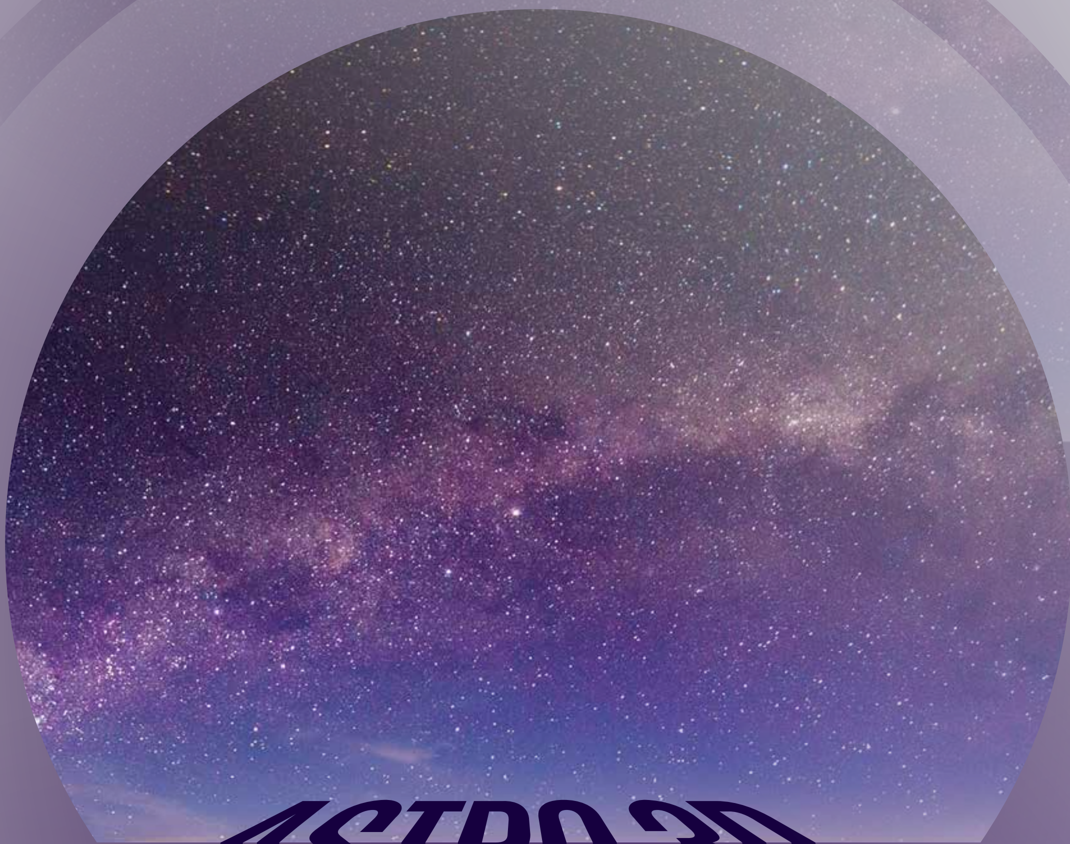


ASTRO 3D

ANNUAL REPORT 2020

ARC CENTRE OF EXCELLENCE
FOR ALL SKY ASTROPHYSICS IN 3D

Australian Government
Australian Research Council

ASTRO 3D

ACKNOWLEDGEMENT

ASTRO 3D acknowledges the support of the Australian Research Council and all of the collaborating and partner institutions in the Centre.

OUR COLLABORATING UNIVERSITIES

Australian National University
Curtin University
The University of Western Australia
Swinburne University of Technology
The University of Melbourne
The University of Sydney

OUR PARTNER INSTITUTIONS

ASTRON Netherlands Institute for Radio Astronomy
California Institute of Technology
Chinese Academy of Sciences
CSIRO
Heidelberg Institute for Theoretical Studies HITS
NCI Australia
University of Oxford
University of Toronto
University of Washington

ACRONYMS AND ABBREVIATIONS

AAO	Australian Astronomical Observatory
AAL	Astronomy Australia Ltd
AAT	Anglo Australian Telescope
ACFR	Australian Centre for Field Robotics
ADACS	Astronomy Data and Computing Services
ADC	Atmospheric Dispersion Corrector
AGN	Active Galactic Nuclei
ALFALFA	Arecibo Legacy Fast ALFA Survey
ALMA	Atacama Large Millimeter Array
ANU	The Australian National University
AOS	Australian Optical Society
APOGEE	APO Galactic Evolution Experiment
ARC	Australian Research Council
ASA	Astronomical Society of Australia
ASKAP	Australian Square Kilometre Array Pathfinder
ASTRO 3D	Centre of Excellence for All Sky Astrophysics in 3 Dimensions
ASTRON	Netherlands Institute for Radio Astronomy
ASVO	All-Sky Virtual Observatory
ATNF	Australia Telescope National Facility
BoRG	The Brightest of Reionising Galaxies
CAASTRO	Centre of Excellence for All Sky Astrophysics
CAS	Chinese Academy of Sciences
CASDA	CSIRO ASKAP Science Data Archive
CASS	CSIRO Astronomy and Space Science
CIRADA	Canadian Initiative for Radio Astronomy Data Analysis
CMB	Cosmic Microwave Background
COCKATOO	COsmological Chemodynamical simulations with Kinetic AGN feedback and other physics TOO
COO	Chief Operating Officer
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DALiuGE	Data Activated Liu Graph Engine
DECaLS	Dark Energy Camera Legacy Survey
DECRA	Discovery Early Career Researcher Award
DES	Dark Energy Survey
DIAP	Data Intensive Astronomy Program
DINGO	Deep Investigation of Neutral Gas Origins
DLA	Damped Lyman Alpha Absorber
DSTG	Defence Science and Technology Group
EAGLE	Evolution & Assembly of GaLaxies and their Environments
ECR	Early Career Researcher
EDI	Equity Diversity and Inclusion
EMP	Extremely Metal-poor Stars
EoR	Epoch of Reionisation
ESO	European Southern Observatory
ESPRESSO	Echelle SPectrograph for Rocky Exoplanets and Stable Spectroscopic Observations
FAST	Five-hundred-metre Apeture Spherical Telescope
FLASH	First Large Absorption Survey in HI
GALAH	GALactic Archeology with HERMES
GAMA	Galaxy and Mass Assembly
GRB	Gamma Ray Burst
GMT	Giant Magellan Telescope
HERMES	High Efficiency and Resolution Multi-Element Spectrograph
HI	H one (neutral hydrogen)
HIRAX	Hydrogen Intensity and Real-time Analysis eXperiment
HITS	Heidelburg Institute for Theoretical Studies
HPC	High-Performance Computing
HST	Hubble Space Telescope
IAB	International Advisory Board
ICRAR	International Centre for Radio Astronomy Research
IFU	Integral Field Units
IGM	InterGalactic Medium
JWST	James Webb Space Telescope
K3-LARS	KMOS z=3-4 Lyα reference survey
KAPA	Keck All-sky Precision Adaptive-optics
KIAA	Kavli Institute for Astronomy and Astrophysics
KiDS	Kilo-Degree Survey
KMOS	K-band Object Spectrograph
KPI	Key Performance Indicator
KROSS	KMOS Redshift One Spectroscopic Survey
LIEF	Linkage Infrastructure Equipment and Facilities
LGBTI	Lesbian Gay Bisexual and Transgender (initalism)
LoBES	Long Baseline Epoch of Reionisation Survey
LTE	Local Thermodynamic Equilibrium
MANIFEST	Many Instrument Fiber System
MIAPP	Munich Institute for Astro- and Particle Physics
MOSFIRE	Multi-Object Spectrograph For Infra-Red Exploration
MOSEL	MOSfire Emission Line survey
MPIA	Max Planck Institute for Astronomy
MSTO	Main Sequence Turn-off
MUSE	Multi-Unit Spectroscopic Explorer
MWA	Murchison Widefield Array
NASA	National Aeronautics and Space Administration
NCA	National Committee for Astronomy
NCI	National Computational Infrastructure
PEONY	Planetary nebula EvOlutioN ifs surveY
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PHISCC	SKA Pathfind HI Science Coordination Committee
QSO	Quasi-Stellar Objects
RSAA	Research School for Astronomy and Astrophysics
SAGE	Semi-Analytic Galaxy Evolution
SAIL	Sydney Astrophotonic Instrumentation Laboratory
SAMI	Sydney-AAO Multi-object Integral field unit
SAM	Semi-Analytic Model
SCA	Subsea Communications Australia
SED	Spectral Energy Distribution
SKA	Square Kilometre Array
SMC	Science Management Committee
SOfIA	Stratospheric Observatory for Infrared Astronomy
SPIRIT	SPICE, Physics, ICRAR, Remote Internet Telescope
STEM	Science Technology Engineering Mathematics
TAO	Theoretical Astrophysical Observatory
TESS	Transiting Exoplanet Survey Satellite
TOSCA	Topology and Orchestration Specification for Cloud Applications
UCSD	University of California San Diego
UNSW	University of New South Wales
UAV	Unmanned Aerial Vehicle
UoM	University of Melbourne
UV	UltraViolet
UW	University of Washington
UWA	University of Western Australia
VIKING	VISTA Kilo-Degree Infrared Galaxy Survey
VISTA	Visible and Infrared Survey Telescope for Astronomy
VLT	Very Large Telescope
VO	Virtual Observatory
VR	Virtual Reality
WALLABY	Widefield ASKAP L-Band Legacy Allsky Blind Survey
WiFeS	WideField Spectrograph

CONTENTS

CONTENTS

DIRECTOR'S WELCOME AND REPORT

We are marching closer to the next generation of telescopes; the Square Kilometre Array (SKA) in the Western Australian desert, the Giant Magellan Telescope, and the European Extremely Large Telescope (E-ELT) in Chile. These are multi-billion dollar telescopes with many international partners. Australia will be in competition with these international partners to make the discoveries that will change our understanding of the Universe and our place within it.

To lead the discoveries that will abound from these telescopes, we need to hit the ground running. ASTRO 3D surveys, described in this annual report, use pathfinders for the next-generation telescopes. These pathfinder surveys and our training programs and workshops nurture and train our young scientists in the skills that they will need to lead the teams, propose for telescope time, and make discoveries on the future multi-billion dollar telescopes. Moreover, the pathfinder surveys and project data provide information on the stars and galaxies to be observed in unprecedented detail with these future telescopes.

We cannot connect observations in the early Universe with nearby galaxies without large-scale supercomputing simulations of the formation and evolution of matter in the Universe. Our Genesis simulations connect all of our surveys and projects, providing theoretical predictions for upcoming observations, and helping to analyse our 3D datasets with mock data cubes of galaxies. These simulations would not be possible without our strong partnership with NCI, Australia's national supercomputing facility.

Finally, we cannot analyse the massive datasets that are incoming from our large radio and optical surveys without dedicated data analysis supercomputers. The Pawsey supercomputing facility in Western Australia and the OzStar Supercomputing facility at Swinburne are providing enormous computational capacity that allows our surveys and projects to be at the productive stage that they are today.

SCIENCE AND DISCOVERIES

Despite the challenges of 2020, our surveys and projects are in full swing, with 227 publications in refereed journals and 11 press releases, which were double our targets for this year. Highlights include the surprising discovery of how gold is created in stars, the discovery of the most distant collisional ring galaxy, an understanding of how the motions of stars and small galaxies contribute to the growth of the most massive galaxies, and how star formation stops in galaxies.

We improved our ability to detect the epoch of reionisation by a factor of 10, the SAMI survey achieved its survey-end milestone of 3000 3D data cubes of nearby galaxies, and the GALAH survey reached its half-way mark of 500,000 stars in the Milky Way. Both massive data sets are available online.

WELCOME TO OUR NEW NODES

The addition of our new nodes has been a major highlight of 2020. During 2019, I was approached by three universities looking to become new nodes of ASTRO 3D. With input and feedback from all surveys and projects, we produced a Partnerships Report. This report identified the unmet needs of the Centre and identified potential new international and national partners that could help the Centre fill its unmet needs.

We ran a transparent process calling for proposals from the academic community, and received proposals from Macquarie University, Monash University, and the University of New South Wales. After a period of consideration by our survey/project leads and executive, and with input from our Advisory Board, we began negotiations with the new nodes, DVC-Rs, culminating with our request to the ARC for approval.

The new nodes have now been approved by the ARC and I am delighted to welcome Macquarie University, Monash University, and the University of New South Wales as new nodes of ASTRO 3D. These new nodes inject an additional $1M into the Centre, but more importantly, provide essential expertise to help the Centre reach its scientific, technical, and outreach goals for 2021-2024. Monash strengthens the Centre in the critical areas of Galactic Archaeology and SAMI/data science. Macquarie University significantly strengthens the Centre in the critical areas of Data Intensive Astronomy and Hector and MAVIS technical development and science. UNSW provides leadership and expertise for the Galaxy Evolution program, as well as leadership of the ASTRO 3D Equity, Diversity and Inclusion committee.

Our new nodes are already making important contributions to the Centre and we look forward to these new collaborative relationships growing over the coming years.

CHALLENGES AND OPPORTUNITIES

This year has been a year of great challenges and also one of opportunity. COVID-19 has set back optical telescope observation and has played a major role in the careers of our youngest researchers.

Early in COVID-19, we surveyed the Centre to gain a full understanding of the impact of COVID-19 shut-downs and closures across the different cohorts in the Centre, as well as on our ASTRO 3D budget, providing a COVID-19 Impact Report to the Centre and Advisory Board. It was clear that some of our students and Early Career Researchers (ECRs) needed more time to complete their projects and that some required bridging funding until they could begin their new positions within Australia and overseas.

The impact of COVID-19 travel restrictions on our budget provided an opportunity. With no travel, no in-person meetings, conferences and workshops, and no in-person professional

DIRECTOR'S WELCOME AND REPORT

development programs, we had a substantial budget reserve that was converted into a COVID-19 emergency fund.

This fund provided 24 extensions to PhD students and postdoctoral researchers based on urgency and need. Many of our students and ECRs have now been able to travel to their new positions, and we continue to allocate funds for extensions on an as-needed basis where COVID-19 related telescope and other delays have impacted projects.

To improve the international visibility of our PhD students and ECRs, we have begun an international ECR seminar series, run by ECR Amelia Fraser-McKelvie and the international seminars committee. This series offers any Australian PhD student and ECR the opportunity to give talks to the international community at times that are within business hours in the North/South American time zone, and in the Europe/Africa time zone.

DIVERSITY AND INCLUSION

One of the goals of ASTRO 3D is to achieve 50% female representation at all levels of the Centre by the end of 2021. At the end of 2020, we achieved 42% female representation across the Centre. In 2020, our Equity, Diversity and Inclusion (EDI) Committee produced a framework and guidelines for inclusive hiring practices that we will be using for our hires in 2021, and we will be encouraging astronomy and physics departments across Australia to use them. Our EDI committee produced a Black Lives Matter Call to Action, which has initiated a sub-committee dedicated to improving the pathways into astronomy and support for people of colour, including Indigenous students. We have submitted an application for the Astronomical Society Pleiades Awards. I am looking forward to the new initiatives that our EDI committee will develop and implement in 2021!

SUSTAINABILITY

In 2020, our Sustainability Committee investigated ways that we can reduce our carbon footprint including sustainable merchandise, virtual conference software, and holding a carbon-neutral (or carbon-negative conference). The committee produced a comprehensive sustainable merchandise report which we will be using for all future merchandise purchases. I am looking forward to running our first in-person carbon-negative conference later this year!

EDUCATION AND OUTREACH

The Education and Outreach team, led by Delese Brewster, is working together on a complement of far-reaching education and outreach programs and has achieved success in obtaining Federal Government grants to support our education and outreach programs, including a recent grant award to support our upcoming Indigenous work experience program.

The Scientists Taking Astronomy to Regional Schools program (STARS) began in the rural towns, and the Telescopes in Schools program using the UWA SPIRIT Telescope has been operating for a full year with much success. The Telescopes in Schools program targets underprivileged schools and girls schools across Australia, and we plan to expand into the ACT and NSW in 2021 with the help of the Macquarie University outreach telescope program.

Our Virtual Reality high school education program is well underway and is being developed in collaboration with high school teachers and astronomers. One of the highlights for me was test-driving the virtual reality program with the headset. It is a very realistic experience with an astronomer avatar, space telescope, and tools that high school students will use to conduct experiments at the Epoch of Reionisation.

To provide a balanced set of role models to counteract stereotypes, we have been developing ASTRO in the Classroom. This program provides talks by astronomers that link with the Year 3-6 Australian Curriculum: Science, as well as providing Q&A sessions with astronomers. We were planning to operate this series live on ZOOM but teachers have overwhelmingly asked for this program to be available as a video series to give full flexibility given differing school schedules. We will be launching this program in 2021.

AN EFFICIENT AND EFFECTIVE TEAM

The Centre would not be possible without the tremendous help and support from our COO Ingrid McCarthy, our management team, and our administrative and education/outreach staff. We are fortunate that our management, administrative, and education/outreach staff members are effective, efficient, and highly professional. This team keeps the Centre running smoothly, as well as leading and contributing to many of the Centre's education initiatives, committees, training programs, and workshops.

THE NEXT CENTRE: ASTRO HD

In 2020, we ran a process to develop the proposal for a Centre beyond ASTRO 3D. We received 20 white papers describing the next Centre visions, science programs, diversity and inclusion programs, and Indigenous programs. After a series of discussion sessions and town halls, we are delighted to support the proposal of ASTRO HD, to be led by Stuart Wyithe (ASTRO 3D Deputy Director) and Cath Trott (ASTRO 3D CI). Rather than being an extension of ASTRO 3D, ASTRO HD has a new scientific vision and brings in >50% new expertise from across Australia and overseas. ASTRO HD aims to understand how the Universe formed and evolved in exquisite detail, with the upcoming generation of high-resolution telescope technology and high-resolution supercomputing simulations. In 2021, the ASTRO HD expression of interest and full proposal will be developed and we are tremendously excited to see these evolve!

TOWARDS 2021

The coming year will be an exciting year for ASTRO 3D, with major discoveries to be made in most of our surveys and projects now that they have reached a critical mass of data. The new nodes bring new scientific expertise and leadership capacity and invigorate the Centre. The proposal preparation for ASTRO HD will propel astronomers to think a decade into the future and we are looking forward to helping bring that vision to fruition!

Lisa Kewley
Centre Director

ABOUT THE CENTRE

The ARC Centre of Excellence for All Sky Astrophysics in 3 Dimensions (ASTRO 3D) commenced in July 2017 and is a Research Centre of Excellence led by the Australian National University (ANU) from its Research School of Astronomy and Astrophysics at Mt Stromlo.
The Centre is comprised of nine collaborating universities — Australian National University, the University of Melbourne, the University of Sydney, Swinburne University of Technology, the University of Western Australia, Curtin University, Monash University, the University of New South Wales and Macquarie University — and a number of world-class Australian and international partners, including:

- Commonwealth Scientific and Industrial Research Organisation (CSIRO)
- National Computational Infrastructure (NCI)
- California Institute of Technology, USA (Caltech)
- University of Washington, USA (UW)
- University of Toronto, Canada
- Netherlands Institute for Radio Astronomy (ASTRON)
- Chinese Academy of Sciences (CAS)
- University of Oxford, UK

The Centre has been funded over seven years with a $30.3m grant from the Australian Research Council (ARC), $9.995m in cash from the nine Australian universities and $134m of in-kind resources from across the collaborating and partner institutions.

OUR VISION

To unlock the mysteries of the Universe using innovative 3D technology, while sharing the excitement and wonder of astronomy to inspire the broader community.

OUR MISSION

- To propel Australia to the forefront of astronomical research by combining Australia's radio, optical and theoretical expertise to understand the origins of our Universe and the galaxies within it.
- To train future Australian astronomers to lead breakthrough science on the next generation of telescopes.
- To share our discoveries and passion for research with the broadest possible audience and inspire the scientists of the future.

OUR STRATEGIC GOALS

1. TRANSFORM OUR UNDERSTANDING OF THE UNIVERSE AND HOW WE GOT HERE

- We will conduct ground breaking new 3-Dimensional surveys alongside an observationally-driven theory program with dedicated telescope and supercomputing facilities.
- We will develop new data intensive astronomy infrastructure to analyse the petabytes (1 petabyte = a billion megabytes, or a million gigabytes) of data that will ensue from the Square Kilometre Array.
- We will translate this research into high-impact publications with broad and far-reaching international dissemination of our results, through our unified and cohesive scientific collaborations and our efficient administrative structure.

2. BUILD AND MAINTAIN THE INFRASTRUCTURE, SKILLS AND EXPERTISE REQUIRED TO MAXIMISE AUSTRALIA'S INVESTMENT IN THE NEW ERA OF MEGA-SCALE OPTICAL AND RADIO TELESCOPES

- Through our research programs, skills workshops, mentoring, leadership and succession planning, we will train young Australian scientists to drive the future world-leading programs on the next generation of telescopes.
- Through the long-term investment and continuity that ASTRO 3D provides, we will ensure that the Federal government's investment in the Square Kilometre Array and Giant Magellan telescopes is realised.

3. INSPIRE, TRAIN AND MENTOR THE NEXT GENERATION OF DIVERSE AUSTRALIAN SCIENTIFIC LEADERS

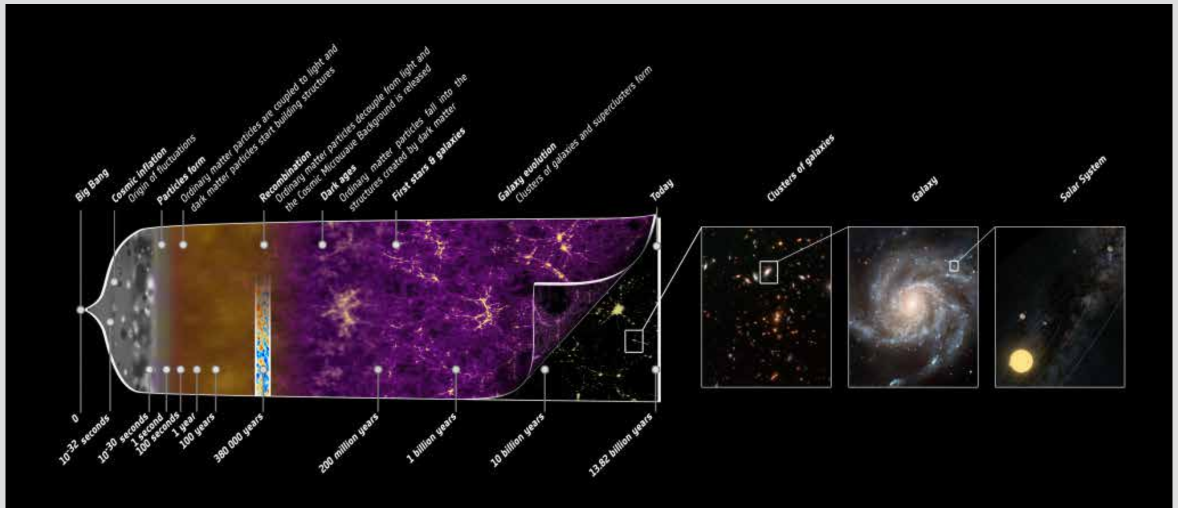
We will inspire students to study science, technology, engineering and mathematics (STEM) through new teacher education programs and our ambitious nation-wide public outreach campaigns.

