image to this report). This work has found a distant galaxy with star clusters that are almost as old as the Universe itself and that appear to contain some of the very first stars to have formed after the Big Bang.

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 (a dense spectroscopic survey of 52 square degrees within the HSC-SSP footprint). Using measured structural and spectroscopic properties of non-star forming (i.e., quiescent) galaxies in HectoMap, Dr Damjanov has led the study that, for the first time, separates *and* quantifies the impact on the average quiescent size growth of (a) galaxies joining the quiescent population with time and (b) galaxies that are evolving after reaching quiescence within this population (Damjanov et al. 2022, submitted to the ASS Journals).

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 in 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. One of Mr. George's most intriguing recent results is that the sizes of star forming galaxies measured from their light profiles that correspond to newly formed stars are always larger than the sizes from profiles that correspond to the light from older stellar populations. This work shows that the inside-out growth of galaxies due to star formation and subsequent quenching persists over most of the cosmic history.

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) and joining the graduate program in Astronomy at Yale University, Mr. Souchereau continues to collaborate with Drs. Damjanov and Sawicki. Devin Williams, a second-year student 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.

The HectoMap survey includes several hundred galaxy clusters. The most massive clusters in the survey display arcs surrounding their most massive galaxies. 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. Measurements of the shapes of and distances to the lensed galaxies enable modelling of the distribution of dark matter within massive galaxy clusters. Dr. Damjanov has developed observing proposals to target these clusters in collaboration with staff astronomers at the W. M. Keck Observatory, the host of the largest-mirror telescopes on Earth. The first massive lensing cluster target was observed in June 2020. As part of his MSc thesis project, graduate student George Ridgeway has been using the data to increase the number of known cluster members (by 100%) and investigate the internal properties of galaxies residing in different regions of the cluster that looks to be a unique analog of the local massive Coma cluster detected when the universe was only 60% of its current age.

The work on galaxy clusters in Dr. Damjanov's research group extends to large samples compiled at smaller cosmological distances. A project developed in collabration with Dr Jubee Sohn (assistant professor of astronomy at the Seoul National University) and the undergraduate student Colby O'Keefe during 2021/22 has shown that the distribution of galaxy average stellar population

age within nearby clusters clearly segregates galaxies into several regions, including cluster core (populated by the oldest galaxies) and various infall regions. Furthermore, the age distributions provided by this statistical sample can be directly compared to the predictions for cluster galaxy evolution from the most recent hydrodynamical simulations. This aspect of the project will be addressed by the incoming postdoctoral fellow Michele Pizzardo.

The population of post-starbursts galaxies (PSBs), systems in which the star formation ceased about a billion years before they are observed, are a key link between galaxies that actively form stars and the ones in which the star formation has completely ceased. Working towards a MSc degree in Computing and Data analytics, Hongo Zhao joined Dr. Damjanov's group in the summer of 2022 to perform statistical analysis of the internal and environmental properties for the sample of PSBs from the Sloan Digital Sky Survey. Mr. Zhao's data mining of different astronomical databases has provided information on internal properties (stellar populations and gaseous content characteristics) as well as the density of galaxies in the vicinity of the PSB targets. The analysis of constructed dataset will reveal how the presence of gaseous material (necessary for star formation) in galaxies that have very recently stoped forming stars depends on the density of galaxy environment.

On the theoretical side, Dr. Rob Thacker and graduate student Fraser Smith have been working to understand galactic star formation on a more statistical footing. Specifically, for theoretical modelling of star formation it is useful to be able relate the overall time variation in star formation within an individual galaxy to the overall statistical variation observed in a sample of galaxies of similar size. The root concept behind this is ergodicity, namely the idea that a single system will, over time, occupy all possible states available to it. This is a significant simplification of evolutionary behaviour but for certain systems, such as gas contained within a box, it is actually an accurate description.

For the evolution of galaxies there is agreement that individual galaxy evolution is not truly ergodic, but the exact departure from this assumption has not been estimated, and neither has the impact of different physics within the galaxy formation process been considered as a part of this process. The goal of this research is to put some constraints on the maximum evolution by considering the different physics at play in galaxy formation in a systematic fashion. Of course, it is challenging to recreate a precise sample of galaxies, so rather than simulating a larger volume, statistical modelling of selected Sloan survey galaxies is being used to create model galaxies with parameters drawn from distributions determined by the observed catalogue. While this does introduce the possibility of creating galaxies that are not allowed physically in nature, since the exact parameters are drawn from modelled distributions in practice the sampled galaxy parameters are reviewed to ensure physical plausibility. By the nature of their construction, they are statistically appropriate. These galaxies are being created using the “make galaxy” code provided to us by Dr Volker Springel, augmented to include additional components such as substructure and a hot gas halo. To calculate evolution of the galaxies we will again be using the GIZMO code, but will consider adding different physics processes, including feedback and winds in a systematic fashion. For each physical situation, the plan is to evolve each set of sampled galaxies over a period slightly less than half the age of the Universe, and to then compare the overall variation in the star formation rate as a function of time, compared to the overall sample. The overall suite of simulations should be finished early in 2023, with Fraser Smith defending his MSc thesis in summer 2023.