4. PROVIDE YOUNG AUSTRALIAN SCIENTISTS WITH TRANSFERABLE SKILLS FOR THE MODERN WORKFORCE

We will train the new generation of young Australian astrophysicists in transferable skills including data intensive science, providing a broad range of career options outside astrophysics, including market analysis, population statistics, medical science, bioinformatics, genomics, and commercial sector data analytics.

5. CREATE AN INNOVATION CULTURE TO FACILITATE THE TRANSFER AND COMMERCIALISATION OF ASTRONOMICAL TECHNOLOGY TO OTHER DISCIPLINES

We will identify fresh ideas and aid the commercialisation of new astronomical technology through our Intellectual Property and Innovation Committee, comprised of experts in commercialisation.



This illustration summarises the history of our Universe. It shows the main events that occurred between the initial phase of the cosmos - where its properties were almost uniform and punctuated only by tiny fluctuations - to the rich variety of cosmic structure that we observe today, ranging from stars and planets to galaxies and galaxy clusters. ***IMAGE CREDIT:*** *NASA*

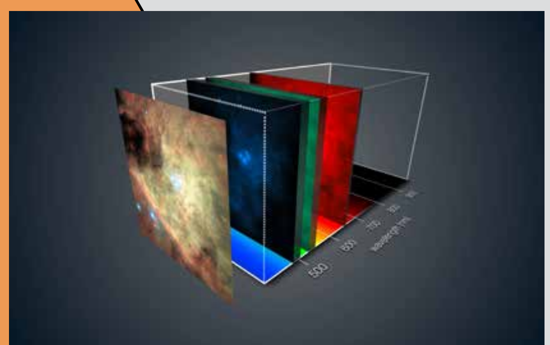
The most fundamental question in astrophysics, "How did we get here?", covers vast ground - from the Big Bang and the stars that first lit the cosmos, to the evolution of the diverse Universe that surrounds us today. No single telescope or theoretical simulation can answer this question. This problem requires new panchromatic all-sky surveys that cover thousands of square degrees of sky to capture the light from hundreds of thousands of galaxies.

Critically, it also requires 3D; the extra dimensions of time and motion are required in addition to the typical space or frequency dimensions in previous surveys. Using new 3D Integral Field Technology (IFU), for every pixel of light we receive from a telescope, we can generate a datacube, that gives us information about:

- spatial properties (what is where)
- spectral properties (what chemical elements are present)
- velocity information (are the stars and the gas moving away from us or towards us)

ASTRO 3D strategically combines new 3D radio, optical, and infrared technology with new supercomputing infrastructure. 3D surveys allow us to track how the different phases of matter, neutral hydrogen gas, ionised gas, stellar mass, and dark matter accumulated and spread across the history of the Universe.

As a consequence of this cutting-edge 3D data and modelling, ASTRO 3D will be able to utilise tools such as virtual reality, 3D movies, 3D printed models and files, coupled with links to school curriculum to help both the general public and students understand and appreciate the new era of discovery in astrophysics.



This image shows how the MUSE IFU instrument on ESO's Very Large Telescope gives a three-dimensional depiction of the Orion Nebula. For each of part of the spectacular star formation region, the light has been split up into its component colours, revealing in detail the chemical and physical properties of each pixel ***IMAGE CREDIT:*** "ESO/MUSE consortium/R. Bacon/L. Calçada"

We have established a collaborative and cohesive structure that focuses on the effective and efficient delivery of the Centre's strategic goals while meeting our Key Performance Indicators.

EXECUTIVE MANAGEMENT COMMITTEE

The Executive Management Committee works collaboratively to oversee day-to-day operations, including financial and risk management, the development of the strategic plan and monitoring performance against agreed outcomes. All collaborating universities are represented on the committee, which is comprised of in 2020:

Centre Director - Prof. Lisa Kewley (ANU)

Centre Deputy Director - Prof. Stuart Wyithe (Melbourne)

Node Leaders at each collaborating university - Prof. Scott Croom (Sydney), Assoc Prof. Emma Ryan-Weber (Swinburne), Dr Barbara Catinella (UWA), Prof. Cathryn Trott (Curtin), Prof. Matthew Colless (ANU), Dr Richard McDermid (Macquarie), Assoc Prof. Kim-vy Tran (UNSW) and Assoc Prof Amanda Karakas (Monash)

Chief Operating Officer - Ms Ingrid McCarthy

Business Manager - Ms Denise Castle

Collaboration Leader - Prof. Joss Bland-Hawthorn (Sydney)

Representatives from other Committees (EDI - Kim-Vy Tran, Snr and Jnr ECRs, Student and Sustainability Committees).

In 2020, the ASTRO 3D Executive Management Committee met 10 times, via Zoom.

ADVISORY BOARD

The Advisory Board meets at least annually to provide support and advice to the Director and Executive Committee on the effectiveness of the Centre in reaching its scientific, technical, and operational goals. In 2020, COVID-19 restrictions prevented an in-person meeting of the board. Instead a virtual meeting was held via Zoom in early June.

The Advisory Board Chair is Professor Tim de Zeeuw, Professor of Theoretical Astronomy at Leiden University and former Director General of the European Southern Observatory.

2020 Advisory Board members:

Dr Linda Tacconi, Scientist, Max Planck Institute for Extraterrestrial Physics.

Professor Lars Hernquist, Mallinckrodt Professor of Astrophysics, Harvard-Smithsonian Centre for Astrophysics.

Sue Weston, CEO of Comcare, previously Deputy Secretary of the federal Department of Industry, Innovation and Science. Sue is also a Chartered Accountant and a Fellow of CPA Australia.

Dr Bobby Cerini, Deputy Director, Director of Science and Learning at Questacon - the National Science and Technology Centre.

Professor Mary Putman, Associate Professor of Astronomy, Columbia University.

ADVISORY BOARD CHAIR REPORT

This was an unexpected and most unusual year for all of us. The ASTRO 3D leadership has been pro-active in dealing with the impacts of the COVID-19 pandemic, and developed a comprehensive and thoughtful response. The earlier investments made in internal communication between the nodes using video conferencing and other means helped in keeping the interactions effective and the projects going well, aided by the sensible decision to use some of the unspent travel money to extend the temporary appointments of students and postdocs.

The International Advisory Board was unfortunately unable to meet 'in 3D' this year. Instead it had a constructive video meeting with the Director and the COO in June. Members of the IAB also attended the science meeting by video, or viewed the programme recording after the fact.

The ASTRO 3D research programme is at the forefront of astrophysics, and the projects advanced significantly during the past year. Collaboration between projects is increasing, adding further value. ASTRO 3D has a remarkably broad and diverse range of engaged students and postdocs who are involved in key research topics under the tutelage of the senior science team leaders. Internal communication is very good, resources are made available to the young scientists for training sessions and retreats, and the administrative support structure has been developed further.

The Education and Outreach program was redesigned to be able to focus on a set of high priority activities aimed at maximising national impact in STEM education and community engagement, and making effective use of Virtual Reality packages. Strong cross-node collaboration was put in place.

This year also saw the addition of three new nodes to ASTRO 3D, at the University of New South Wales, Monash University, and Macquarie University. This strengthens the Galaxy Evolution and First Galaxies efforts and provides additional stellar structure expertise to the Galactic Archaeology and First Stars projects. It also brings strong instrumental expertise to the Center, which will further increase Australian participation in instrumentation efforts for the ESO Very Large Telescope.

The year's remarkable progress despite the pandemic is described in this Annual Report. It once again demonstrates that the Director and her senior team lead a unique world-class astrophysics centre.

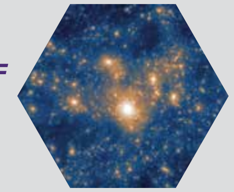
Tim de Zeeuw
IAB Chair

Advisory Board Chair, Professor Tim de Zeeuw Image credit: ESO

2020 MEDIA RELEASES

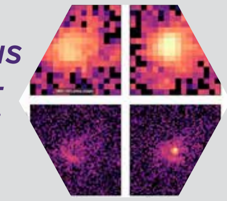
CANBERRA ASTRONOMER BECOMES FIRST AUSTRALIAN TO WIN MAJOR US SCIENCE AWARD IN 133 YEARS (JANUARY).

HUNGRY GALAXIES GROW FAT ON THE FLESH OF THEIR NEIGHBOURS (APRIL).



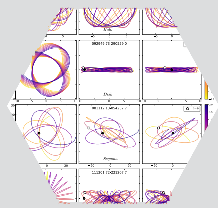
ASTRONOMERS SEE 'COSMIC RING OF FIRE', 11 BILLION YEARS AGO (MAY).

BLINDED BY THE LIGHT NO MORE: SIMULATIONS SHOW NASA'S WEBB TELESCOPE WILL REVEAL HIDDEN GALAXIES (MAY).



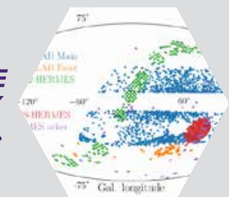
CAN YOU SEE THE STARS? WHO HAS THE DARKEST SKIES? (JULY).

ELEMENTS OF SURPRISE: NEUTRON STARS CONTRIBUTE LITTLE, BUT SOMETHING'S MAKING GOLD, RESEARCH FINDS (SEPTEMBER).



ORBITS OF ANCIENT STARS PROMPT RETHINK ON MILKY WAY EVOLUTION (NOVEMBER).

PLAYING DETECTIVE ON A GALACTIC SCALE: HUGE NEW DATASET WILL SOLVE MULTIPLE MILKY WAY MYSTERIES (NOVEMBER).



FREE TELESCOPES SET SCHOOL KIDS DANCING WITH THE STARS (DECEMBER).

2020 AWARDS AND GRANTS

ASTRO 3D Director, Professor Lisa Kewley, is awarded the James Craig Watson Medal by the US National Academy of Sciences.

ASTRO 3D Chief Investigator, Professor Rachel Webster, from University of Melbourne Node, is awarded an Officer of the Order of Australia in this year's Australia Day Honours

Chief Investigator, Professor Karl Glazebrook, from Swinburne, reaches 300 refereed papers and h-index = 100 exactly.

ASTRO 3D Chief Investigator, Professor Joss Bland-Hawthorn, from the University of Sydney is awarded the 2020 Research Leader in the field of Astronomy and Astrophysics by The Australian.

ASTRO 3D Chief Investigator, Professor Scott Croom receives the University of Sydney's 2020 Vice Chancellors award for his contribution as part of the Physics Undergraduate Lab Team.

ASTRO 3D fellow, Katie Auchettl, from the University of Melbourne receives the Louise Webster Prize for outstanding research by a scientist early in their post-doctoral career.

ASTRO 3D Fellow, Dr Katie Grasha, from the Australian National University was a finalist for the ANU's 2020 Vice-Chancellor Award for Early Career Researchers.

ASTRO 3D Associate Investigator, Aaron Robotham, from the University of Western Australia, is awarded an ARC Future Fellowship.

"Beacons in the Night" - ARC Discovery Project awarded to Dr Claudia Lagos; Dr Aaron Robotham; Dr Aaron Ludlow; Dr Caroline Foster; Dr Tiantian Yuan; Dr Jon Mendel; and Dr Alfred Tiley.

Why do galaxies stop forming stars? - ARC Discovery Project Awarded to ASTRO 3D Associate Investigator, Dr Luca Cortese, (from the University of Western Australia) and team.

ASTRO 3D Affiliate, Karen Lee-Waddell, from the University of Western Australia has been appointed first Director of the Australian Square Kilometre Array Regional Centre (AusSRC).

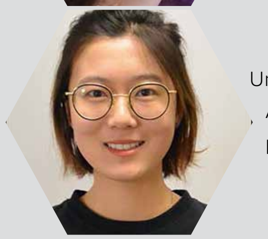
"Wobbling stars reveal their hidden companions" - ARC Discovery Project awarded to ASTRO 3D Affiliate Dr Andrew Casey (from Monash University) and team.

2020 AWARDS AND GRANTS

ASTRO 3D Affiliate Sergio Leon-Saval receives the University of Sydney's 2020 Vice Chancellors award for his contribution as part of the Physics Undergraduate Lab Team.

ASTRO 3D Postdoc, Dr Thomas Nordlander, from the Australian National University, is awarded ASTAC (AAL Astronomy Supercomputer Time Allocation Committee) grant for millions of CPU hours on Gadi, valued at around $280,000.

ASTRO 3D Postdoc, Dr Nichole Barry, from the University of Melbourne is awarded a prestigious Forrest Research Foundation Fellowship at Curtin University for 2021



University of Sydney, Faculty of Science, Learning and Teaching Awards won by ASTRO 3D PhD Student Di Wang for her work as part of the Junior Physics Lab Team.

ASTRO 3D PhD Student, Madeline Marshall from University of Melbourner receives a research fellowship at the National Research Council of Canada, Herzberg Astronomy & Astrophysics, British Columbia.

"STARS" - $85K Federal Government Maker Project grant. awarded to Dr Delese Brewster, Dr Brad Tucker and the rest of the education/outreach team.

AWARDS HIGHLIGHT

2020 JAMES CRAIG WATSON MEDAL

ASTRO 3D Director, Professor Lisa Kewley has transformed our understanding of the early years of the Universe, the development of galaxies, and what happens when they collide.

For her pioneering investigations across theory, modelling and observation, she will receive the US National Academy of Science's biennial James Craig Watson Medal in Washington DC. She is the first person in Australia and the Southern Hemisphere to be awarded the James Craig Watson Medal. Named after American-Canadian nineteenth century astronomer James Craig Watson, the award has been presented every two years since 1887 "for outstanding contributions to the science of astronomy."

In awarding her the Medal, the Academy recognised the global impact of her research on our understanding of how galaxies have formed and evolved over the past 12 billion years.

"Now we understand how to make a computer model of the impact of star formation and supermassive black holes on their host galaxies. We can run the model forward and see how we expect galaxies to evolve, and we can go backwards and see how galaxies like the Milky Way formed, shortly after the epoch of reionisation, when the early Universe lit up,"

She says we're living in a golden era for astronomy. "Early in my career I benefited from the Hubble Space Telescope and the 10 metre Keck telescopes in Hawaii. Students starting today are going to have access to amazing new telescopes including the James Webb Space Telescope, massive new optical telescopes in Chile and the Square Kilometre Array in Australia and South Africa.

"We're going to require astronomers, engineers, data experts and artificial intelligence to use these new instruments, taking us back to the moment of the Big Bang, finding new planets and more."

During her career, Professor Kewley has made fundamental contributions to the study of galaxy collisions, cosmic chemical abundances, galaxy energetics, and the star-formation history of galaxies.

"I am deeply honoured to have been awarded the James Craig Watson Medal," Professor Kewley says. "It speaks to the strength of astronomy in Australia. In pursuing my academic passion, I have been fortunate to be able to collaborate with many talented and insightful scientists. I am also grateful that my work has been supported by the Australian National University, by ASTRO 3D, and by funding bodies such as the Australian Research Council."

ASTRO 3D Director, Professor Lisa Kewley, wins the 2020 James Craig Watson Medal. She is the first Australian to win in 133 years.

ADVISORY BOARD MEMBER TESTIMONIAL

Through its many unique characteristics, ASTRO 3D has established itself as a Center of Excellence with an outstanding reputation for research, mentoring, and inclusion. By bringing together scientists in a variety of fields from numerical simulations, pure theory, and observations, ASTRO 3D has made significant advances to our understanding of the early Universe, the nature of the first stars, cosmic reionization, galaxy formation and evolution, the assembly of the Milky Way, the distribution of gas in and around galaxies, and the detailed internal structure and kinematics of galaxies across a broad range in redshifts. ASTRO 3D has not only been recognized as an international leader in all these fields, it has also laid the groundwork for Australia's future in astrophysics by its involvement in the development of the Giant Magellan Telescope and Square Kilometer Array.

The advances made by scientists in ASTRO 3D have been made possible in no small measure by fostering interactions across disciplines, in particular theory and observations, and through its exceptional efforts in diversity and inclusion, which are nearly unmatched in any research organization in our field. This attention to diversity and inclusion is a testament to the leadership provided by Director Kewley and the heads of the project at participating institutions in Australia and world-wide.

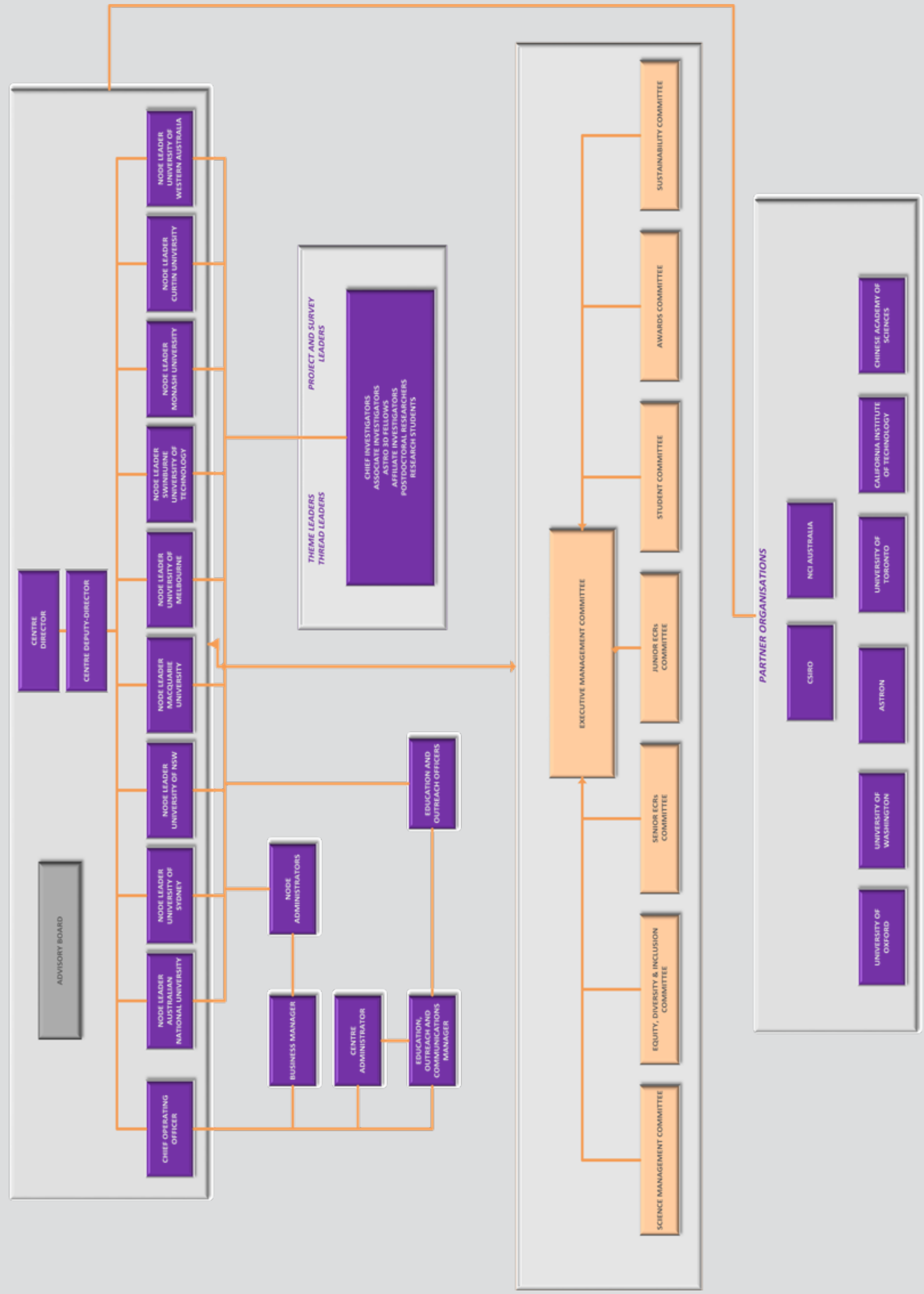
As a participant in many activities of ASTRO 3D, I and members of my research team at Harvard have had the opportunity to experience first-hand the benefits of the approaches being pioneered by this collaboration. The workshops and conferences sponsored by ASTRO 3D are among the best I have ever attended because of the breadth of research discussed and the collegial atmosphere engendered by the inclusive nature of the center. Moreover, I have been able to maintain and expand long-standing relationships with members of the Australian scientific community, including Joss Bland-Hawthorn (Sydney), Lisa Kewley (ANU), Peter Quinn (UWA), and many others. In particular, work with Kewley and Kathryn Grasha (ANU) comparing the distribution of metals in observed and simulated galaxies will inform us about feedback processes that are known to be critical for understanding galaxy evolution, and research being done with Adam Stevens, Claudia Lagos, and Barbara Catinella (all UWA) constrains the impact of environment on gas retention and depletion in galaxies.

In short, ASTRO 3D is a Center of Excellence in every sense and in every way provides an example for the rest of the world to emulate.

Mallinckrodt Professor Lars Hernquist
Advisory Board Member
Harvard-Smithsonian Center for Astrophysics

IMAGE CREDIT: Lars Hernquist

ASTRO 3D ORGANISATIONAL STRUCTURE



THE MWA EOR SURVEY

The Murchison Widefield Array (MWA) is a low-frequency radio telescope in the Western Australian desert. It has been operational since 2013, and has explored our Galaxy's magnetic field, the remains of dead stars, the Sun, and radio-bright distant galaxies that harbour a supermassive black hole at their centres. Aside from these scientific advances, one of the primary objectives of the MWA and future Square Kilometre Array is the search for signals from neutral hydrogen gas that resides in the first billion years of the Universe. During this crucial evolutionary period, the first stars and galaxies in our Universe were born in the Cosmic Dawn, followed by a transformation of the Universe from neutral to ionised in the epoch of reionisation (EoR). Understanding these evolutionary periods will help complete our understanding of the full history of the Universe. The hydrogen signal encodes key information about the spatial location and evolution of these first astrophysical objects, but its detection is extremely challenging due to the signal's weakness compared with radio-bright galaxies in the sky, our own galaxy, and systematic effects of the instrument. Despite this, the past few years have started to reveal clues about this important period.

The ASTRO 3D EoR program provides new measurements of this period of the Universe, and combines them with astrophysical interpretation and underlying physical models. During 2020, the observational team published a major paper exploring a wide period in time and using the largest set of MWA data to-date. This work built on Postdoctoral Fellow Dr Nichole Barry's 2019 paper using a smaller sample of data to achieve the best upper limits on the signal strength. The 2020 publication, led by CI Cathryn Trott from the Curtin node, and involving the full team, was a larger exploration of the reionisation period, studying a wider range in time and space, and yielded limits that improved and expanded on those from 2019. Mahsa Rahimi, PhD student from the University of Melbourne, has been working hard to improve the results from our EoR1 observing field (traditionally our most difficult field), using a new model for the complex Fornax A extended radio galaxy, published by Dr Jack Line this year. Mahsa's results have vastly improved on the signal limits published earlier in 2020, and this work will be published early in 2021.

The improvements in our measurements of the reionisation epoch have all come from the diligent work by the team to improve our calibration sky model and instrument model, and our ability to assess data quality. Much of the team's work focuses effort on these crucial aspects of data preparation that have underpinned the excellent progress. Notable among these are the improved telescope beam measurements by PhD student Aman Chokshi, ionospheric characterisation by Postdoc Chris Jordan and PhD student Kariuki Chege, instrument spectral fitting improvement from Postdoc Bart Pindor, and the high-resolution LoBES sky model from Postdoc Christene Lynch. PhD students Ronniy Joseph, who contributed to understanding the full spectrum of errors on calibration, and Bella Nasirudin, who worked with MWA EoR and Genesis to produce realistic simulations of our data, both submitted their PhDs during 2020.

A new study by Postdoc Bart Pindor and Japan Society for the Promotion of Science (JSPS) Fellow Dr Shintaro Yoshiura has demonstrated the challenging systematics SKA-Low will encounter observing Cosmic Dawn. This study also improved the published MWA limit by over an order of magnitude. In a completely new ASTRO 3D connection for 2020, the broad MWA signal measurements published by the team were sufficient for the first astrophysical interpretation study by University of Melbourne ASTRO 3D Fellow Brad Greig. This work used all of the MWA measurements and a statistical model of the underlying astrophysics to exclude astrophysical models of the evolution and structure of the early Universe. The MWA results were able to exclude models that other astrophysical probes could not, demonstrating that MWA EoR is helping us to understand the first billion years of the Universe. This work also highlights the cross-node and cross-project collaboration afforded by ASTRO 3D.

Murchison Widefield Array ***IMAGE CREDIT:*** *Aman Chokshi*

MWA EOR SURVEY PEOPLE

ASSOC. PROF. CATHRYN TROTT

Curtin University
Project Lead: MWA EoR
Curtin Node Leader

Associate Professor Cathryn Trott is using the current and expanded MWA and in the future, the SKA to explore the evolution of ionised hydrogen in the early Universe.

Cath is leading the ICRAR MWA Epoch of Reionisation (EoR) project for the Origin of the Ionised Universe Theme. Cath is using the supercomputing facilities at the Pawsey Centre for EoR data storage, triage and analysis, augmented by existing and future-developed sophisticated signal processing algorithms.

She is also assessing the scientific progress of the Centre against goals as part of the Science Management Committee, and developing her team with leadership and mentoring skills.

PROF. RACHEL WEBSTER

University of Melbourne
Project Lead: MWA EoR
Curtin Node Leader

Professor Rachel Webster is a Redmond Barry Distinguished Professor in the University of Melbourne School of Physics. She is a world expert in the field of reionisation and is currently the chair of the Board of Directors for Australian Astronomy Limited (AAL). She brings extensive leadership expertise to ASTRO3D.

Rachel is leading the data reduction and analysis of the epoch of reionisation signals observed with the MWA. The extension of the MWA from 128 tiles to 256 tiles will break open the veil on the Epoch of Reionisation, allowing fundamental parameters of the Early Universe to be constrained.

Professor Webster's other research interests include quasar emission regions, gravitational lensing and cosmology; with a side interest in the physics of geothermal energy.

Nichole Barry
University of Melbourne
Postdoctoral Researcher

James Kariuki Chege
Curtin University
PhD Student

Aman Chokshi
University of Melbourne
PhD Student

Jaiden Cook
Curtin University
PhD Student

Bryan Gaensler
University of Toronto
Partner Investigator

Bradley Greig
University of Melbourne
Research Fellow

Chris Jordan
Curtin University
Postdoctoral Researcher

Ronniy Joseph
Curtin University
PhD Student

Michael Kriele
Curtin University
PhD Student

Jack Line
Curtin University
Postdoctoral Researcher

Christene Lynch
Curtin University
Postdoctoral Researcher

Benjamin McKinley
Curtin University
Associate Investigator

Miguel Morales
University of Washington
Partner Investigator

Ainulnabilah (Bella) Nasirudin
Curtin University
PhD Student

Hasti Nateghi
Swinburne
PhD Student

Masha Rahimi
University of Melbourne
PhD Student

Steven Tingay
Curtin University
Associate Investigator

Randall Wayth
Curtin University
Associate Investigator

Shintaro Yoshiura
University of Melbourne
Postdoctoral Researcher

Antennas of the Murchison Widefield Array (MWA) low-frequency radio telescope, located at CSIRO's Murchison Radio Astronomy Observatory.
IMAGE CREDIT: *Dragonfly Media.*

MEMBER HIGHLIGHT

DR CHRISTENE LYNCH

POSTDOCTORAL RESEARCHER AT CURTIN UNIVERSITY

I am Dr Christene Lynch and I'm a Postdoctoral Researcher based at Curtin University in the Murchinson Widefield Array Epoch of Reionisation Survey. I am an expert in reducing and imaging radio data using telescopes from all over the world.

To identify radio bursts and determine whether they are astronomical or terrestrial or due to data analysis artifacts, you need to understand both the telescope and the data reduction processes very well. The cosmological 21 cm line is very weak when compared to the telescope noise and all the astronomical sources between us and the signal. I am working on creating a highly accurate foreground model to remove all of the astronomical sources between us and the signal. Using the new extended configuration of the MWA, I am creating a catalogue that we can use to calibrate our data and minimise any errors associated with that calibration.

I also really enjoy teaching and passing on my own knowledge to students and developing projects that they take on as their own.

This catalogue provides multi-frequency information for over 80,000 sources as well as high angular resolution modelling for these sources. This catalogue will not only be used by the current EoR project but also by the Hydrogen Epoch of Reionisation Project in the United States.

There was no single moment where I realised I wanted to be an astronomer. I've always known that I wanted to be a scientist. In high school, I realised I really enjoyed trying to understand how the Universe works using mathematics. This lead me to focus and major in physics at University and during summer internships I found an interest in astronomy.

One aspect of my job that I really enjoy is teaching, so I think that if I was not an astronomer, I would teach science and mathematics at high school.

The best thing about working in astronomy is that I continually get to learn new things, be it new analysis techniques or new aspects of astronomy. What's great is I can read about new discoveries, mull them over and put them into my own research. I also really enjoy teaching and passing on my own knowledge to students and developing projects that they take on as their own.

One aspect of astronomy that I find challenging is the need to do networking. I am naturally a very introverted and quiet person and so I find it very difficult to make those first steps. ASTRO 3D has helped with this aspect by providing natural ways to collaborate and discuss ideas with people.

In 10 years' time I would like to have formed my own research group at a university that's looking into polarised radio sources using telescopes that are currently on the horizon like the Square Kilometre Array or the next generation Very Large Array. I'd also like to create an internship program that helps support and provide mentoring for students that are part of underrepresented groups in STEM.

MEMBER HIGHLIGHT

KARIUKI CHEGE

PHD STUDENT AT CURTIN UNIVERSITY

My name is Kariuki Chege. I'm a PhD student at Curtin University working in the International Centre for Radio Astronomy Research (ICRAR) and part of the ASTRO 3D EoR project team. EoR stands for epoch of reionisation and is the period in the early Universe when neutral hydrogen was re-ionising – basically when the first stars and galaxies started forming. My PhD research is studying the effects of the Earth's ionosphere on data taken from the Murchison Widefield Array Radio Telescope. The main focus of EoR experiments is to measure the signal emitted during the early Universe and it is referred to as the 21cm signal.

A recent highlight for me is that I am in the final stage of making a coding program that simulates our ionospheric effects at different levels and drives them through a mock observation of the MWA. The end product would be seeing how these manifest in our attempts to measure the 21cm signal. That is something I am pretty happy about.

A recent highlight for me is that I am in the final stage of making a coding program that simulates our ionospheric effects at different levels and drives them through a mock observation of the MWA.

I have liked science since primary school back in Kenya. Getting into astronomy was actually by chance. When I got to university I was placed in a Bachelor of Arts course for my undergraduate and I knew I wanted to change it to a science course. Astronomy was the only science course that had a position, so I had to get into that one and here I am. Actually, there were two courses, astronomy and microbiology, and someone told me "do astronomy!" If I wasn't in astronomy, I would probably be running a business in Kenya or since microbiology was the other option, I would be in microbiology and biotechnology.

I would also like to be inspiring students back in my home country to get into STEM courses.

The main challenge doing a PhD far away from my home country is being away from my family and friends who are my closest support structure.

Some of the things I enjoy in my work are the programming aspect and working with data from world leading telescopes in my specific area of research, as well as working with awesome, great scientists that I look up to.

In ten years' time I would like to be applying the skills that I am gaining during my PhD in a scientific research position or even an industry job. I would also like to be inspiring students back in my home country to get into STEM courses.

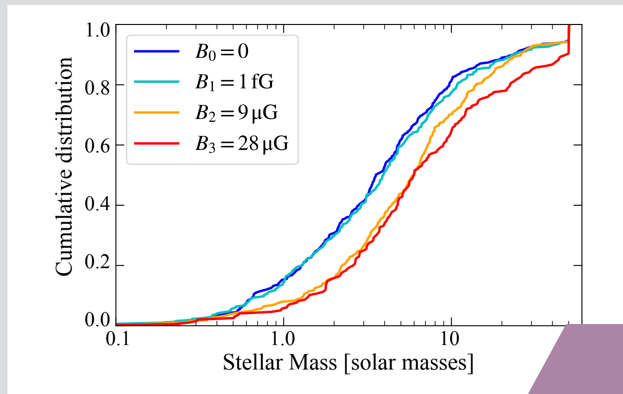
THE FIRST STARS PROJECT

The Universe was created in the Big Bang some 13.8 billion years ago. The very first stars in the Universe formed a few hundred million years later and were made up of only hydrogen, helium and lithium. The evolution of these stars, however, was responsible for producing the elements from carbon onwards, and they have strongly influenced how subsequent generations of stars and galaxies formed and evolved. The nature of these first stars, and whether any could have survived to the present day, remains one of the hottest topics in modern cosmology and astrophysics.

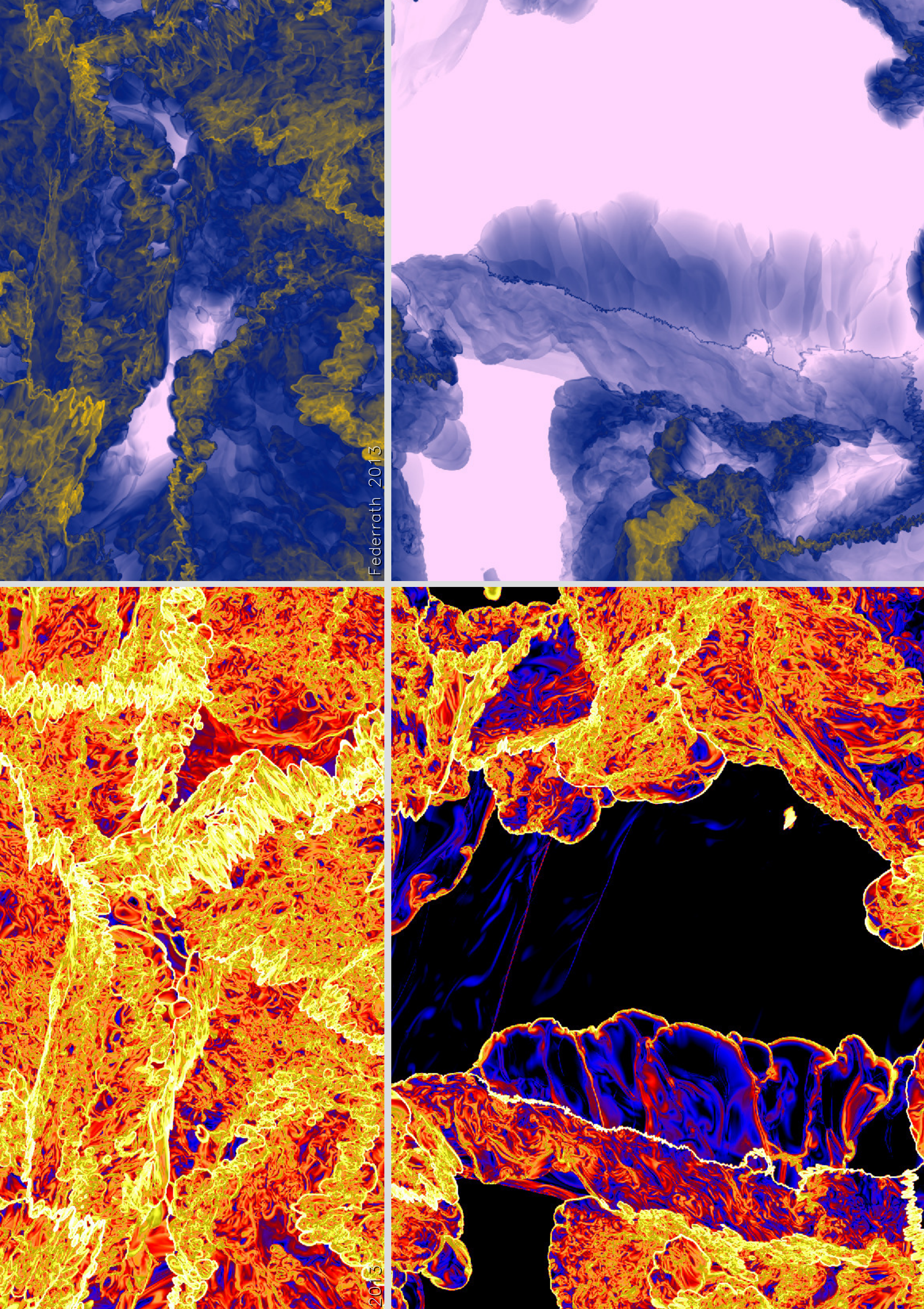
To survive to the present-day, a genuine first star must have formed with a mass approximately equal to or less than the Sun. However, no such stars are known at the present time: is this because only massive stars formed immediately after the Big Bang? PhD student Piyush Sharda (ANU) together with AIs Christoph Federrath (ANU) and Mark Krumholz (ANU) used the National Computational Infrastructure (NCI) supercomputer to conduct three-dimensional, magneto-hydrodynamic simulations of the formation of stars in gas clouds of primordial composition, i.e., made up of only hydrogen and helium. The simulations predict that in the presence of strong magnetic fields, the formation of first stars with masses low enough to survive to the present day would be strongly suppressed. The results are illustrated in the image on the right, which shows the model predictions of the number of stars expected in our First Stars program given different magnetic field strengths. These new predictions will be compared with our First Stars observations to shed light on the magnetic fields that existed in the First Stars in the Universe.

The chemical elements from carbon to uranium are made in stars of different mass, and the amount of each element in stars like the Sun is the result of the evolution of previous generations of stars, starting with the first stars. This process is known as the chemical evolution of galaxies. With detailed knowledge of the rate of how stars of different mass form and die, together with knowledge of which elements they make and how much, it is possible to model the chemical evolution of our own Milky Way galaxy from its formation to the present day. Such detailed chemical evolution models have been constructed by Affiliate Chiaki Kobayashi (Univ. of Hertfordshire, UK) and CI Amanda Karakas (Monash) and Afilliate Maria Lugaro (Konkoly Obs, Hungary) using the most recent stellar physics models. In general, the models (Kobayashi et al. 2020) reproduce well the abundances of the elements in solar neighbourhood stars. However, the results reveal some discrepancies between the model predictions and observations. For example, in the models, elements such as barium and europium are made via the merger of neutron stars, but the predicted amounts of these elements disagree with the observed abundances in old metal-poor stars. Kobayashi and her colleagues suggested that energetic explosions of massive stars which are rapidly rotating and which are also strongly magnetic, might produce sufficient quantities of these elements to explain the discrepancy. Their suggestion has received observational confirmation in recent work led by AI David Yong (ANU). Using observations obtained on the ESO VLT in Chile, the team derived detailed abundances for the most metal-poor star known that possesses substantial enhancements in elements such as barium and europium. The abundance pattern of all the observed elements was found to be consistent with enrichment predicted from the supernova of a magneto-rotational massive first star. The alternative, involving enrichment from a neutron star merger, provides a less satisfactory fit to the data.

ASTRO 3D members are investigating the signatures of the first stars in the chemistry of present-day stars. PhD Students Conrad Chan (Monash), James Grimmett (Monash) and Aldo Mura-Guzman (ANU) have each led work investigating chemical enrichment from faint supernovae, extremely luminous hypernovae, and massive binary stars in three recently published studies.



Our simulations predict how many first stars of each mass will survive to the present day given different possible magnetic field strengths (from Sharda et al. MNRAS 2020, 497, 336).



MEMBER HIGHLIGHT

DR ANDY CASEY

AFFILIATE AT MONASH UNIVERSITY

I'm Andy Casey and I'm an ASTRO 3D Associate Investigator at Monash University. There's so much great science to work on in ASTRO 3D that I feel like Scooby Doo trying to solve mysteries of the Universe! However, most of my science in ASTRO 3D is focussed on the First Stars and GALAH projects.

I'm primarily an observational astrophysicist, so much of my expertise comes from analysing and interpreting spectra from stars. A single spectrum can tell us an incredible amount about what that star is made of, what kind of life it has lived, and it retains a fossil record of the stars that came before it. But to do that well means we often need bespoke data analysis tools that can effortlessly make use of all the data we have, and a strong understanding of stellar evolution (how stars evolve) and nucleosynthesis (how elements are made).

I enjoy making a plot and you suddenly learn something new about the Universe that no human, in the history of our planet, has ever known.

My role in the project is primarily in data analysis and trying to find new First Star candidates. I like that we can so precisely measure the detailed chemical abundances of truly ancient stars, and so a lot of my research is based on trying to measure precise chemical abundances for many metal-poor star candidates (where metal refers to all elements other than hydrogen and helium). But since metal-poor stars are so rare, we need a lot of data in order to find them! So much of my research is on methods to identify new First Star candidates, and wading through all the "junk" the Universe has produced in the last 13 billion years.

I feel like Scooby Doo trying to solve the mysteries of the Universe!

We used to think the First Stars would all be massive (and short lived), but simulations have shown that low mass stars should exist. This was recently corroborated by our discovery of an ultra metal-poor star (below 1/10,000th of the Sun's metal) near the hydrogen burning limit. The star we found is in a binary system and is so low mass it is only just able to burn hydrogen. Although it's not a First Star, it's the first observational evidence that suggests there ought to be low mass First Stars that have survived to the present day.

I came to be working in astronomy by accident: I was working as an engineer and knew I wanted to do a PhD, but I thought it might be cheating if I did a PhD in something I already knew a little bit about. I was always interested in space but had never taken any classes, so I thought that would be something fun to dive into. I enjoy making a plot and suddenly learning something new about the Universe that no human, in the history of our planet, has ever known. It's like the Universe has told you a secret and you get to write it up and tell other people about it.

FIRST STARS PROJECT PEOPLE

PROF. GARY DA COSTA

Australian National University
Project Lead: First Stars

Emeritus Professor Gary Da Costa is currently leading the First Stars program. He has extensive experience in this research area having led for a number of years an international research team that is searching for, and analysing the element abundances in, extremely metal-poor stars. He mentors ECRs and graduate students and is actively seeking to increase cross-node research collaboration within the program.

Mike Bessell
Australian National University
Associate Investigator

Jonathan Bland-Hawthorn
University of Sydney
Chief Investigator

Luca Casagrande
Australian National University
Associate Investigator

Andy Casey
Monash University
Affilate

Jeff Cooke
Swinburne
Associate Investigator

Christoph Federrath
Australian National University
Associate Investigator

Melanie Hampel
Monash University
PhD Student

Alexander Heger
Monash University
Affiliate

Meridith Joyce
Australian National University
Affiliate

Amanda Karakas
Monash University
Affiliate

Maria Lugaro
Konkoly Observatory & Monash University
Affiliate

Dougal Mackey
Australian National University
Associate Investigator

Aldo Mura
Australian National University
PhD Student

Thomas Nordlander
Australian National University
Postdoctoral Researcher

Wei Shen Oh
Australian National University
PhD Student

Xi (Ella) Wang
Australian National University
Student

David Yong
Australian National University
Associate Investigator

THE FIRST GALAXIES PROJECT

The First Galaxies Project is focused on discovering galaxies during the first billion years after the Big Bang, characterising their properties, and investigating how these objects evolve into today's galaxies. These goals are achieved through a combination of observations by some of the most powerful telescopes (space and ground-based) with theoretical and numerical modelling. We are also working on the design of Australia's first space telescope, tiny but powerful, which would contribute to identify some of the very first stellar nurseries in the Universe.

Work continued in 2020 on Hubble Space Telescope data collected as part of the Wide Field Camera 3 Brightest of Reionising Galaxies (BoRG) survey, led by CI Michele Trenti, and searched for galaxies within the first 700 million years after the big bang. A new project in 2020 included extending the search for quasars in the epoch of reionisation beyond the tip of the luminosity function, by exploring parallel infrared (IR) images taken with the Hubble Space Telescope.

PhD student Keven Ren (U.Melb) investigated how the physical origin for the luminosity function of quasars by considering the impact of stochasticity induced by the processes that determine the quasar luminosity for a given host halo and redshift. In 2020 we welcomed Miftahul Hilmi who joined the University of Melbourne node as a new PhD student. Hilmi's PhD will focus on studying galaxies in the epoch of reionisation primarily through space-based infrared observations.

The team continues to develop the mission concept for an Australia space telescope - the SkyHopper CubeSat. This is both a national and international project led by CI Trenti to design, build and operate a small, but powerful, infrared space telescope that fits into a 22kg nano-satellite (a "shoe-box" space telescope).