With honours thesis student Starling Cox, Dr. Thacker is investigating the transfer of energy from dark matter to gas in large scale simulations of collisions of clouds of dark matter and gas. Although heavily simplified as compared to evolution in the actual universe, these modelled collisions allow the precise exchange of energy to be evaluated under controlled conditions. Normally in any situation where there are different types of particles we expect equipartition of energy between the particles. However, hydrodynamics has distinctly different behaviour from the “collisionless” evolution of both dark matter and stars. For example, under high compression or high velocities gas will undergo shock heating which is an irreversible process leading to a different (higher) entropy state for the gas.

Low resolution studies of these kinds of collisions were undertaken quite some time ago, but as yet no higher resolution follow-ups have been conducted. By using a slight change to the initial conditions, it

will also be examined whether there is an upper limit on the amount of energy that can be transferred. This might be expected because as the implicit velocity of interaction rises the actual transfer of energy will go down, specifically the impulse due to the interaction is shortened. By considering interactions where there are repeated oscillations back and forth, as has been used extensively in model simulations of feedback processes within galaxies, we can investigate maximum transfers under controlled conditions.

2.5. Development of new research tools

ICA scientists are involved in the development of new astronomy research tools.

2.5.1. GIRMOS

ICA astronomers Drs. Damjanov, Hénault-Brunet, Sawicki, and Zabl are participating in the CFI-funded GIRMOS project to build a multi-unit field spectrograph for the giant 8-metre Gemini telescope in Hawaii. When coupled with Gemini's new NSF-funded Adaptive Optics (AO) system now also under construction, GIRMOS will enable detailed spectroscopic studies of distant objects and will be complementary in that regard to the recently-launched JWST. All four are members of the GIRMOS Science Team, where they help guide the development of the instrument's capabilities with reference to science goals.

Drs. Zabl and Sawicki, and grad student Tanmaya Murthy have been the GIRMOS software tool suite, which will be vital for all users of GIRMOS in processing the instrumen's raw data into science-ready products. In May 2022, the GIRMOS project passed its external Preliminary Design Review (PDR) and is now in the Final Design Phase before fabrication begins in late 2023. For the PDR, the SMU GIRMOS software team, led by Dr. Zabl, delivered a complete preliminary design package which gathered strong praise from the PDR committee for its completeness and thoroughness.

2.5.2. CASTOR

CASTOR is the #1 priority for space astronomy in Canada (source: Canadian Astronomy Long Range Plan 2020-2030) and is moving forward with development funding from the Canadian Space Agency, aiming for launch in the late 2020s. CASTOR is a project that has long-standing ICA connections that started in 2010 when Dr. Sawicki and then-graduate student Robert Sorba provided the first studies of CASTOR precursor's expected performance for measuring the Dark Energy equation of state, and continued through the subsequent years with contributions from ICA sabbatical visitor Dr. Ikuru Iwata, postdoc Dr. Thibaud Moutard, and student Martin Hellmich.

Starting in early 2022, CASTOR has entered a period of accelerated development, and ICA plays key roles in several areas, supported by funding from the Canadian Space Agency. Notably, ICA received a third of the current CSA funding going to Canadian universities and ICA faculty Drs. Damjanov, Hénault-Brunet, and Sawicki, along with postdocs Drs. Gaël Noirot and Robert Sorba, and students Nolan Dickson and Rebecca Hamel play key roles in the CASTOR project.

Dr. Hénault-Brunet is the Lead of the CASTOR's Near-Field Cosmology Science Working Group (SWG). This involves coordinating a group of near-field cosmology experts to provide feedback on mission requirement, updating and designing proposed legacy surveys for the mission, and assessing and optimizing surveys for astrometric programs (proper motions and parallaxes). As part of this effort, summer undergraduate research assistant Rebecca Hamel worked on simulating proper motion measurements with the CASTOR telescope and applications to kinematics in the diffuse outskirts of globular clusters. Nolan Dickson (MSc 2022, starting his PhD with Hénault-Brunet in September 2022) is also expected to contribute to this study in the near future.