Artist view of 22kg SkyHopper Space Telescope, a concept for an Australian nano-satellite mission to launch and operate a 15cm aperture telescope optimized for infrared imaging from 0.8 to 1.7 micron that has the potential to contribute to the First Galaxies and Galaxy Evolution projects. Image credit: S. Barraclough, M. Trenti (UoM) and the SkyHopper team

First Galaxies team members are also very excited to be involved in the construction of Australia's other space telescope, the SpIRIT nanosatellite, which was announced in June as the first and only spacecraft project selected for funding by the Australian Space Agency (International Space Investment - Expanding Capability scheme). SpIRIT, expected to be launched in 2022, is an international partnership with the Italian Space Agency. SpIRIT will detect Gamma Ray Bursts (GRBs), as well as electromagnetic counterparts of gravitational wave events. GRBs have great untapped potential to be used as probes of both star formation processes and physical properties of the gas in and around the first galaxies formed during the epoch of reionisation. Thus this new mission will be an excellent opportunity to expand the range of space telescope data to study the first billion years after the Big Bang.

MEMBER HIGHLIGHT

MADELINE MARSHALL

PHD STUDENT AT THE UNIVERSITY OF MELBOURNE

I'm Madeline Marshall and I work with the First Galaxies and Genesis projects within ASTRO 3D. I have just finished my PhD at the University of Melbourne, and am soon to be a Postdoctoral Fellow at the National Research Council of Canada, Herzberg Astronomy & Astrophysics in Victoria, British Columbia.

I study the first quasars in the Universe, which are intensely accreting supermassive black holes that are so bright that they completely outshine their host galaxies. I want to determine the properties of their hosts to help to understand how their supermassive black holes have formed and grown so quickly in the first billion years of the Universe. Unfortunately, this is very difficult as the bright quasars stop us from observing the host galaxies directly. So, I use sophisticated observational analysis techniques and detailed galaxy evolution simulations.

I never thought I would become an astronomer. I grew up in rural Tasmania, where academic careers were completely unheard of.

My work connects the First Galaxies and Genesis teams. The First Galaxies Project has a large focus on observing galaxies in the early Universe with space telescopes. I have been using the Hubble Space Telescope to observe these quasar host galaxies, using a state-of-the-art modelling technique to subtract the light from the quasar to see the underlying host emission. I also use simulations in collaboration with the Genesis team, to make theoretical predictions for the properties of these host galaxies and detailed predictions for what we should see with new telescopes such as the James Webb Space Telescope.

A recent highlight of my work was using the BlueTides simulation to study quasar hosts at z=7. We found that the galaxies hosting quasars tended to be more compact than average, spanning only about 1/30 the diameter of the Milky Way despite containing almost as much mass as our galaxy. The quasar hosts in the simulation also tended to be forming stars rapidly, up to 600 times faster than the current star formation rate in the Milky Way. I was recently awarded 16 hours observation time on the JWST to investigate this further, which is exciting!

I never thought I would become an astronomer. I grew up in rural Tasmania, where academic careers were completely unheard of. I enjoyed math and physics at school, and so went to university in Hobart, not knowing where it would take me. But I'm very glad I followed my interests and ended up where I am today. Now I am passionate about educating students with backgrounds like me of the amazing careers that are out there that they never thought were possible.

If I weren't an astronomer, I might have chosen to be a meteorologist or a teacher.

The thing I enjoy most about being an astronomer is getting to think about something as mind-boggling as a black hole every day. I like problem solving, so it's enjoyable to take a problem that nobody has solved before and try to find a solution. I also love being able to travel the world and meet like-minded people who are solving some of the Universe's big questions.

In 10 years' time I'd love to still be an astronomer. But who knows where it will take me!

FIRST GALAXIES PROJECT PEOPLE

ASSOC. PROF. MICHELE TRENTI

University of Melbourne

Project Lead: First Galaxies

Associate Professor Michele Trenti is an ARC Future Fellow who has built a strong international reputation for combining theoretical simulations and observations to understand the first galaxies in the Universe.

Michele is using the current Hubble Space Telescope and will use the future JWST to observe the chemical elements within the First Galaxies of the Universe. This involves understanding how much of the elements were produced in the first galaxies and whether they are blown out of these galaxies by massive galactic-scale winds from stars or supermassive black holes.

Michele is also connecting theorists with observers to understand galaxy formation from both a theoretical and observational practice, aiding in linking the First Galaxies observations with the deep understanding of galaxy evolution that ASTRO 3D will provide.

Stephanie Bernard
University of Melbourne
PhD Student

Jonathan Bland-Hawthorn
University of Sydney
Chief Investigator

Andrew Bunker
University of Oxford
Partner Investigator

Alex Cameron
University of Melbourne
PhD Student

Karl Glazebrook
Swinburne
Chief Investigator

Miftahul Hilmi
University of Melbourne
PhD Student

Nicha Leethochawalit
University of Melbourne
Postdoctoral Researcher

Benjamin Metha
University of Melbourne
Student

Simon Mutch
University of Melbourne
Postdoctoral Researcher

Keven Ren
University of Melbourne
PhD Student

Christian Reichardt
University of Melbourne
Associate Investigator

Emma Ryan-Weber
Swinburne
Chief Investigator

Kim-Vy Tran
University of New South Wales
Affiliate

Stuart Wyithe
University of Melbourne
Chief Investigator

SCIENCE HIGHLIGHT

COSMIC "RING OF FIRE" FOUND

Astronomers have captured an image of a super-rare type of galaxy – described as a "cosmic ring of fire" – as it existed 11 billion years ago.

The galaxy, which has roughly the mass of the Milky Way, is circular with a hole in the middle, rather like a titanic doughnut. Its discovery, announced in the journal Nature Astronomy, is set to shake up theories about the earliest formation of galactic structures and how they evolve.

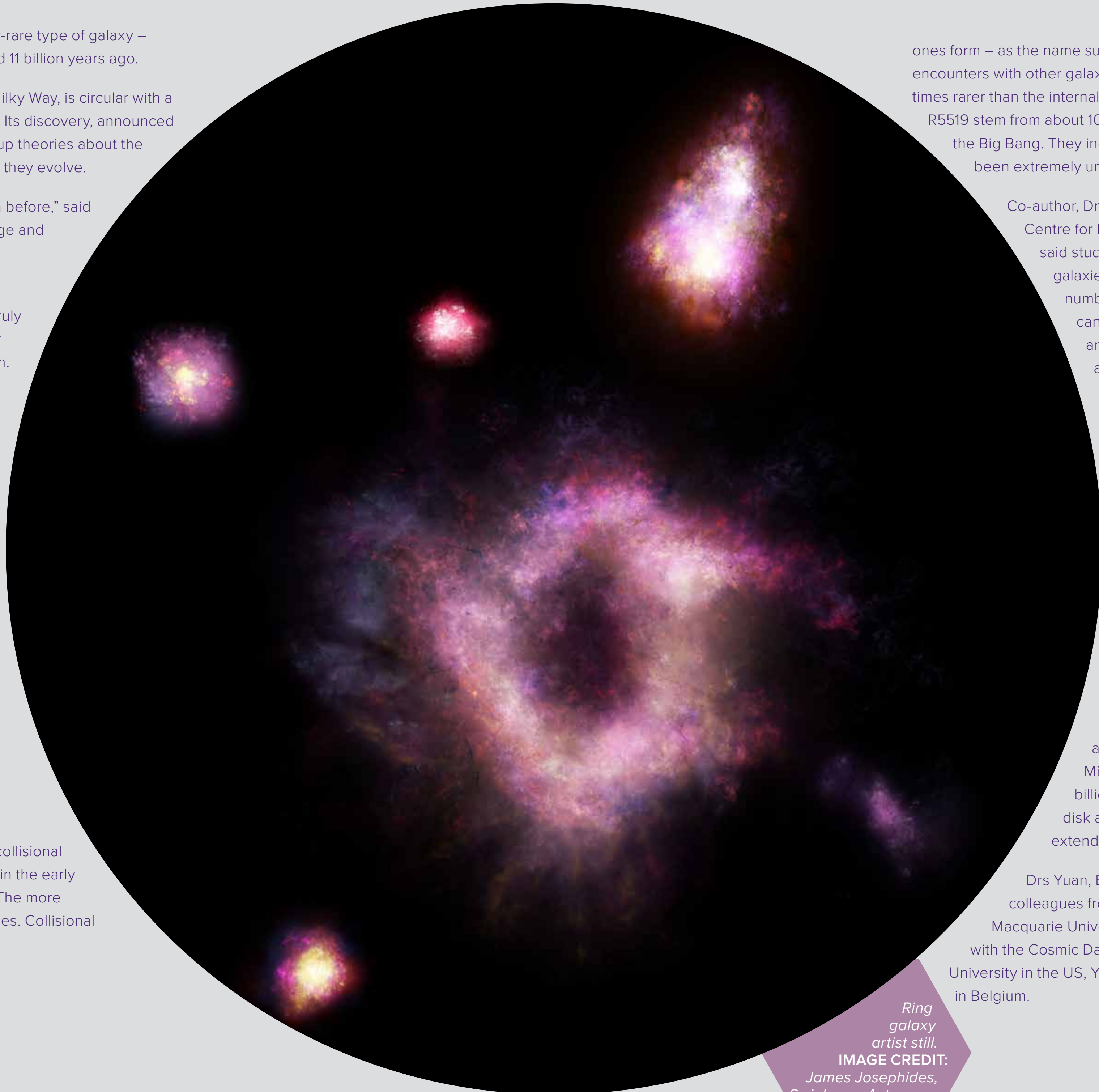
"It is a very curious object that we've never seen before," said lead researcher Dr Tiantian Yuan, "It looks strange and familiar at the same time."

The galaxy, named R5519, is 11 billion light-years from the Solar System. The hole at its centre is truly massive, with a diameter two billion times longer than the distance between the Earth and the Sun. To put it another way, it is three million times bigger than the diameter of the supermassive black hole in the galaxy Messier 87, which in 2019 became the first ever to be directly imaged.

"It is making stars at a rate 50 times greater than the Milky Way," said Dr Yuan, who is a Fellow based at the Centre for Astrophysics and Supercomputing at Swinburne University of Technology.

"Most of that activity is taking place on its ring – so it truly is a ring of fire." Working with colleagues from around Australia, US, Canada, Belgium and Denmark, Dr Yuan used spectroscopic data gathered by the WM Keck Observatory in Hawaii and images recorded by NASA's Hubble Space Telescope to identify the unusual structure.

The evidence suggests it is a type known as a "collisional ring galaxy", making it the first one ever located in the early Universe. There are two kinds of ring galaxies. The more common type forms because of internal processes. Collisional ones form – as the name suggests – as a result of immense and violent encounters with other galaxies. In the nearby "local" Universe they are 1000 times rarer than the internally created type. Images of the much more distant R5519 stem from about 10.8 billion years ago, just three billion years after the Big Bang. They indicate that collisional ring galaxies have always been extremely uncommon.



Ring galaxy artist still. **IMAGE CREDIT:** *James Josephides, Swinburne Astronomy Productions*

Co-author, Dr Ahmed Elagali, based at the International Centre for Radio Astronomy Research in Western Australia, said studying R5519 would help determine when spiral galaxies began to develop. "Further, constraining the number density of ring galaxies through cosmic time can also be used to put constraints on the assembly and evolution of local-like galaxy groups," he added.

Another co-author, Professor Kenneth Freeman from the Australian National University, said the discovery had implications for understanding how galaxies like the Milky Way formed. "The collisional formation of ring galaxies requires a thin disk to be present in the 'victim' galaxy before the collision occurs," he explained. "The thin disk is the defining component of spiral galaxies: before it assembled, the galaxies were in a disorderly state, not yet recognisable as spiral galaxies."

"In the case of this ring galaxy, we are looking back into the early Universe by 11 billion years, into a time when thin disks were only just assembling. For comparison, the thin disk of our Milky Way began to come together only about nine billion years ago. This discovery is an indication that disk assembly in spiral galaxies occurred over a more extended period than previously thought."

Drs Yuan, Elagali and Professor Freeman worked with colleagues from the University of New South Wales, Macquarie University, and University of Queensland together with the Cosmic Dawn Centre (DAWN) in Denmark, Texas A&M University in the US, York University in Canada, and Ghent University in Belgium.

THE GALAXY EVOLUTION PROJECT

The Galaxy Evolution team is undertaking a series of interlinked surveys to track galaxy formation and evolution across 12 billion years of cosmic time. These surveys address the three main ASTRO 3D science questions: understanding the origins of the ionisation, chemical elements, mass and motions of galaxies in the universe. The surveys use the world's largest telescopes, and together trace the different phases of the gas and cover 12 billion years of galaxy evolution. The European Southern Observatory VLT plays a major role in these surveys, with multiple instruments being used, including KMOS, MUSE, and X-shooter.

KOALA (Kilofibre Optical AAT Lenslet Array) is taking Gemini observations of "single star" HII regions and AAT observations of planetary nebulae that will be used as test beds for ionisation science like Lyman continuum escape and UV emission line modeling. This new project is led by Swinburne postdoc Rob Bassett and connects experts at U.Queensland, Swinburne, Monash, U.Melbourne and the ANU, with telescope proposals submitted.

DUVET (Deep near UV observations of Entrained gas in Turbulent galaxies) uses observations from the Keck telescope to study``feedback" from star formation in which the young stars and supernova explosions redistribute gas in galaxies. We do so by studying the details of the populations of stars as well as the kinematics of the gas that have been driven out by the explosions of stars. DUVET is led by Swinburne CI Deanne Fisher and continued taking observations in 2020.

MAGPI (Middle Ages Galaxy Properties with Integral Field Spectroscopy) uses the VLT MUSE instrument to study the transformation of massive galaxy morphology and kinematics over cosmic time. It acts as an extension to our highly-successful local integral field spectroscopy survey SAMI. The MAGPI survey is led by a collaboration of ASTRO 3D fellows and investigators across ANU, Swinburne, U.Sydney, UWA, Macquarie, UNSW, and U.Melbourne. It began taking data in 2020, and is recruiting students to work on the data.

The Galaxy Evolution team meet each month for updates on projects related to our three main themes of chemical evolution, kinematics, and ionisation. To promote linkages and cross-project collaborations, we have liaisons to the other main ASTRO 3D projects who report as needed. We also regularly have "Spotlight" talks to learn more about specific projects, e.g. by students and new members. **IMAGE CREDIT:** *Kim-Vy Tran*

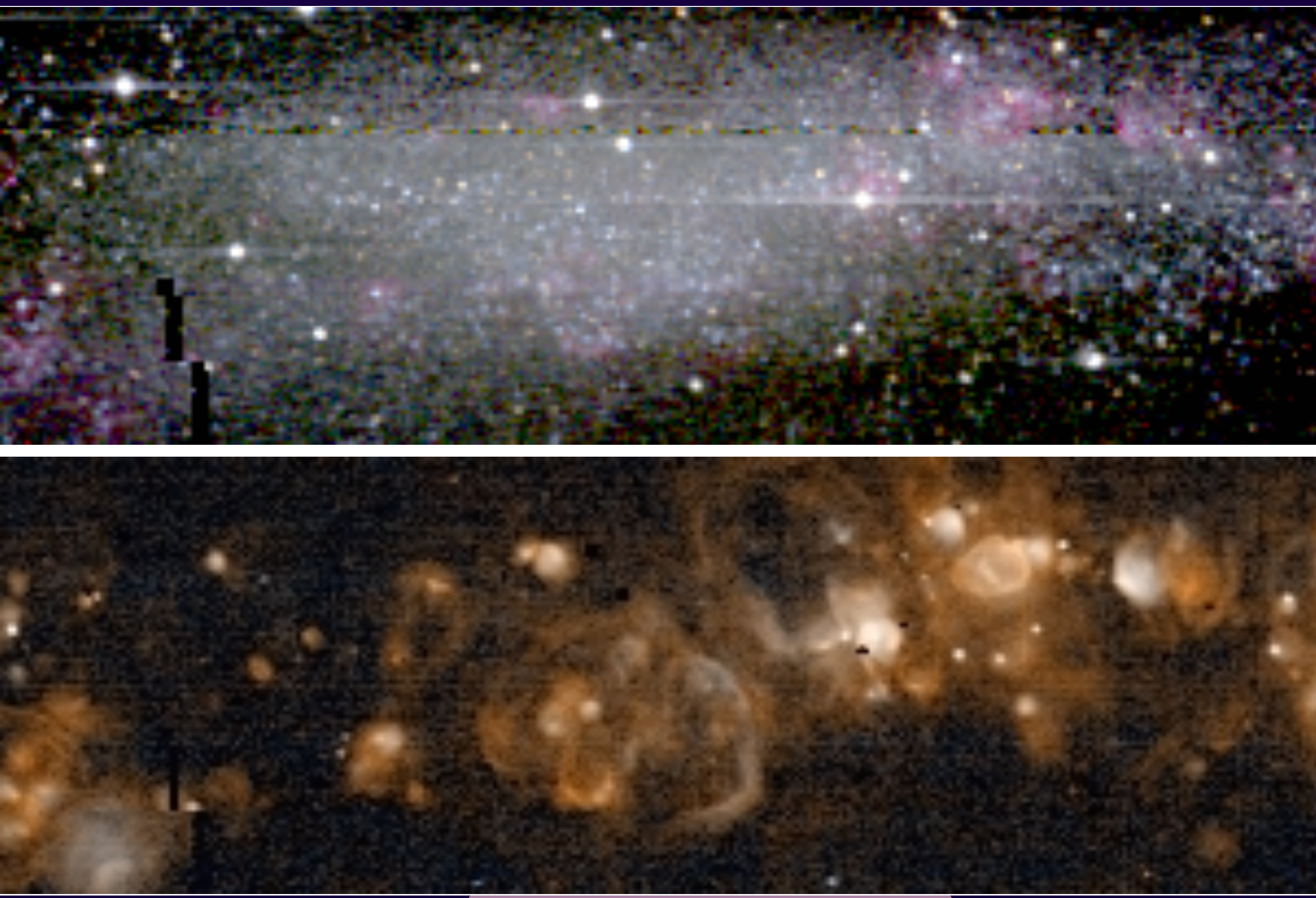
ASTRO 3D Fellow Katie Grasha (ANU) giving a talk to primary school kids in Canberra as part of a Space Squad event in October 2020. Members of the Galaxy Evolution team regularly engage in community and public outreach by giving talks and developing new programs, e.g. as part of the SciX mentoring program at UNSW

K3-LARS – K3-LARS (KMOS Lyman Alpha Reference Survey at z~3) This multi-wavelength VLT legacy data set will characterise typical z = 3 to 4 Lyman alpha emitting galaxies by tracing galaxy kinematics, conditions of the interstellar medium, and Lyman continuum escape. Led by ANU ASTRO 3D Fellow, Emily Wisnioski, K3-LARS will provide a high-redshift reference point comparable to the successful local Lyα reference sample (LARS). K3-LARS data is in hand and is currently being analysed.

MOSEL The Multi-Object Spectroscopic Emission Line survey is led by UNSW CI Kim-Vy-Tran with colleagues at Swinburne, ANU, and U.Melbourne. MOSEL uses Keck and the VLT to study galaxies that are 12 billion light years away using a technique called gravitational lensing. The light of distant galaxies is bent by the most massive structures in the universe, creating a magnifying glass the size of galaxies. We have discovered hundreds of gravitationally lensed galaxies using the Dark Energy Survey. By measuring the properties ofthe lensed galaxies, MOSEL is determining what drives the rise and fall of star formation in these young galaxies and how they assemble their stars. This project has received Keck and VLT time to obtain spectroscopy for kinematics of lensed galaxy targets.

The XQR-30 ESO large program has obtained high quality VLT X-shooter spectra of 30 redshift 6 quasars. It aims to detect metals (elements heavier than hydrogen & Helium) up to 1 billion years after the Big Bang. Analysis of the VLT data is ongoing.

The Galaxy Evolution team has continuing its work to develop the next generation photoionization models to accurately model star forming regions and distant galaxies across the full wavelength range from the UV through to the sub-mm. PhD student Yifei Jin has made a major breakthrough by successfully modelling HII regions with fractal and blister geometries in full 3 dimensional Monte Carlo photoionization models with the emission-lines of 30 chemical elements calculated. These models are the only self-consistent detailed 3D Monte Carlo photoionization models in the world. Yifei and the ANU team (CI Kewley and AI Sutherland) will calculate a large model grid in 2021-2022, with the full suite of models to be published and released to the astronomical community when complete.



The upper panel shows a composite image of the stellar continuua in the nearby dwarf galaxy NGC 3109 using three colour filters.

The lower panel emphasises the ionised gas component, with the emission line map of Hβ and [OIII]λ5007 shown with different shades of orange and blue, respectively. These data come from the TYPHOON survey, an IFU dataset that provides a spectrum at every pixel for nearly 100 local galaxies. (Grasha et al.).

MEMBER HIGHLIGHT

ANISHYA HARSHAN

PHD STUDENT AT THE UNIVERSITY OF NEW SOUTH WALES

My name is Anishya Harshan. I am a PhD Student at the University of New South Wales in Sydney and a member of the Galaxy Evolution team.

I am interested in learning how galaxies like our own Milky Way formed and evolved for 13 billion years. For my PhD, I am studying young (extremely distant) galaxies at a time when the Universe was just 3 billion years old to learn how their properties and star formation evolved in different environments.

I use spectroscopy and imaging data to study galaxy properties like the star formation history of galaxies in this epoch and compare the galaxies that exist in different environments to discern the early effects of environment on the evolution of galaxies. I also use data from large hydrodynamical simulations to study how our theories of galaxy evolution compare to what we observe and to understand different processes that could explain the observational results.

> ***What I love the most about astronomy is looking at data. It's like looking for invisible things! Since I work with high redshift galaxies, it's like the game "Where's Waldo?"***

Earlier this year I published my first research paper, which was really exciting for me. In this paper we explored galaxies in proto-cluster and field environments at redshift 1.5, that is about 10 billion years ago. We looked at how the average electron density of the star forming regions in these galaxies were different. And we found the first sign of elevation of electron density in the higher density environments which is contrary to what we see in the local Universe.

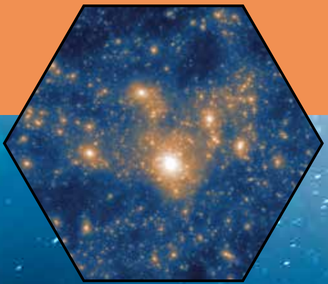
In high school I was really inspired by my physics teacher who made me really curious about how everything works. I went to the Luxembourg Institute of Socio-Economic Research (LISER) to study physics. The two subjects that I got really interested in were astronomy and ecology. So I did a project in ecology with a scientist who himself was an astronomer turned ecologist! I asked him how I can be both an astronomer and ecologist like him! That's when he advised me that if I study physics, I can apply my knowledge from it to ecology. I have completed almost 3/4 of my PhD and I am finding it interesting and enjoyable.

If I cannot be an astronomer, I would like to be an ecologist or have a job that involves biodiversity or conservation. I am passionate about our planet and love to learn about animals; their behaviours and evolution. Or I would like to complete my training in classical dance in India and be a Odissi dancer on the side!

What I love the most about astronomy is looking at data. It's like looking for invisible things! Since I work with high redshift galaxies, it's like the game "Where's Waldo?" Using such little information that is present in these images or spectra, we are trying to solve a very complex puzzle. Some of the most satisfying moments during my PhD however have been, when I have struggled to figure out something, and then suddenly I have a light-bulb moment and I am able to resolve the problem.

In ten year's time I hope to have become an independent scientist and be working with other brilliant researchers and students. There are many new exciting surveys and telescopes that will be coming up in the near future and I am looking forward to getting new information from these projects to study the high redshift Universe.

GALAXY EVOLUTION PROJECT PEOPLE



ASSOC. PROF. KIM-VY TRAN

University of New South Wales

Project Lead: Galaxy Evolution

Kim-Vy Tran's research program advances our knowledge of how galaxies assemble over cosmic time by capitalising on the high resolution, extreme sensitivity, and broad wavelength coverage of ground and space-based telescopes. This comprehensive approach enables her to study galaxies from the local neighborhood to the edge of the observable Universe.

Kim-Vy has leading roles in the ZFOURGE, ZFIRE, and MOSEL galaxy surveys that integrate multi-wavelength imaging and spectroscopic campaigns to track how galaxies evolve. She is currently the Executive Chair of the ASTRO 3D Galaxy Evolution project and managing the AGEL survey. Kim-Vy also currently serves as Vice-President of the Galaxies Division in the International Astronomical Union.

Kim-Vy is devoted to promoting Equity, Diversity, and Inclusion (EDI) at all levels and helping people achieve their full potential. In addition to her science leadership, she Chairs the ASTRO 3D EDI committee and contributes to professional development workshops at ASTRO 3D meetings.

ASSOC. PROF. EMMA RYAN-WEBER

Swinburne University of Technology

Project Lead: Galaxy Evolution

Associate Professor Emma Ryan-Weber is an international leader in the observation of metals in the Intergalactic Medium at high redshifts.

Her pioneering near-infrared spectroscopic observation was the first to demonstrate the viability of detecting intergalactic metals towards the end of the Epoch of Reionisation.

Within the Galaxy Evolution Project Emma is overseeing work on ionisation: directly measuring the ionising radiation from galaxies at redshifts in the broad range $z\sim3–4$ and developing calibration for escaping flux.

The results will be applied to galaxies at higher redshifts to ultimately understand how the Universe was reionised.

Roberto Abraham
University of Toronto
Partner Investigator

Maryam Arabsalmani
University of Western Australia
Postdoctoral Researcher

Robert Bassett
Swinburne
Postdoctoral Researcher

Adam Batten
Swinburne
PhD Student

Andrew Battisti
Australian National University
Postdoctoral Researcher

Dorota Bayer
Swinburne
Postdoctoral Researcher

Jean Brodie
Swinburne
Associate Investigator

Sarah Brough
University of New South Wales
Associate Investigator

Andrew Bunker
University of Oxford
Partner Investigator

Alex Cameron
University of Melbourne
PhD Student

Andy Casey
Monash University
Affiliate

Andrew Connolly
University of Washington
Associate Investigator

Jeff Cooke
Swinburne
Associate Investigator

Elena D'Onghia
University of Wisconsin-Madison
Affiliate

Elisabete da Cunha
University of Western Australia
Research Fellow

Julianne Dalcanton
University of Washington
Partner Investigator

Rebecca Davies
University of Melbourne
PhD Student

James Esdaile
Swinburne
PhD Student

Deanne Fisher
Swinburne
Associate Investigator

Gary Foran
Swinburne
PhD Student

Duncan Forbes
Swinburne
Affiliate

Caroline Foster
University of Sydney
Research Fellow

Marianne Girard
Swinburne
Associate Investigator

Karl Glazebrook
Swinburne
Chief Investigator

Kathryn Grasha
Australian National University
Postdoctoral Researcher

GALAXY EVOLUTION PROJECT PEOPLE

Brent Groves
University of Western Australia
Associate Investigator

Anshu Gupta
University of New South Wales
Postdoctoral Researcher

Jennifer Hardwick
University of Western Australia
PhD Student

Anishya Harshan
University of New South Wales
Postdoctoral Researcher

Colin Jacobs
Swinburne
Associate Investigator

Yifei Jin
Australian National University
PhD Student

Melanie Kassinen
Max Planck Institute of Technology
Affiliate

Glenn Kacprzak
Swinburne
Associate Investigator

Lisa Kewley
Australian National University
Chief Investigator

Chiaki Kobayashi
University of Hertfordshire
Affiliate

Claudia Lagos
University of Western Australia
Research Fellow

Sarah Leslie
Leiden University
Affiliate

Emily Levesque
University of Washington
Associate Investigator

Jing Li
Australian National University
Student

Angel Lopez-Sanchez
Macquarie University
Associate Investigator

Elizabeth Mahony
CSIRO
Associate Investigator

Ilya Mandel
Monash University
Affiliate

Christopher Martin
California Institute of Technology
Partner Investigator

Richard McDermid
Macquarie University
Affiliate

Rebecca McElroy
University of Sydney
Affiliate

Daniel McPherson
Swinburne
PhD Student

Trevor Mendel
Australian National University
Research Fellow

Uros Mestric
Swinburne
PhD Student

Stephanie Monty
Australian National University
PhD Student

Aaron Myszka
Swinburne
PhD Student

Nikki Nielsen
Swinburne
Postdoctoral Researcher

Cristina Popescu
University of Central Lancashire
Affiliate

Tom Quinn
University of Washington
Associate Investigator

Bronwyn Reichardt Chu
Swinburne
PhD Student

Stephanie Rowlands
Swinburne
Student

Lee Spitler
Macquarie University
Associate Investigator

Sarah Sweet
Swinburne
Postdoctoral Researcher

Ji-Jia Tang
Australian National University
PhD Student

Adam Thomas
Australian National University
Postdoctoral Researcher

Jesse van de Sande
University of Sydney
Associate Investigator

Benjamin Wibking
Australian National University
Postdoctoral Researcher

Matthew Wilkinson
University of Western Australia
Postdoctoral Researcher

Emily Wisnioski
Australian National University
Research Fellow

Tiantian Yuan
Swinburne
Research Fellow

HUNGRY GALAXIES GROW FAT ON THE FLESH OF THEIR NEIGHBOURS

Galaxies grow larger by eating their smaller neighbours, new research reveals.

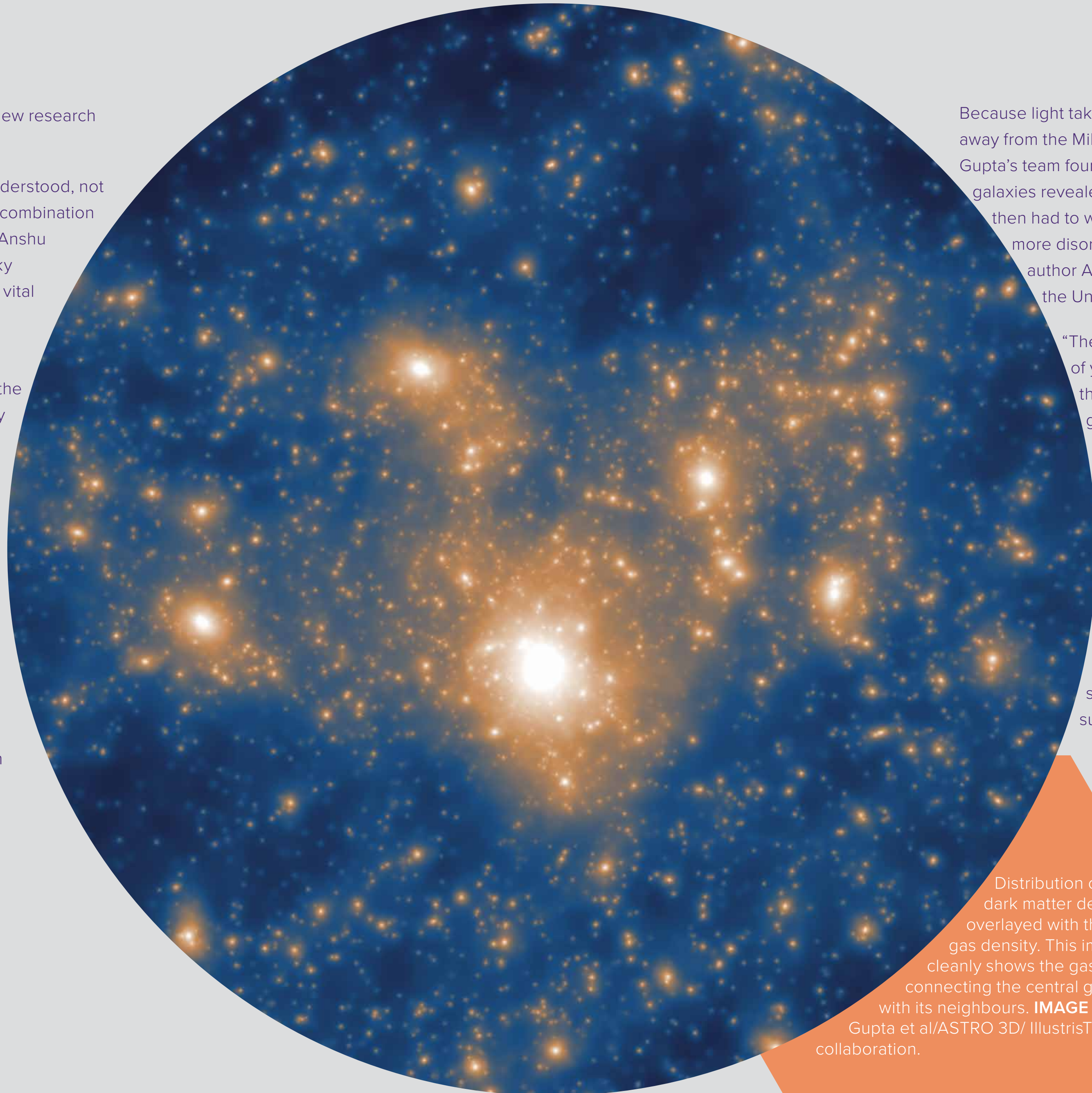
Exactly how massive galaxies attain their size is poorly understood, not least because they swell over billions of years. But now a combination of observation and modelling from researchers led by Dr Anshu Gupta from Australia's ARC Centre of Excellence for All Sky Astrophysics in 3 Dimensions (ASTRO 3D) has provided a vital clue.

In a paper published in The Astrophysical Journal, the scientists combine data from an Australian project called the Multi-Object Spectroscopic Emission Line (MOSEL) survey with a cosmological modelling program running on some of the world's largest supercomputers in order to glimpse the forces that create these ancient galactic monsters.

By analysing how gases within galaxies move, Dr Gupta said, it is possible to discover the proportion of stars made internally – and the proportion effectively cannibalised from elsewhere.

"We found that in old massive galaxies – those around 10 billion light years away from us – things move around in lots of different directions," she said.

"That strongly suggests that many of the stars within them have been acquired from outside. In other words, the big galaxies have been eating the smaller ones."



Distribution of dark matter density overlayed with the gas density. This image cleanly shows the gas channels connecting the central galaxy with its neighbours. **IMAGE CREDIT:** Gupta et al/ASTRO 3D/ IllustrisTNG collaboration.

Because light takes time to travel through the Universe, galaxies further away from the Milky Way are seen at an earlier point in their existence. Dr Gupta's team found that observation and modelling of these very distant galaxies revealed much less variation in their internal movements."We then had to work out why 'older', closer big galaxies were so much more disordered than the 'younger', more distant ones," said second author ASTRO 3D's Dr Kim-Vy Tran, who like Dr Gupta, is based at the University of New South Wales (UNSW).

"The most likely explanation is that in the intervening billions of years the surviving galaxies have grown fat and disorderly through incorporating smaller ones. I think of it as big galaxies having a constant case of the cosmic munchies."

The research team – which included scientists from other Australian universities plus institutions in the US, Canada, Mexico, Belgium and the Netherlands – ran their modelling on a specially designed set of simulations known as IllustrisTNG.

This is a multi-year, international project that aims to build a series of large cosmological models of how galaxies form. The program is so big that it has to run simultaneously on several of world's most powerful supercomputers.

"The modelling showed that younger galaxies have had less time to merge with other ones," said Dr Gupta. "This gives a strong clue to what happens during an important stage of their evolution."

THE ASKAP SURVEYS

Australian Square Kilometre Array Pathfinder (ASKAP) telescope. Image credit: CSIRO

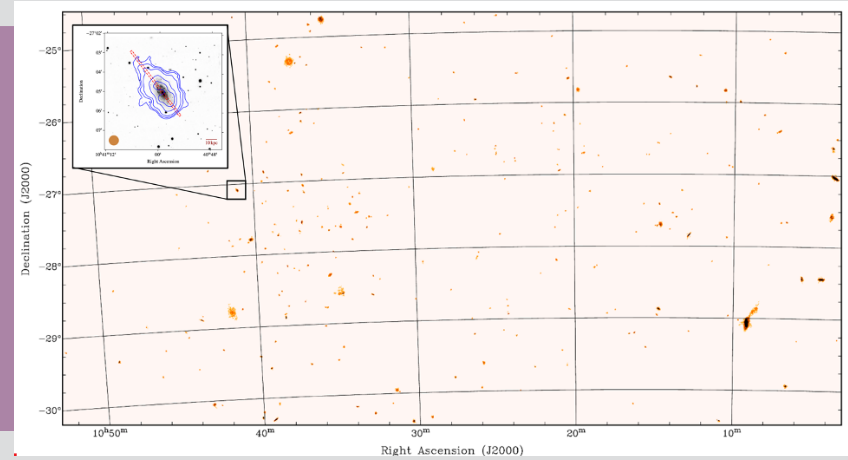
The ASKAP Surveys project tracks the evolution and buildup of neutral hydrogen in galaxies over the past 7–8 billion years. Neutral hydrogen gas (HI) provides the reservoir of material from which new stars can form in galaxies, and so is key to understanding how galaxies evolve over cosmic time. ASTRO 3D researchers are members of several ASKAP HI survey teams, using the new Australian SKA Pathfinder to map out the cosmic distribution of HI in unprecedented detail via three different but interlinked ASKAP surveys.

- The WALLABY survey (led by CI Lister Staveley-Smith) is covering three-quarters of the sky and is expected to detect the 21cm HI emission line from up to 500,000 galaxies, looking back 2 billion years in cosmic time.
- The DINGO survey (led by AI Martin Meyer) is focussing on the evolution of galaxies and the gas-rich Universe out to 4 billion years ago and expects to detect up to 100,000 galaxies through ultra-deep ASKAP observations spanning 60 square degrees of sky.
- The FLASH survey (led by CI Elaine Sadler and AI James Allison) is searching for the 21cm HI line in absorption against bright continuum sources across the whole southern sky, and will probe the neutral gas content of several hundred individual galaxies between 4 and 8 billion years ago, where the HI emission line is too weak to be detectable in even the deepest ASKAP surveys.

In 2020, all teams carried out pilot phase I observations with the full 36-antenna ASKAP array.

WALLABY

Analysis of Phase 1 pilot survey observations, which cover three 60 deg^2 areas of sky was the main focus in 2020. The three regions targeted were the Hydra cluster, the NGC 4636 group, and the Norma Cluster. Pipeline reduction of the Hydra cluster data is complete (approximately 200 TB of data), and the data has been made publicly available on the CSIRO ASKAP Science Data Archive (CASDA). Further (level 7) data products have been made available to the team in two separate data releases. A total of 270 separate HI sources have been characterised, and the team is proceeding with its scientific analysis of the data. Reduction of data in the other two regions is proceeding. The first WALLABY pilot paper has been submitted to MNRAS by Postdoc Tristan Reynolds, and the WALLABY reference paper is published (Koribalski+ 2020, Ap&SS, 365, 188). Other papers using pilot, pre-pilot and early science data are being prepared for submission.



ASKAP WALLABY DR2 HI column density image of 270 galaxies in the region around the Hydra cluster. An expanded view of ESO 501-G075, which appears to be interacting with hot gas in the cluster, is shown. ***IMAGE CREDIT:*** *Tristan Reynolds and Tobias Westmeier.*

There continues to be major progress in our technical post-processing efforts. The SoFiA 3D Source Finding Application has now been multithreaded and parallelised. A paper describing the SoFiA pipeline has been submitted to MNRAS by Tobias Westmeier. Further activities associated with automating the kinematic fitting and distributing the post-processing pipeline across partner organisations are proceeding.

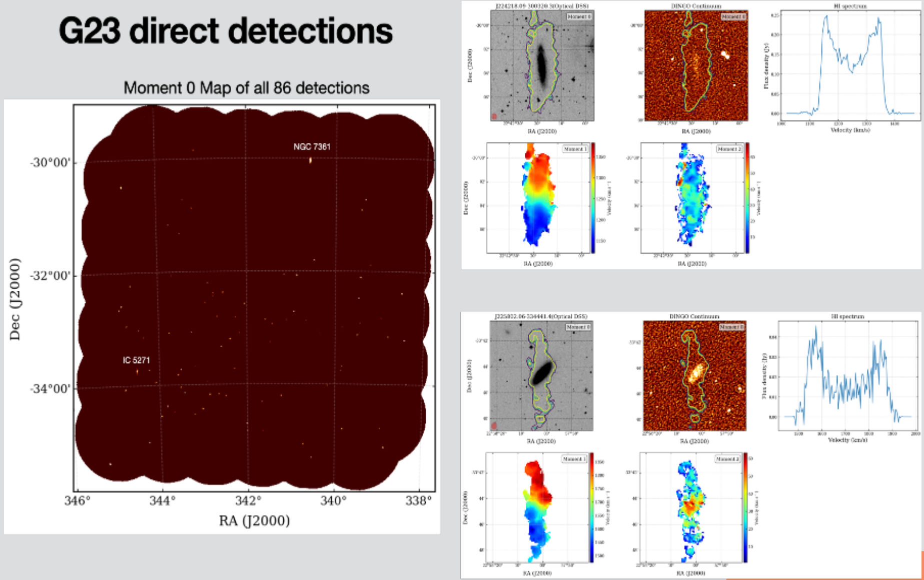
WALLABY was represented at several meetings and workshops throughout the year, including the ASTRO 3D Science meeting, the 2^{nd} Australia-ESO Joint Conference on $17\text{-}21^{st}$ February, the Pathfinders HI Survey Coordination Committee (PHISCC) meeting, organised by the University of Groningen on 11^{th} and 13^{th} May, and the ACAMAR workshop on $3\text{-}5^{th}$ November. A special multi-time zone WALLABY science workshop was also held on 12^{th} November 2020.

DINGO

DINGO pilot phase 1 observations covered the GAMA G23 and G15 fields with integration times of 74 hr and 35.5 hr, respectively. Data processing is still ongoing, but the first 16.3 hours of the G23 data has been fully reduced and is available in the CASDA archive. Analysis of the data already processed shows that the quality of the DINGO pilot phase 1 data is good (~1.6 mJy/beam RMS noise). A source-finding analysis using SoFiA in half of the nominal G23 coverage (30 square degrees) detected HI emission from 86 objects, all of which can be cross-matched with galaxies in the GAMA optical catalogue. After more G23 data have been processed, the deepest HI data will be used for DINGO direct detection science. Additional science using HI emission stacking techniques is planned to follow up on the early science results of G23 with the ASKAP full array and deep integration data. Reduction of the G15 data has also been completed, and data validation is underway.

Postdoc Sambit Roychowdhury found that the HI fraction in galaxies with similar stellar masses is higher when they reside in group environments than when they are isolated. This phenomenon was spotted in preparatory work done by stacking spectra from the ALFALFA survey in the GAMA regions. He is now using DINGO pilot phase 1 data (G15) to confirm these results with ASKAP interferometric data, and to check whether the extra HI per galaxy in group environments is located mainly within the galaxy disks, or in between them.

Postdoc Jonghwan Rhee has completed the analysis of early science data focusing on key DINGO science cases using HI stacking technique, such as HI gas contents of galaxies, environment effects, HI scaling relations, HI-Halo mass relation and cosmic HI gas density.



*A moment 0 map of all 86 direct detections in the DINGO G23 data is shown on the left. As examples, moment 0 maps of NGC 7361 and IC 5271 are overlaid on optical and continuum images, and other moment maps are also shown along with the HI spectra **IMAGE CREDIT:** Jonghwan Rhee.*

PhD student Qingxiang Chen completed his PhD thesis, which is based on analysis of data from the DINGO-VLA survey, using a new stacking technique using data cubes obtained from VLA observation data for 3622 galaxies z < 0.1 in the GAMA G09 field.

PhD student Kristof Rozgonyi has built an uv-grid pipeline for DINGO deep imaging after carrying out extensive simulations. He is now working with processed pilot phase 1 data for one beam that is known to have a bright HI detection (NGC7361). This work aims to address technical issues of the new imaging pipeline with realistic DINGO data.

Although most of the conferences planned in 2020 were affected by the pandemic, DINGO team members presented science and technical highlights at several offline and online conferences and workshops, including the ESOz-2020 in Perth, the online PHISCC science meeting, a workshop on joint Australian and Korean contributions to SKA, ACAMAR virtual workshop, European Astronomical Society Annual Meeting 2020 and the ADASS conference.