Dr. Damjanov and Sawicki are senior members of CASTOR's Galaxy Evolution SWG, and Dr. Sawicki is also a senior member of the Cosmology SWG. Working under Dr. Sawicki's direction, Dr. Sorba has generated realistic photometric performance forecasts essential for assessing and optimizing CASTOR's performance in measuring the Deark Energy equation of state. He has also produced simulations of deep spatially-resolved CASTOR observations of distant galaxies, assessing how well CASTOR will do in studies of star-formation quenching in the distant universe. In parallel, Dr. Noirot is building detailed simulations

of CASTOR's slitess grism spectrograph (similar to that of JWST'S NIRISS but operating over a much wider field of view and in the ultraviolet instead of the infrared). These sets of simulations are now being used by these ICA members and other CASTOR participants to develop and assess CASTOR's observing strategy and finalize its science performance metrics.

3. ICA Seminar Series

In AY2021-22 the ICA began a new online series in Astrophysical Data Analytics. These seminars provide presentations by and follow-up discussions with leading data analytics experts, and are designed to appeal to faculty, postdocs, and research students from astronomy as well as computational sciences. In this inaugural year, the series was trialed primarily for the local, Halifax audience (albeit with one well-attended nationally-broadcast talk).

In AY2021-22 the series included the following talks:

- Dr. Sébastien Fabbro (NRC-Herzberg and Canadian Astronomy Data Centre): *"Teaching a machine to learn to extract stellar properties from sky surveys"*
- Dr. Joshua Speagle (University of Toronto Banting Fellow): *"An Introduction to Dynamic Nested Sampling"*
- Dr. Gaël Noirot and Dr. Vicente Estrada Carpenter (ICA / Saint Mary's): *"Grism Spectroscopy for Extragalactic Astronomy, a How-to"*

With the strong success and popularity of this first, trial year of the Data Analytics series in AY2021-22, the ICA will continue the series into the future, with several talks already scheduled for AY2022-23.

4. 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.

4.1. 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, and on the University Pension Committee (where he Chairs the Investment Subcommittee). Dr. Hénault-Brunet serves as the Director of the Burke-Gaffney Observatory since February 2022, and Dr. Damjanov as the Graduate (MSc and PhD) Astronomy Program Coordinator. Dr. Sawicki continued to serve for the fourth year as the ICA's Acting Director.

As Director of the SMU Science Outreach Centre, Dr. Thacker coordinated Faculty open houses, student visits to the Faculty of Science, and Chaired of Faculty of Science Community Engagement & Outreach Committee. He conducted numerous outreach events – 95 in total, includiding 43 episodes of Science Files on the Todd Veinotte Show (CityNews Halifax); 44 episodes of CFRA Live! (580 CFRA Ottawa); 6 CTV interviews; plus two interviews in other outlets. Finally, a large fraction of Dr. Thacker's time over the summer has been devoted to issues related to being SMUFU Lead Negotiator and preparing for the 2022-2025 collective agreement negotiation.. Dr. Hénault-Brunet served as the Department's Science Atlantic representative, has served as the Vice-chair of the Physics & Astronomy division of Science Atlantic since February 2022, organized the Department's student participation in the 2022 Atlantic Undergraduate Physics and Astronomy Conference (AUPAC), and is the faculty liaison for the organization of the 2023 Atlantic Undergraduate Physics and Astronomy Conference to be hosted by Saint Mary's. He also coordinated the Department of Astronomy & Physics colloquium series. Dr. Sawicki hosted and coordinated SMU's Dan MacLennan Memorial Lecture in Astronomy.

4.2. National

On the national scene, Dr. Thacker served as Acting President of the Canadian Astronomical Society (CASCA) — stepping back into the role after a society crisis — which entailed an extensive amount of intervention and conflict management. In this role he reassumed the co-Chairship of the Coalition 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 as CASCA's representative to NDRIO. He was also

the Chair of the Canadian National Committee for the International Astronomical Union. Dr. Thacker also served as an ex-officio Board member of the Association of Canadian Universities for Research in Astronomy (ACURA) and the SMU institutional representative to the ACURA Council, although he passed this role on to Dr Hénault-Brunet in spring 2022.

Dr. Hénault-Brunet serves on the ACEnet Research Directorate, on the CASCA Sustainability Committee and on the CASCA Awards Committee, on NSERC's selection committee for the Vanier Scholarship, and also served on the panel reviewing "JWST Early Release Science (ERS) and General Observers (GO) cycle 1" funding proposals for the Canadian Space Agency. Dr. Hénault-Brunet leads the Near-Field Cosmology Science Working Group for the CASTOR mission.