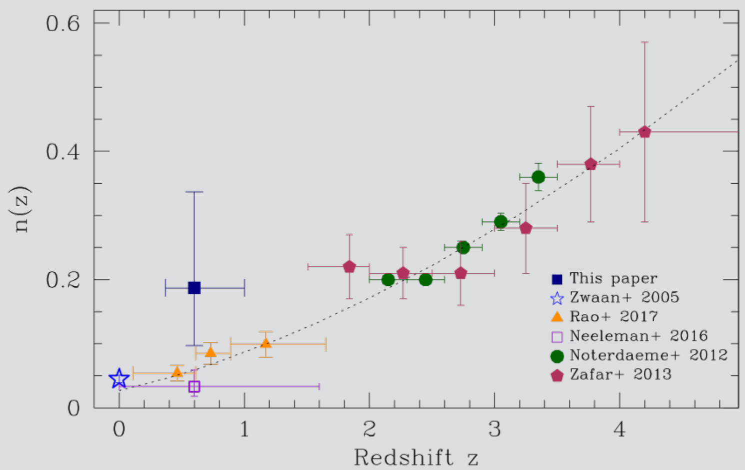
FLASH

The FLASH Phase 1 pilot survey observations were completed in mid-2020 and cover 32 ASKAP fields spanning almost 1000 deg^2 of sky. Much of this year was spent on testing and refinement of the ASKAPsoft processing pipeline to meet the FLASH requirements for accurate continuum subtraction and uniformity of the spectral bandpass. In parallel with this, ASTRO 3D postdoc Hyein Yoon developed a suite of quality assessment (QA) tools for the ASKAP images and spectra from the pilot survey, which have now been incorporated into the ASKAPsoft pipeline. These FLASH QA tools built on and extended the WALLABY QA tools developed by Bi-Qing For, and this has been a valuable technical collaboration with the WALLABY team. ASTRO 3D AI (and FLASH co-PI) James Allison has recently developed a KDE-based machine-learning tool to identify spectral artefacts and determine the detection reliability of individual lines.

Two major FLASH science papers were published in 2020, and together these provide an important 'proof of concept' for the full FLASH survey. Allison et al. (2020) published a full survey of the GAMA 23hr field, obtaining a new detection of 21cm HI absorption at an impact parameter of 17 kpc in the disk of GAMA J22450.05−343031.7, a massive early-type galaxy at z=0.356, while Sadler et al. (2020) reported the detection of four intervening HI absorption lines (two of them new) against bright background quasars and made a first 21cm estimate of the Damped Lyman Alpha absorber (DLA) number density n(z) at redshift z ~ 0.6 (see image below). The ASKAP value lies somewhat above the general trend of n(z) with redshift seen in optical DLA studies, possibly because our radio survey allows us to pick up dusty systems that might not have been included in optical QSO surveys. A larger sample of 21 cm HI absorption detections from the full FLASH survey will allow us to explore this question further.

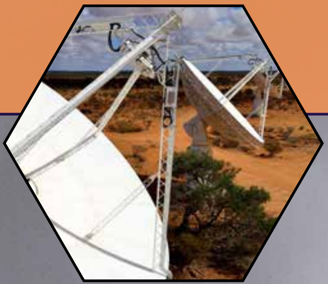
In early 2020, we had a very productive visit from Di Li and Zheng Zheng from ASTRO 3D Partner Institution NAOC to discuss progress on our FAST project to search for OH absorption associated with HI absorption systems. The first results from this work have now been published (Zheng et al. 2020).

ASTRO 3D student Simon Weng completed his Honours year at the University of Sydney in July. Simon's thesis 'Extragalactic Tug-of-War: An HI-selected galaxy group at redshift z=0.45' was co-supervised by Caroline Foster (SAMI/Hector) and Elaine Sadler (FLASH) as a cross-team project combining ASKAP HI and ESO MUSE data.



FLASH team members attended several meetings and workshops throughout the year, with presentations at the Perth Australia-ESO Joint Conference in February, the May Pathfinders HI Survey Coordination Committee (PHISCC) meeting, the ASTRO 3D virtual science meeting and the June American Astronomical Society (AAS) meeting.

The number density of HI absorption systems with column density above 2 x 10^{20} cm^{-2}, n(z), as a function of redshift. The dark blue square at redshift z = 0.6 (marked as 'This paper') shows the 21 cm value derived by Sadler et al. (2020) from ASKAP commissioning and Early Science data, while the open star at z=0 shows the 21 cm HI emission point from Zwaan et al. (2005). The other points all come from optical/UV studies of Damped Lyman-alpha (DLA) absorption line. The dashed line shows the empirical n(z) versus z relation derived by Rao et al. (2017).



ASKAP SURVEYS PEOPLE

PROF. ELAINE SADLER
University of Sydney
Theme Leader: Origin of Matter and the Periodic Table
Survey Lead: FLASH

Professor Elaine Sadler has extensive expertise in leading large radio astronomy surveys with extremely high international impact.

Elaine's research expertise covers both optical and radio astronomy, and she brings extensive science management experience.

Elaine is the Leader of the Origin of Matter and Periodic Table Theme as well as the ASKAP FLASH survey. She is a Fellow of the Australian Academy of Science, ATNF Chief Scientist and in January 2019 was awarded Officer of the Order of Australia (AO) for distinguished service to science as an astrophysicist in the field of galaxy evolution and to gender equality.

DR. BARBARA CATINELLA
University of Western Australia
Node Leader: UWA

Chief Investigator Barbara Catinella is a radio astronomer passionate about understanding how galaxies form and evolve.

She leads state-of-the-art legacy surveys using the largest radio telescopes in the world to investigate how cold gas - the raw fuel for star formation - cycles in and out of galaxies. These surveys provided the deepest observations of cold gas in the local Universe, uniquely probing the vastly unexplored gas-poor regime and yielding strong constraints to theoretical models and simulations of galaxy evolution. Barbara also pioneered the applications of the spectral stacking technique to the study of gas scaling relations.

Her mission within ASTRO 3D is to make sure that the next-generation cold gas surveys with the Australian Square Kilometre Array Pathfinder (WALLABY and DINGO) will be scientifically exploited to the fullest potential and to maximise their synergy with state-of-the-art optical surveys with integral field spectrographs such as SAMI and Hector.

James Allison
Oxford University
Associate Investigator

Jonathan Bland-Hawthorn
University of Sydney
Chief Investigator

Michael Brown
Monash University
Affiliate

Matthew Colless
Australian National University
Chief Investigator

Luca Cortese
University of Western Australia
Associate Investigator

Elena D'Onghia
University of Wisconsin-Madison
Affiliate

Joanne Dawson
Macquarie University
Affiliate

Bi-Qing For
University of Western Australia
Postdoctoral Researcher

Bryan Gaensler
University of Toronto
Partner Investigator

Lilian Garratt-Smith-son
University of Western Australia
Postdoctoral Researcher

Jennifer Hardwick
University of Western Australia
PhD Student

Virginia Kilborn
Swinburne
Associate Investigator

Baerbel Koribalski
CSIRO
Partner Investigator

Claudia Lagos
University of Western Australia
Research Fellow

Karen Lee-Waddell
CSIRO
Affiliate

Di Li
Chinese Academy of Sciences
Partner Investigator

Elizabeth Mahony
CSIRO
Affilate

Naomi McClure-Griffiths
Australian National University
Associate Investigator

Martin Meyer
University of Western Australia
Associate Investigator

Raffaella Morganti
ASTRON
Partner Investigator

Chandrashekar Murugeshan
Swinburne
PhD Student

Tristan Reynolds
University of Western Australia
Postdoctoral Researcher

Jonghwan Rhee
University of Western Australia
Postdoctoral Researcher

Aaron Robotham
University of Western Australia
Associate Investigator

Sambit Roychowdhury
University of Western Australia
Postdoctoral Researcher

Kristof Rozgonyi
University of Western Australia
PhD Student

Lister Staveley-Smith
University of Western Australia
Chief Investigator

Adam Stevens
University of Western Australia
Affiliate

Adam Watts
University of Western Australia
PhD Student

Simon Weng
University of Sydney
PhD Student

Tobias Westmeier
University of Western Australia
Associate Investigator

Ivy Wong
CSIRO
Affiliate

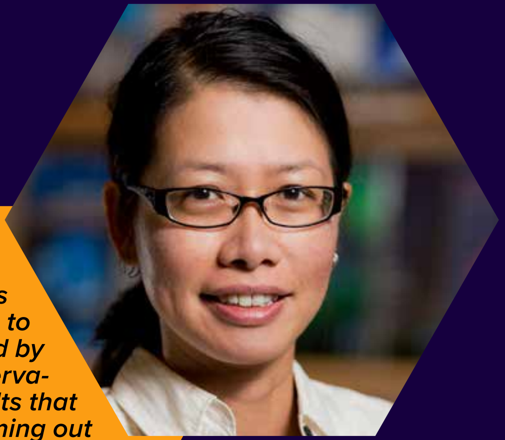
Hyein Yoon
University of Sydney
Postdoctoral Researcher

Storm brewing over the MWA. Image credit: Aman Chokshi

MEMBER HIGHLIGHT

DR IVY WONG

ASSOCIATE INVESTIGATOR AT CSIRO



I am Dr Ivy Wong. I'm a radio astronomer and Associate Investigator working at the CSIRO Astronomy and Space Science division in Perth.

I study the physical processes that govern how galaxies accrete gas to form stars, grow central supermassive black holes and evolve. I am especially interested in galaxies with extreme star formation properties and evolutionary histories. My research interests also extend to using non-traditional methods such as citizen science and the application of machine learning methods in order to maximise the science output from the very large survey datasets.

In 10 years time, I hope to be impressed by the new observations and results that would be coming out of the Square Kilometre Array.

Much of my current research relates to the HI and radio continuum large area surveys planned for the Australian Square Kilometre Array Pathfinder (ASKAP) such as WALLABY, EMU, DINGO & FLASH. I am a co-chair of the WALLABY Local Universe Science Working Group and contribute towards the ASKAP spectral line commissioning team through helping with the verification of the observations as well as the output of the standard ASKAP soft pipeline. So far, we have trained a deep learning model on a citizen science-based dataset (Radio Galaxy Zoo) in order to automate the classification of radio galaxies for very large all-sky radio surveys such as EMU (Wu et al 2019). We have also explored the potential for machine learning to contribute towards post-processing images from radio continuum synthesis observations (Glaser et al 2019). In the coming years, our current plans are to explore the application of such techniques towards HI observations (and spectral line science in general) where we are probing fainter emissions across a much greater data volume.

I am currently working on a WALLABY paper that explores the potential origin of two massive HI clouds that were observed during the ASKAP pre-pilot survey period. Due to the clouds' projected location on the sky, we were not able to pinpoint any associated stellar components to these clouds. While the original aim was to provide some constraints on the formation and origin of these clouds, our results are now suggesting that further follow-up observations and modelling are required to provide the necessary constraints.

I first decided to pursue Astronomy as a career during my summer vacation work with the Astrophysics group at Melbourne University as a 2nd year Physics undergraduate student, I was sent up to the Parkes radio telescope to observe for the HI Parkes All-Sky Survey (HIPASS) survey over the 1999/2000 New Year period. That HIPASS observing run was key to my decision to "give it a go" in terms of pursuing astronomy as a career.

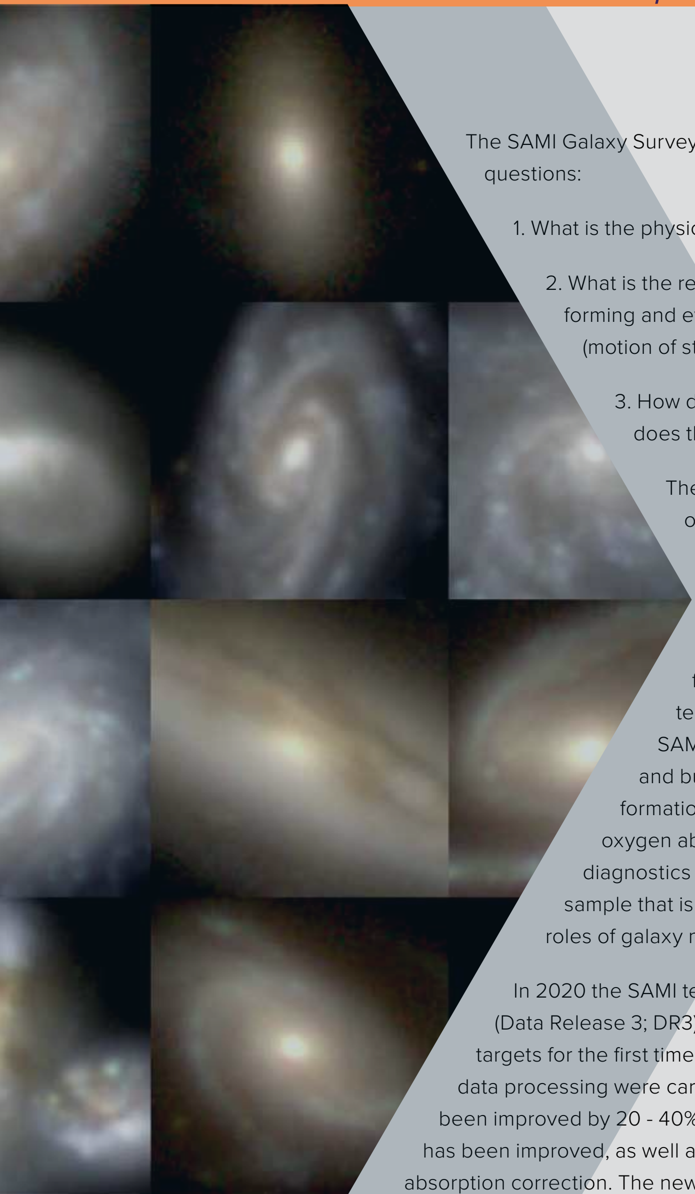
If I wasn't an astronomer, I would be a physicist and would have possibly continued with another research group such as optics as I prefer the observational or experimental side of physics.

My favourite thing about being an astronomer is discovering the science in the data and the data itself.

In 10 years time, I hope to be impressed by the new observations and results that would be coming out of the Square Kilometre Array.

ASKAP Radio Telescopes. Visible in the twilight is the Phased Array Feed (PAF) receiver reflecting the setting sun. Each PAF is made up of 188 individual receivers positioned in a checkerboard like arrangement. ***IMAGE CREDIT:*** *CSIRO*

THE SAMI/HECTOR SURVEYS



The SAMI Galaxy Survey began in March 2013 to address the following questions:

1. What is the physical role of environment in galaxy evolution?
2. What is the relationship between stellar mass growth (stars forming and evolving) and angular momentum development (motion of stars, gas and dark matter) in galaxies?
3. How does gas get into and out of galaxies, and how does this drive star formation?

The SAMI Galaxy Survey has now completed its observational program to obtain 3D data cubes for over 3000 galaxies in the nearby Universe. Integral field spectroscopy with SAMI allows the measurement of a huge range of galaxy properties that are impossible to obtain from single fibre surveys and allows direct tests of the latest galaxy formation simulations. SAMI observables include gas and stellar internal and bulk kinematics, the spatial distribution of star formation, stellar metal content and age gradients, gas oxygen abundance distributions, resolved ionisation diagnostics and many others. This is the first integral field sample that is sufficiently large to disentangle the competing roles of galaxy mass and environment.

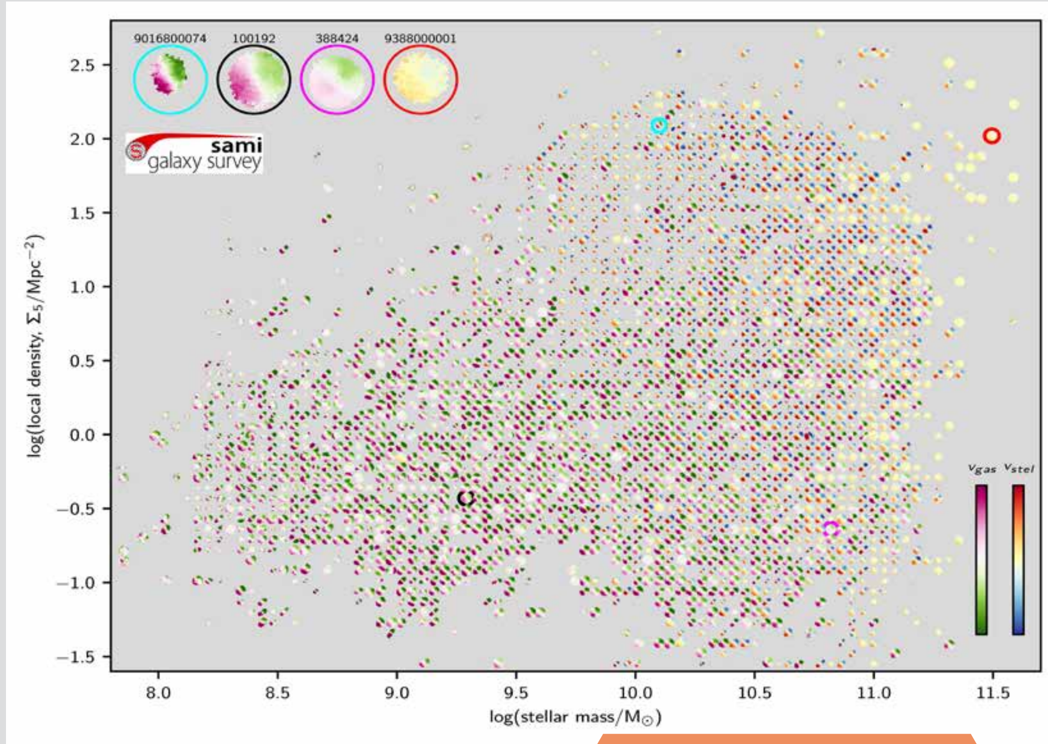
In 2020 the SAMI team was preparing for the final data release (Data Release 3; DR3) of all data, including the SAMI cluster targets for the first time. As part of DR3, major upgrades to the data processing were carried out. For example, sky subtraction has been improved by 20 - 40%. Both absolute and relative flux calibration has been improved, as well as wavelength calibration and atmospheric absorption correction. The new data cubes, as well as derived data products such as stellar and gas velocity maps, stellar population measurements and emission line maps, are described in the submitted DR3 paper (Croom et al.). The data will be served through Australian Astronomical Optics' Data Central, https://datacentral.org.au/. After final testing with Data Central, the data were made public in January 2021.

As well as the DR3 efforts, SAMI team members have been busy working on a variety of SAMI science papers. PhD student Mathew Varidel used his new Bayesian forward modelling technique to measure the gas velocity dispersion in SAMI galaxies. Mathew made comparisons to theoretical models and found that star formation density has the best correlation with dispersion (Varidel et al. 2020).

Building on the fruitful collaboration we have with the group of Sukyoung Yi at Yonsei University, we have compared the misalignment between gas and stellar kinematics measured in SAMI to numerical simulations (Donghyeon et al. 2020). This shows that the Horizon-AGN simulations can mostly reproduce the misalignment distribution we have previously reported (Bryant et al. 2019).

Postdoc Sree Oh used a combination of photometric bulge-disk decomposition and kinematic measurements from SAMI to separately measure the stellar motions in bulges and disks. The bulges are found to be largely pressure supported, although typically with some bulk rotation. Each component separately sits on galaxy scaling relations (Oh et al. 2020).

PhD student Kate Harborne (UWA, also in the Genesis team) developed new ways to correct kinematics for beam-smearing caused by atmospheric seeing (Harborne et al. 2020). These corrections were used by Jesse van de Sande and Sam Vaughan to take a new look at kinematic classification of galaxies. Using a Bayesian mixture model, they are able to define the likelihood of being a



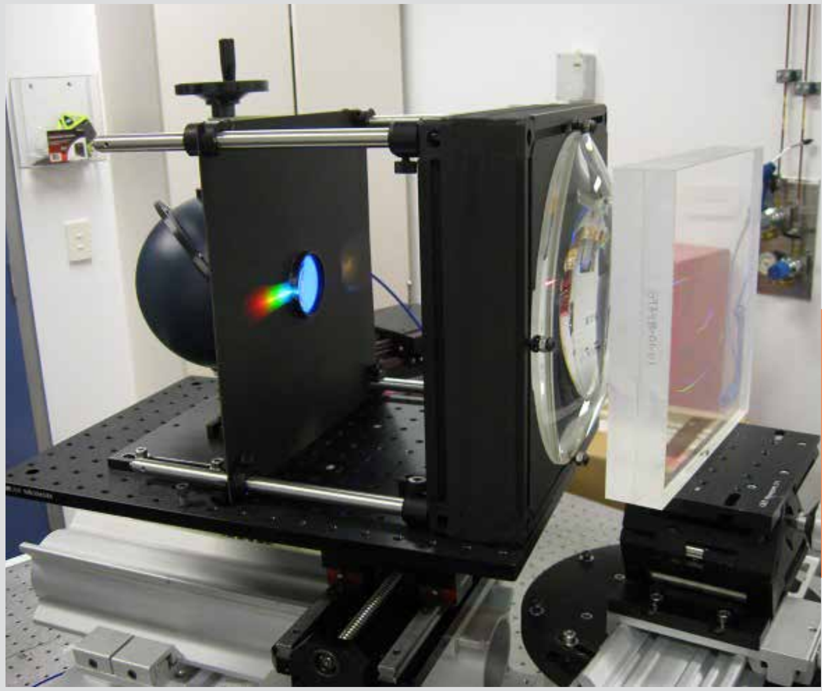
Velocity fields for SAMI galaxies in the plane of environmental density (Σ5) vs. stellar mass, taken from the SAMI DR3 paper (Croom et al.)

Stellar velocities are shown for early-type galaxies, while gas kinematics are shown for late-type galaxies, as defined by the SAMI visual morphology catalogue.

Each velocity map has the same image scale in arcseconds. In the top right, we show zoom-ins of four example galaxies, where their locations in Σ5 and stellar mass are indicated by the coloured circles.

As we get to higher stellar mass, the velocity gradients get weaker, showing that high-mass galaxies are more likely to be slow rotators. However, there is not a strong trend in local density.

THE SAMI/HECTOR SURVEYS



The Hector spectrograph VPH grating being tested at AAO-MQ in Sept 2020.

fast or slow rotator probabilistically in the spin-mass plane (van de Sande et al. 2021). In another international collaboration Lucy Hogarth (PhD student at University College London) led a project using ALMA to follow up SAMI galaxies selected to have outflowing gas. The ALMA data shows that galaxies with outflowing gas have a higher central concentration of molecular gas than regular galaxies (Hogarth et al. 2020).

Hector, the new integral field spectrograph instrument for the AAT is an upgrade to the highly successful SAMI instrument. It has a new higher-resolution spectrograph, new improved and larger optical imaging bundles called “hexabundles” and a novel unique positioner. This year the Hector Science team finalised the target selection criteria that will define the galaxies chosen for the Hector Survey and how they are allocated to the different sized hexabundles and the two spectrographs. This has been a detailed process to optimise the science returns for the full team ahead of the beginning of the Hector Galaxy Survey in 2021.

The Hector instrument has all final parts in hand or on order and the complete assembly is underway. It will be commissioned on the telescope in mid-2021. A key aspect of the instrument is the new hexabundles, and two PhD students, Adeline Wang and Rebecca Brown, played a key role in the development of the new techniques for glass processing of hexabundles and in characterising the optical performance.

The Hector Instrument and Science teams are lead by AI A/Prof. Julia Bryant.

MEMBER HIGHLIGHT

DR SREE OH

POSTDOCTORAL RESEARCHER AT AUSTRALIAN NATIONAL UNIVERSITY

My name is Sree Oh. I am an ASTRO 3D Postdoc based at the Australian National University and I am a part of the SAMI and the HECTOR Galaxy Surveys.

I am interested in many aspects of galaxy evolution and under the ASTRO 3D umbrella I am mostly working on the kinematic aspects of galaxies using the SAMI 3D Spectroscopic Survey. I am also interested in galaxy evolution in very dense environments like clusters using deep imaging data.

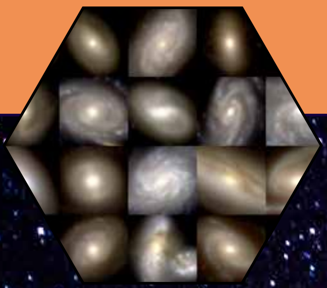
I am a part of the data reduction and quality control working groups which helps me learn more about 3D spectral data. SAMI’s successor, HECTOR, is in the preparation stage, we haven’t started observing yet. I am working on the data reduction pipeline using mock images to develop the HECTOR data pipeline as the deputy data reduction coordinator.

This year I published a paper on the spectroscopic bulge-disk decomposition for 826 SAMI galaxies. This is the largest sample for spectroscopic bulge-disk decomposition and the first sample including all types of galaxies. In this study, I quantitatively show that bulge and disk components are kinematically distinct. This study also suggests that the relative contributions of the two components explain the complex kinematic behaviour of galaxies.

I was fascinated by the astronomers who worked with these beautiful objects

I decided to become an astronomer when I was in early secondary school. I was good at science and my science teacher liked me a lot. One day she called me and my friend and said she had a ticket for a science concert at a university. The event was okay, but afterwards I had some time to look around and I found a building with beautiful pictures on the wall. I was in shock because I had never thought about these beautiful objects in the sky and I was fascinated by the astronomers who worked with these beautiful objects. At that moment I decided to be an astronomer. I majored in astronomy and physics (at the University where I first saw the pictures). After I finished my PhD I was fortunate to get a job with ASTRO 3D here at the Australian National University.

If I wasn’t an astronomer I would be a code developer. I enjoy writing code - that makes me happy every day. I also like beautiful pictures of galaxies. I am an observer and I have many raw images to be reduced so I can make my own collection of beautiful galaxy images.



SAMI/HECTOR SURVEYS PEOPLE

PROF. SCOTT CROOM

University of Sydney
Survey Lead: SAMI/Hector
Node Leader: University of Sydney

Professor Scott Croom brings over a decade of experience leading large spectroscopic surveys to ASTRO 3D.

Scott leads the SAMI Survey and plays a major role in the Hector survey. SAMI results include new insights into galaxy scaling relations, the discovery of outflows in star-forming galaxies, and greater understanding of the formation mechanism behind dispersion-dominated galaxies.

SAMI will be replaced by the Hector spectrograph in 2021. Hector will survey 15,000 galaxies within a five year period and be significantly faster than SAMI.

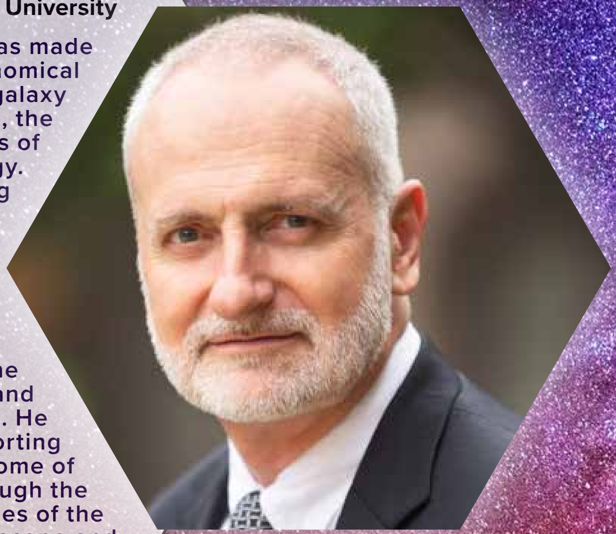
Scott is also facilitating collaborations with the Genesis team to compare the theoretical star-formation history of galaxies with observation.

PROF. MATTHEW COLLESS

Australian National University
Survey Lead: SAMI/Hector
Node Leader: Australian National University

Professor Matthew Colless has made major contributions to astronomical research in the fields of galaxy evolution, clusters of galaxies, the large-scale structure and motions of galaxies, and observational cosmology. As part of ASTRO 3D, he is leading a research team using the SAMI and Hector instruments to investigate the dynamical structure of galaxies and the accretion of angular momentum and how these affect their star formation histories and stellar populations.

Matthew is also Director of the Research School for Astronomy and Astrophysics (RSAA) at the ANU. He plays a significant role in supporting ASTRO 3D, as RSAA provides some of the Centre's key facilities, through the wide-field optical capabilities of the ANU-owned SkyMapper Telescope and the ANU-operated Anglo-Australian Telescope.



Dilyar Barat
Australian National University
PhD Student

Tania Barone
Australian National University
PhD Student

Jonathan Bland-Hawthorn
University of Sydney
Chief Investigator

Rebecca Brown
University of Sydney
Masters Student

Sarah Brough
University of New South Wales
Affiliate

Julia Bryant
University of Sydney
Associate Investigator

Andy Casey
Monash University
Affiliate

Matthew Colless
Australian National University
Chief Investigator

Barbara Catinella
University of Western Australia
Chief Investigator

Robin Cook
University of Western Australia
PhD Student

Luca Cortese
University of Western Australia
Associate Investigator

Roger Davies
Oxford University
Partner Investigator

Caroline Foster
University of Sydney
Research Fellow

Amelia Fraser-McKelvie
University of Western Australia
Associate Investigator

Brent Groves
University of Western Australia
Associate Investigator

Jennifer Hardwick
University of Western Australia
PhD Student

Claudia Lagos
University of Western Australia
Research Fellow

Sarah Leslie
Leiden University
Affiliate

Sergio Leon-Saval
University of Sydney
Affiliate

Richard McDermid
Macquarie University
Affiliate

Rebecca McElroy
University of Sydney
Affiliate

Anne Medling
University of Toledo
Affiliate

SAMI/HECTOR SURVEYS PEOPLE

Trevor Mendel
Australian National University
Research Fellow

Aaron Myszka
Swinburne
PhD Student

Sree Oh
Australian National University
Postdoctoral Researcher

Henry Poetrodjojo
University of Sydney
Postdoctoral Researcher

Tom Quinn
University of Washington
Associate Investigator

Bruce Riding
University of Sydney
Student

Thomas Rutherford
University of Sydney
PhD Student

Diane Salim
Australian National University
PhD Student

Giulia Santucci
University of New South Wales
PhD Student

Nicholas Scott
University of Sydney
Associate Investigator

Sarah Sweet
Swinburne
Postdoctoral Researcher

Haobin (Adeline) Wang
University of Sydney
PhD Student

Di Wang
University of Sydney
PhD Student

Jessica Werk
University of Washington
Associate Investigator

Emily Wisnioski
Australian National University
Research Fellow

Jesse van de Sande
University of Sydney
Associate Investigator

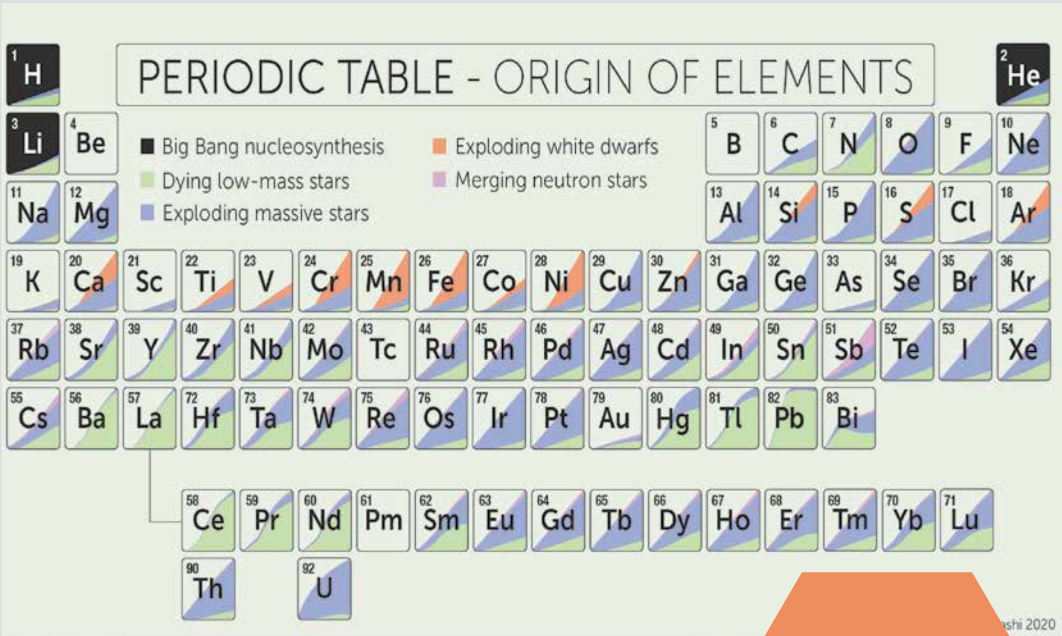
Matthew Varidel
University of Sydney
PhD Student

Sam Vaughan
University of Sydney
Postdoctoral Researcher

Dr Ángel López-Sánchez inside the AAT preparing the SAMI instrument for the night.
IMAGE CREDIT:
›Ángel López-Sánchez.

SCIENCE HIGHLIGHT

ELEMENTS OF SURPRISE!



The Periodic Table, showing naturally occurring elements up to uranium. Shading indicates origin ***IMAGE CREDIT:*** *Chiaki Kobayashi et al Artwork: Sahm Keily*

Colliding neutron stars were touted as the main source of some of the heaviest elements in the Periodic Table. Now, not so much …

Neutron star collisions do not create the quantity of chemical elements previously assumed, a new analysis of galaxy evolution finds. The research also reveals that current models can't explain the amount of gold in the cosmos – creating an astronomical mystery.

The work has produced a new-look Periodic Table, showing the stellar origins of naturally occurring elements from carbon to uranium. All the hydrogen in the Universe – including every molecule of it on Earth – was created by the Big Bang, which also produced a lot of helium and lithium, but not much else. The rest of the naturally occurring elements are made by different nuclear processes happening inside stars. The mass of stars governs exactly which elements are forged, but they are all released into galaxies in each star's final moments – explosively in the case of really big ones, or as dense outflows, similar to solar wind, for ones in the same class as the Sun.

"We can think of stars as giant pressure cookers where new elements are created," explained co-author Associate Professor Amanda Karakas, from Australia's ARC Centre of Excellence for All Sky Astrophysics in 3 Dimensions (ASTRO 3D). "The reactions that make these elements also provide the energy that keeps stars shining bright for billions of years. As stars age, they produce heavier and heavier elements as their insides heat up."

Half of all the elements that are heavier than iron – such as thorium and uranium – were thought to be made when neutron stars, the superdense remains of burnt-out suns, crashed into one another. Long theorised, neutron star collisions were not confirmed until 2017. Now, however, fresh analysis by Amanda Karakas and fellow astronomers Chiaki Kobayashi and Maria Lugaro reveals that the role of neutron stars may have been considerably overestimated – and that another stellar process altogether is responsible for making most of the heavy elements.

"Neutron star mergers did not produce enough heavy elements in the early life of the Universe, and they still don't now, 14 billion years later," said Karakas. "The Universe didn't make them fast enough to account for their presence in very ancient stars, and, overall, there are simply not enough collisions going on to account for the abundance of these elements around today." Instead, the researchers found that heavy elements needed to be created by an entirely different sort of stellar phenomenon – unusual supernovae that collapse while spinning very fast and generating strong magnetic fields.

The finding is one of several to emerge from their research, which has just been published in The Astrophysical Journal. Their study is the first time that the stellar origins of all naturally occurring elements from carbon to uranium have been calculated from first principles. The new modelling, the researchers say, will substantially change the presently accepted model of how the Universe evolved. "For example, we built this new model to explain all elements at once, and found enough silver but not enough gold," said co-author Associate Professor Chiaki Kobayashi, from the University of Hertfordshire in the UK. "Silver is over-produced but gold is under-produced in the model compared with observations. This means that we might need to identify a new type of stellar explosion or nuclear reaction."

The study refines previous studies that calculate the relative roles of star mass, age and arrangement in the production of elements. For instance, the researchers established that stars smaller than about eight times the mass of the Sun produce carbon, nitrogen, and fluorine, as well as half of all the elements heavier than iron.

Massive stars over about eight times the Sun's mass that also explode as supernovae at the end of their lives, produce many of the elements from carbon through to iron, including most of the oxygen and calcium needed for life.

"Apart from hydrogen, there is no single element that can be formed only by one type of star," explained Kobayashi.

"Half of carbon is produced from dying low-mass stars, but the other half comes from supernovae.

"And half the iron comes from normal supernovae of massive stars, but the other half needs another form, known as Type Ia supernovae. These are produced in binary systems of low mass stars."

Pairs of massive stars bound by gravity, in contrast, can transform into neutron stars. When these smash into each other, the impact produces some of the heaviest elements found in nature, including gold.

On the new modelling, however, the numbers simply don't add up.

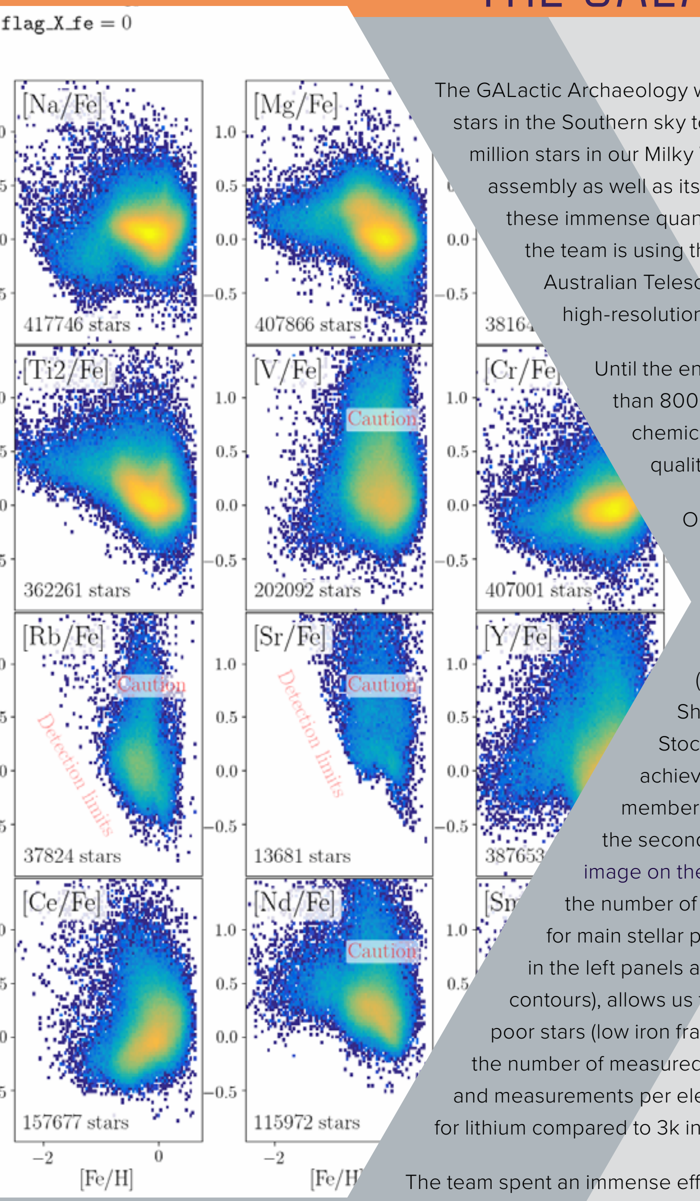
"Even the most optimistic estimates of neutron star collision frequency simply can't account for the sheer abundance of these elements in the Universe," said Karakas. "This was a surprise. It looks like spinning supernovae with strong magnetic fields are the real source of most of these elements."

Co-author Dr Maria Lugaro, who holds positions at Hungary's Konkoly Observatory and Australia's Monash University, thinks the mystery of the missing gold may be solved quite soon.

"New discoveries are to be expected from nuclear facilities around the world, including Europe, the USA and Japan, currently targeting rare nuclei associated with neutron star mergers," she said.

"The properties of these nuclei are unknown, but they heavily control the production of the heavy element abundances. The astrophysical problem of the missing gold may indeed be solved by a nuclear physics experiment."

THE GALAH SURVEY



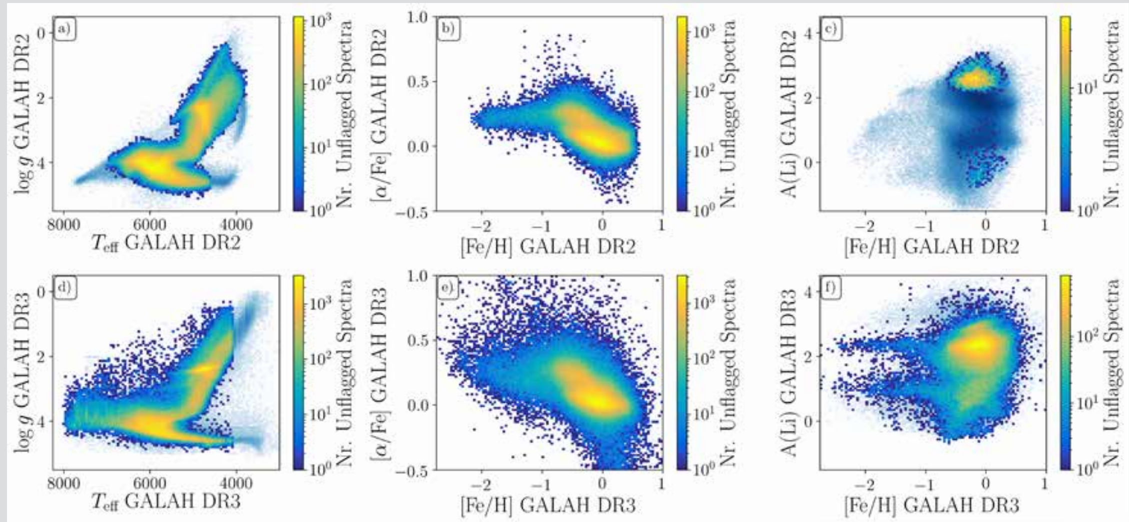
The GALactic Archaeology with HERMES (GALAH) survey is observing stars in the Southern sky to unravel the chemical composition of up to a million stars in our Milky Way. This information is key to infer the Galaxy's assembly as well as its dynamical and chemical evolution. To achieve these immense quantities of measurements with the needed quality, the team is using the HERMES spectrograph attached to the Anglo Australian Telescope (AAT), which allows the observation of high-resolution stellar spectra for up to 400 stars at a time.

Until the end of 2020, the elemental abundances of more than 800,000 stars have been measured, unveiling the chemical signature of the Milky Way in unprecedented quality and quantity.

On November 6 2020, GALAH's third data release was made public to the world. This effort was spearheaded by the analysis team at the ANU, led by Sven Buder, with critical support from colleagues at UNSW (Sarah Martell, Jeffrey Simpson), USyd (Sanjib Sharma), University of Ljubljana (Janez Kos), and Stockholm's University (Karin Lind), but is truly an achievement with countless contributions from all members of the collaboration. The improvements from the second to the third data release are shown in the image on the facing page. This data release has doubled the number of stellar measurements, improved the accuracy for main stellar parameters (like temperature and surface gravity in the left panels as can be seen from the much sharper yellow contours), allows us to provide more reliable abundances of metal-poor stars (low iron fraction [Fe/H] in the middle plots), and increased the number of measured elements (32 in DR3 compared to 23 in DR2) and measurements per element (including more than 100k measurements for lithium compared to 3k in the right panels).

The team spent an immense effort in developing state-of-the-art pipelines, models, and techniques for stellar abundance measurements. The computations performed will allow the GALAH survey, as well as all other world-leading surveys, to overcome systematic shortcomings in traditional spectroscopic analysis, that may bias results by as much as a factor two - a vital contribution for unraveling the detailed chemistry of stars.

AI Luca Casagrande (ANU) used GALAH to validate his temperature calibration from photometry - an important anchor for estimating accurate stellar parameters for billions of stars for which no spectra are available.

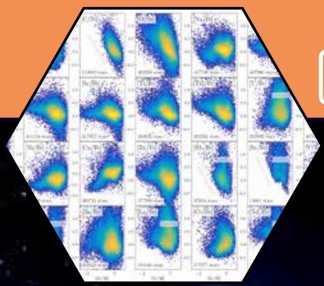


Improvements from GALAH Data Release 2 (Top Panels, Buder et al., 2018) to GALAH Data Release 3 (Bottom Panels, Buder et al., 2020) in logarithmic density plots. Main improvements for stellar parameters (left panels), and abundances (middle and right panels) are described in the text.

The GALAH survey is designed to observe nearby stars with exquisite measurements of positions and motions from the Gaia Satellite. Thanks to this mission, we now know the distance to the stars observed by GALAH typically better than 1.5%. By combining GALAH and Gaia data, the GALAH team have explored the Galactic structure in unprecedented detail. AI Sanjib Sharma (University of Sydney) used the data to find fundamental relations for the velocity dispersion of stars in the Milky Way and estimate a better metallicity (mass fraction of elements larger than hydrogen or helium) of the stellar thick disk - one of the major building blocks of our Milky Way. Govind Nandakumar (ANU), Maosheng Xiang (MPIA) and Adam Wheeler (Columbia) have combined GALAH data with other complementary large-scale surveys - an important milestone to explore the Galactic structure near and far as well as for different abundances. Lorenzo Spina (Monash) further used GALAH to trace the Galactic disk with Open Clusters. Jake Clark (USQ) used the information to refine our knowledge of potential planet host stars, observed by the TESS satellite.

One of the key strengths of the GALAH survey is its selection of stars, which ultimately will lead to a legacy data set of chemical composition, spatial and kinematic information, as well as stellar ages. Because reliable spatial and kinematic information has been only available since 2015, this field is still new. GALAH team members like ASTRO 3D Fellow Michael Hayden (University of Sydney) are pioneering studies to explore the solar neighbourhood in this high-dimensional space and understand the physical origin of observed correlations.