Dr. Damjanov serves on two CASCA committees: Ground-based Astronomy Committee and Equity and Inclusivity Committee (which she currently chairs). She also serves (as the Extragalactic Panel Chair) on the Canadian Time Allocation Committee (CanTAC), the body appointed to assess Canadian observing-time proposals for the CFHT and Gemini telescopes. 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 NSERC Discovery Grant evaluation committee, and in mid-2022 he became the Chair of the Astrophysics and Cosmology Panel. He continued to serve 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.

4.3. International

On the international level, Dr. Sawicki served on the Board of Director's of the Gemini International Observatory, one of the premier world observatories with 8-metre-class telescopes located in Chile and Hawaii. In early 2022 Dr. Damjanov was invited to serve as one of two Canadian representatives on the Gemini Science and Technology Advisory Committee that advises Gemini International Observatory's Board of Directors on policy matters of long-range scientific and technological importance to the Observatory. Dr. Thacker was the Canadian National Representative on the International Astronomical Union National Member Council during the 2021 IAU Business Meeting sessions.

5. Upcoming Activities

The Institute has recently undergone a strategic planning exercise and submitted its result to the SMU Senate. We are now continuing with the implementation our new strategic plan, which focuses on increasing our strength in the area of astrophysical data analytics. As part of this, Institute members play key roles in the development of future research tools that will both fuel and benefit from this effort. (see Section 2.5).

6. 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.

7. Publications

ICA members primarily publish their research 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), Monthly Notices of the Royal Astronomical Society (MNRAS, IF = 5.2), and Nature Astronomy (Nat. Astron., IF = 15.6).

Papers published or submitted by ICA members and associated students and post-docs during AY 2021-22 are listed below.

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2. A dusty starburst masquerading as an ultra-high redshift galaxy in JWST CEERS observations, Zavala, J. A., Buat, V., Casey, C. M., Burgarella, D., Finkelstein, S. L., Bagley, M. B., Ciesla, L., Daddi, E., Dickinson, M., Ferguson, H. C., Franco, M., Jim'enez-Andrade, E. F., Kartaltepe, J. S., Koekemoer, A. M., Le Bail, A., Murphy, E. J., Papovich, C., Tacchella, S., Wilkins, S. M., Fontana, A., Giavalisco, M., Grazian, A., Grogin, N. A., Kewley, L. J., Kocevski, D. D., Kirkpatrick, A., Lotz, J. M., Pentericci, L., Perez-Gonzalez, P. G., Pirzkal, N., Ravindranath, S., Somerville, R. S., Trump, J. R., Yang, G., Yung, L. Y. A., Almaini, O., Amorin, R. O., Annunziatella, M., Arrabal Haro, P., Backhaus, B. E., Barro, G., Behroozi, P., Bell, E. F., Bhatawdekar, R., Bisigello, L., Buitrago, F., Calabro, A., Castellano, M., Chavez Ortiz, O. A., Chworowsky, K., Cleri, N. J., Cohen, S. H., Cole, J. W., Cooke, K. C., Cooper, M. C., Cooray, A. R., Costantin, L., Cox, I. G., Croton, D., Dave, R., de la Vega, A., Dekel, A., Elbaz, D., Estrada-Carpenter, V., Fernández, V., Finkelstein, K. D., Freundlich, J., Fujimoto, S., García-Argumánez, Á., Gardner, J. P., Gawiser, E., Gómez-Guijarro, C., Guo, Y., Hamilton, T. S., Hathi, N. P., Holwerda, B. W., Hirschmann, M., Huertas-Company, M., Hutchison, T. A., Iyer, K. G., Jaskot, A. E., Jha, S. W., Jogee, S., Juneau, S., Jung, I., Kassin, S. A., Kurczynski, P., Larson, R. L., Leung, G. C. K., Lucas, R. A., Magnelli, B., Mantha, K. B., Matharu, J., McGrath, E. J., McIntosh, D. H., Medrano, A., Merlin, E., Mobasher, B., Morales, A. M., Newman, J. A., Nicholls, D. C., Pandya, V., Rafelski, M., Ronayne, K., Rose, C., Ryan, R. E., Santini, P., Seillé, L.-M., Shah, E. A., Shen, L., Simons, R. C., Snyder, G. F., Stanway, E. R., Straughn, A. N., Teplitz, H. I., Vanderhoof, B. N., Vega-Ferrero, J., Wang, W., Weiner, B. J., Willmer, C. N. A., & Wuyts, S. (2022), arXiv e-prints, arXiv:2208.01816.

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