The GALAH team is also pioneering the field of temporal analysis of the Galactic disk. Jane Line (ANU) and Sanjib Sharma (Sydney) found strong correlations between the abundances of several chemical elements and the ages of stars in the Galactic disk, while Michael Hayden (Sydney) was even able to use these correlations to build models of "chemical clocks" to predict reliable stellar ages from stellar abundances for GALAH data.



GALAH SURVEY PEOPLE

PROF. JOSS BLAND-HAWTHORN

University of Sydney
Collaboration Leader
Survey Lead: GALAH

Professor Joss Bland-Hawthorn is an ARC Laureate Fellow renowned for innovative and broad-reaching science of both theoretical and observational astronomy, covering optical, infrared and radio wavelengths. Joss also develops astronomical instrumentation, having developed SAMI and HERMES instruments that will be used in the SAMI and GALAH surveys.

Joss and his team are using the GALAH survey to trace the chemical and mass assembly history of the Milky Way. In combination with the Genesis dynamical models, Joss is untangling the many complex processes involved in shaping a typical spiral galaxy like ours.

He is also identifying the science areas that require more collaboration. He is prioritising visits for these areas, identifying, and directing key participants to facilitate and encourage collaboration.

Arthur Alencastro Puls
Australian National University
PhD Student

Kirsten Banks
University of New South Wales
PhD Student

Sven Buder
Australian National University
Associate Investigator

Luca Casagrande
Australian National University
Associate Investigator

Andy Casey
Monash University
Affiliate

Boquan Chen
Univeristy of Sydney
PhD Student

Giulia Cinquegrana
Monash University
PhD Student

Gayandhi De Silva
Macquarie University
Associate Investigator

Ken Freeman
Australian National University
Associate Investigator

Michael Hayden
University of Sydney
Research Fellow

Meridith Joyce
Australian National University
Affiliate

Amanda Karakas
Monash University
Affiliate

Alex Kemp
Monash University
PhD Student

Chiaki Kobayashi
University of Hertfordshire
Affiliate

John Lattanzio
Monash University
Affiliate

Jinying (Jane) Lin
Australian National University
PhD Student

Sarah Martell
University of New South Wales
Affiliate

Stephanie Monty
Australian National University
PhD Student

Govind Nandakumar
Australian National University
Postdoctoral Researcher

Thomas Nordlander
Australian National University
Postdoctoral Researcher

Sanjib Sharma
University of Sydney
Associate Investigator

Jeffrey Simpson
University of New South Wales
Affiliate

Dennis Stello
University of New South Wales
Affiliate

Thorsten Tepper Garcia
University of Sydney
Affiliate

Xi (Ella) Wang
Australian National University
Student

Zixian (Pumortal) Wang
University of Sydney
PhD Student

Daniel Zucker
Macquarie University
Affiliate

MEMBER HIGHLIGHT

ASSOCIATE PROFESSOR SARAH MARTELL

AFFILIATE AT THE UNIVERSITY OF NEW SOUTH WALES

My name is Sarah Martell. I am a Scientia Associate Professor at the University of New South Wales and I am a member of the GALAH survey.

My area of research is galactic archaeology. I help to plan and run big survey projects that collect data on hundreds of thousands of stars, and then go searching in the data sets for clues about events in our Galaxy's past.

Recently I've been focusing on building bridges to other projects in ASTRO 3D, in particular the Galaxy Evolution group. Both groups will learn a lot by combining our research methods and our insights on how galaxies grow and interact with their neighbours.

A recent highlight for me personally was being awarded a Scientia Fellowship from the University of New South Wales. The Scientia program recognises ambitious researchers whose work is having an impact in their area of specialty. There are Fellows from across the university, in humanities and physical sciences and engineering and medicine. It's a really inspiring group to be part of, and it's a great feeling to have that recognition.

I help to plan and run big survey projects that collect data on hundreds of thousands of stars

I always liked math and science when I was in school, but I didn't know that "astronomer" was a job you could have until I got to university. I took an introductory astronomy class just for fun, and one day while I was asking the tutor a question, I said offhand "if there was more math in this, it would be really interesting". He lit up when I said that, and introduced me to the student advisor for the physics and astronomy departments.

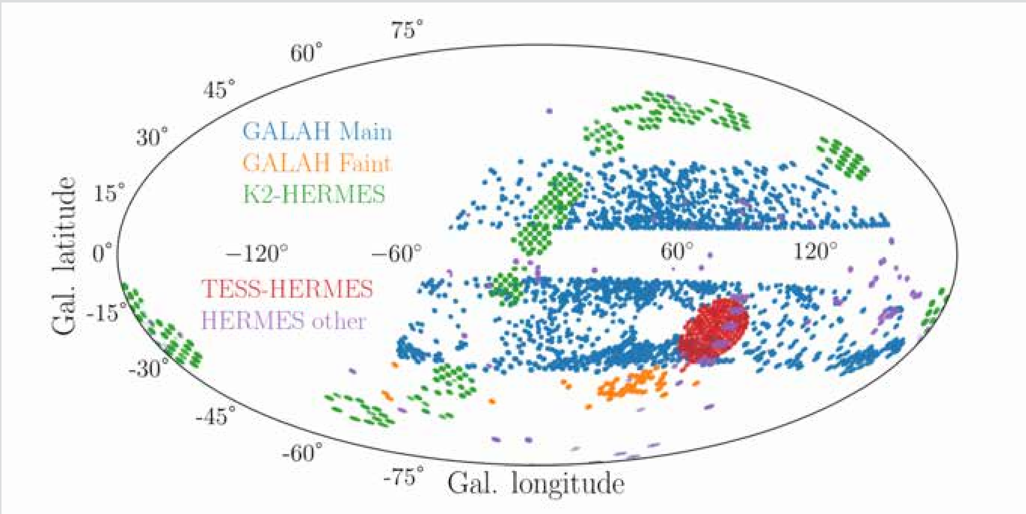
If I wasn't an astronomer at a university, I would like to be working in a field that uses a lot of the same research and communication skills.

My favourite thing about my job is staring off into space, figuratively and literally. Research is a process of constantly asking questions. It's a really creative process.

I have a lot of research ideas that I'm excited to try. For example, I want to know what the best way is to find stars in the Milky Way that have been captured from other galaxies. I want to develop a method for comparing all the individual stars we can observe in the Milky Way against the stellar populations that we can observe in other spiral galaxies. From that I want to understand what kinds of imprints are left by events in their history like galaxy collisions or by the environment that the galaxy lives in. Research projects always branch out into new ideas and questions, so I know I will have plenty to work on in the future.

SCIENCE HIGHLIGHT

PLAYING DETECTIVE ON A GALACTIC SCALE



Sky map of GALAH DR3 targets, including the K2-HERMES and TESS-HERMES programs

Australian-led Galactic Archaeology with HERMES (GALAH) project releases chemical information for 600,000 stars.

How do stars destroy lithium? Was a drastic change in the shape of the Milky Way caused by the sudden arrival of millions of stellar stowaways? These are just a couple of the astronomical questions likely to be answered following the release of 'GALAH DR3', the largest set of stellar chemical data ever compiled.

The data, comprising more than 500 GB of information gleaned from more than 30 million individual measurements, was gathered by astronomers including Dr Sven Buder, Associate Professor Sarah Martell and Dr Sanjib Sharma from Australia's ARC Centre of Excellence in All Sky Astrophysics in 3 Dimensions (ASTRO 3D) using the Anglo Australian Telescope (AAT) at the Australian Astronomical Observatory at Siding Spring in rural New South Wales.

The release is the third from the project, which aims to investigate star formation, chemical enrichment, migration and mergers in the Milky Way. It does this using an instrument called the High Efficiency and Resolution Multi-Element Spectrograph, or HERMES, which is connected to the AAT. The new data covers 600,000 stars and takes the project very close to meeting its goal of surveying one million. "It's a bit like a galactic version of the game Cluedo," said ASTRO 3D's Sven Buder, a research fellow at the Australian National University. "The chemical information we've gathered is rather like stellar DNA – we can use it to tell where each star has come from. We can also determine their ages and movements, and furnish a deeper understanding of how the Milky Way evolved." And, just like in Cluedo, the information can be used to get to the bottom of mysterious events. For instance, while we are mainly surveilling our solar neighbourhood, we have found more than 20,000 stars which do not have the same chemical composition or age as our Sun and its neighbours," explained Dr Buder.

"We know that roughly eight billion years ago the shape of the Milky Way changed drastically when it collided with another, smaller galaxy, which contained millions of stars. We've now used the stellar DNA to identify some of the prime suspects for the assault. These stowaways are so different they can only have come from somewhere else."

Another mystery likely soon to be solved thanks to new evidence uncovered is called the 'Cosmological Lithium Puzzle'. Lithium was one of the elements created during the Big Bang. It is also destroyed by some types of stars. However, modelling aimed at estimating its abundance has so far always come up short – with the calculated total not matching the empirical evidence.

GALAH DR3 looks like offering a solution. "Basically, a lot of the oldest stars have burned much of the Big Bang lithium, so our measurements for this element come out lower than the amount that was initially synthesised in the early Universe," said Dr Sanjib Sharma from the University of Sydney. "At the same time, we have found that one type of star, known as evolved giants, should have burned through pretty much all of their lithium by now, but a lot of them have much more of it than we expected. The GALAH data will help us discover why."

Day and night at the Anglo Australian Telescope. Half right image taken in the late afternoon, the Moon is up. Half left image taken just some few minutes before the beginning of the morning twilight of the same night. Orion and the Pleiades shine over the AAT on a very dark night. 4-5 November 2011. Siding Spring Observatory, NSW, Australia.

IMAGE CREDIT:
Dr Ángel R. López-Sánchez/Australian Astronomical Optics/Macquarie University/ASTRO 3D

As with the two previous data releases from the GALAH survey, the information is freely available to astronomers around the world. "Making large datasets like GALAH DR3 widely available is really important for astronomical research," explains Associate Professor Sarah Martell from the University of New South Wales. "Since the start of the GALAH project we have focused on building a dataset that can answer our questions about the history of the Milky Way, and also many others. I'm excited to see what our international colleagues will do with GALAH DR3."

The GALAH project's previous data release – known of course as DR2 – took place in 2018. It has fuelled a raft of significant discoveries regarding the evolution of the Milky Way, the existence of exo-planets, hidden star clusters, and many more.

GENESIS THEORETICAL SIMULATIONS

The ASTRO 3D Genesis Simulation program focuses on three key science areas:

1. Simulating the birth of the first stars and their impact on early Universe chemical enrichment, proto-galaxy formation, reionisation and the evolution of the intergalactic medium (IGN).

2. Tracking galaxy growth through star formation and mergers, and the build-up of angular momentum at all galactic scales, leading to the emergence and evolution of large-scale structure and the epoch of quasars.

3. Uncovering the history of the local galaxy population, including radio galaxies and active galactic nuclei (AGN), by following the dynamical, stellar and chemical evolution of the galaxies across cosmic time to the present day.

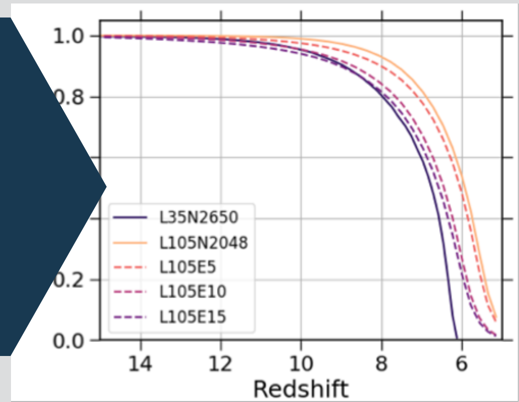
These questions are being addressed through the concurrent development of a new generation of integrated N-body/hydrodynamical galaxy formation simulations coupled to sophisticated semi-analytic galaxy models; the "Genesis Suite". Genesis will be available to both ASTRO 3D and the wider astronomical community through an update to the Theoretical Astrophysical Observatory (TAO++), opening up Genesis to be easily usable to address all the key ASTRO 3D science goals.

The Genesis Simulations thread combines suites of large N-body simulations that are coupled to semi-analytical models to produce synthetic galaxy populations across cosmic time, all run in-house, with bespoke analysis of state-of-the-art hydrodynamical simulations, such as EAGLE (Schaye et al. 2015) and Illustris-TNG (Pillepich et al. 2016), which address specific problems with an ASTRO 3D focus.

The Genesis team has been working with our partners at the National Computational Infrastructure (NCI) and the developers of the Swift simulation code to run a large, high resolution, volume – 210 Mpc/h and approximately 100 billion particles. This simulation has the resolution to resolve low-mass dark matter halos that powered the growth of the ionizing background during the Epoch of Reionisation (EoR), whilst also having the large volume to capture not only reionisation by ultra-violet radiation from the first stars, but also X-rays generated by the first black holes.

This work on modelling the EoR leverages novel work by U.Melbourne PhD student, Yisheng Qiu, who has produced an algorithm to augment the merger trees drawn from N-body simulations. Using Monte Carlo trees to extend the mass range of the merger trees, Yisheng's technique allows us to more accurately model the growth of low-mass dark matter haloes, which were responsible for producing an important contribution to the ionizing background of ultra-violet radiation.

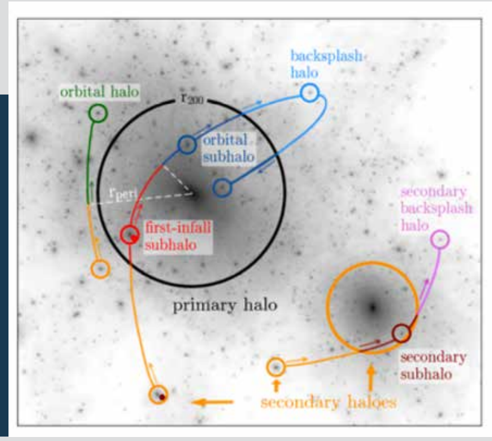
The neutral atomic hydrogen fraction variation with redshift, predicted by Meraxes coupled to a simultion of differing effective mass resolution. Augmented trees extend the utility of large volume simulations. From Qiu et al. (2020).

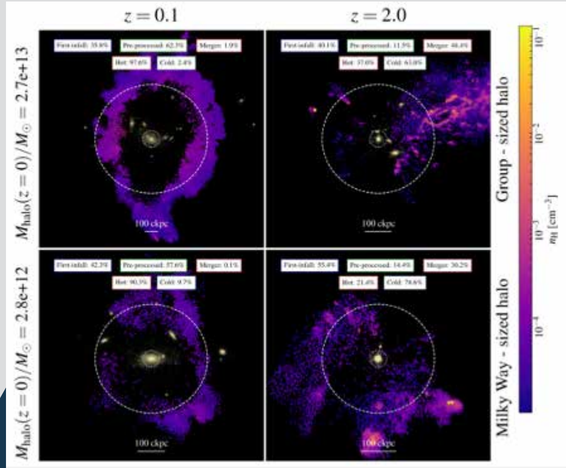


Yisheng's work has been integrated into U.Melbourne Postdoc Simon Mutch's semi-analytical model Meraxes, which self-consistently predicts the ionizing background for the population of high-redshift galaxies. This image shows the prediction for the global neutral atomic hydrogen as a function of redshift for a set of simulations with different effective resolutions and highlights how important extending the merger trees is for predicted observables. These predictions form an important core of Genesis work in 2021.

The Genesis N-body simulations are also being utilized to carry out fundamental research in structure formation. UWA PhD students Lucie Bakels and Rhys Poulton have used the Genesis Simulations to characterize the orbits and interactions of dark matter haloes and subhaloes. Lucie's work focused on classifying haloes and subhaloes around more massive systems by their interaction histories and identifying which systems had undergone interactions previously compared to which ones were falling into a more massive host for the first time (Bakels et al. (2020). Rhys' work demonstrated that estimates of the merging timescale of haloes presented in the literature deviate systematically from what is measured in simulations and proposed a revised merger timescale estimate that better captures the measured behaviour (Poulton et al. 2020). These studies have significant implications for semi-analytical models, which rely on dynamical information from N-body simulations that must often be supplemented by analytical modelling.

Classifying dark matter haloes and subhaloes allows us to better understand how interaction history is likely to influence the properties of observed galaxies at the present day. ***IMAGE CREDIT:*** *Bakels et al. 2020*

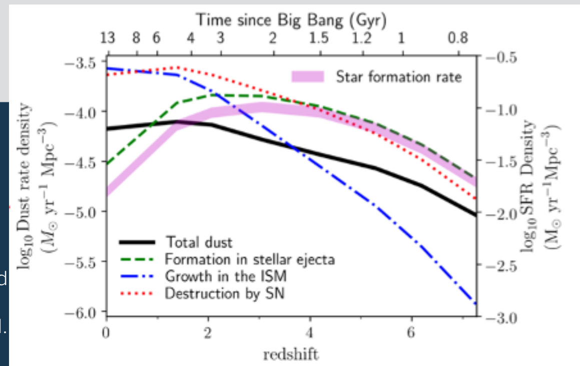




Accreting gas from the cosmic web, at various epochs and on various mass scales, can profoundly influence the metal enrichment of the circum-galactic media of galaxies. From Wright et al. (In Preparation)

UWA PhD student Ruby Wright has been working closely with ASTRO 3D Fellow Claudia Lagos to characterize how gas gets into galaxies using the EAGLE hydrodynamical simulations. Her recent work has demonstrated the clear connection between the metallicity of the circum-galactic medium (CGM) and recent gas accretion rate – the lower the rate, the more metal enriched the CGM is measured to be at a particular mass scale and epoch. The image on the left illustrates the modes in which gas accretion varies with cosmic epoch and mass scale.

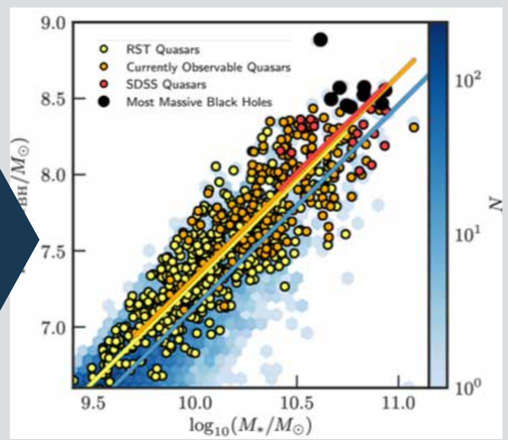
Swinburne PhD student Dian "Pipit" Triani has developed a version of the SAGE semi-analytical galaxy formation model (Croton et al. 2016), which she calls Dusty SAGE. As the name implies, Dusty SAGE is designed to study the formation and destruction of dust in galaxies across cosmic time. Her holistic model tracks the growth of dust in stellar ejecta and within giant molecular clouds, whilst also following its destruction in supernovae. This image on the right from Triani et al. (2020) shows the cosmic dust rate density and makes clear how different modes of formation dominate at different epochs – formation in stellar ejecta dominates at early times, in contrast to growth in the interstellar medium at late times.



Cosmic dust rate density as a function of redshift, with cosmic star formation rate density overplotted for comparison. From Triani et al. (2020).

Finally, U.Melbourne student Madeleine Marshall has worked closely with the BlueTides simulation teams to identify the hosts of quasars in the early Universe, identifying analogues to those that have been captured in the Sloan Digital Sky Survey and will be captured by the Nancy Roman Space Telescope (formerly WFIRST). Her work has highlighted that we should expect observed quasars to be associated with black holes that are preferentially massive, given the stellar mass of their underlying galaxy (see image, right)

Black hole mass to galaxy stellar mass relation from the BlueTides simulation – black holes are preferentially massive for the host galaxy stellar mass. From Marshall et al. (2020).



MEMBER HIGHLIGHT

PROFESSOR STUART WYITHE

CHIEF INVESTIGATOR AT THE UNIVERSITY OF MELBOURNE

I'm Stu, ASTRO 3D Deputy Director, Chief Investigator and the Genesis Simulations Thread Lead. I work at the University of Melbourne, with a focus on the Dragons simulations of early galaxies and reionisation.

The Genesis simulations complement the optical and radio surveys being undertaken within ASTRO 3D. The results of the Genesis simulations can be used both to interpret the results of the observational surveys, and to motivate new measurements or survey strategies. The simulations are also constrained by the observations, leading to more accurate models of galaxy formation and evolution.

My primary research interests lie in the field of quasar formation and reionisation in the early Universe. In particular, I am interested in the evolution of the earliest galaxies and how this evolution may be studied with the next generation of radio telescopes. I have also worked in the field of gravitational lensing, studying problems in quasar microlensing and the statistical properties of gravitational lensing by galaxies.

Being an astronomer means that you have continual opportunities to learn something new about the Universe.

I am supervising work focussed on high-redshift galaxies and quasars. We are developing semi-analytic models which focus on the earliest galaxies, and their connection with reionisation; the process by which the earliest stars heated and ionised intergalactic hydrogen. This work is in close collaboration with Genesis team members who perform the large N-body simulations needed to study reionisation, and also with members of the Murchison Widefield Array - Epoch of Reionisation (MWA-EoR) collaboration who are trying to measure the reionisation using redshifted 21cm radiation.

In a recent paper we used the Bluetides simulations to predict what the James Webb Space Telescope (JWST) would see in observations of high-redshift quasars. Specifically, we are interested in the properties of the host galaxies of the luminous high-redshift quasars. The work, which was part of Madeline Marshall's thesis, found that the host galaxy could be detected after removal of the bright quasar, although it will still be very challenging due to the galaxy's small size on the sky. This work motivates proposals for exciting experiments with JWST when it is launched next year.

I always liked mathematics and physics, and studied these at university. I found astronomy to be the most interesting field to study.I don't know what I would be doing if I wasn't an astronomer. Perhaps I'd be a professional mountain climber! I have always been fascinated by space. Being an astronomer means that you have continual opportunities to learn something new about the Universe.

GENESIS THEORETICAL SIMULATIONS PEOPLE

PROF. DARREN CROTON

Swinburne University of Technology

Project Lead: Genesis Simulations

Professor Darren Croton is an internationally-known theoretical astrophysicist who works on the formation of galaxies in the nearby and distant Universe. He conducts massive cutting-edge supercomputer simulations and mines large observational data sets from some of the world's largest telescopes.

Darren is using his extensive experience working as a theorist within large survey teams to lead the development of new models, built with SAGE (Semi-Analytic Galaxy Evolution). These models will be applied to the interpretation of the vast amounts of data ASTRO 3D astronomers will have on hand across the Centre.

Darren will also assist the Data Intensive Astronomy team to create a single, cohesive interface where astronomers can query both the Genesis Simulations and the observational data simultaneously.

ASSOC. PROF. CHRISTOPHER POWER

University of Western Australia

Project Lead: Genesis Simulations

Associate Professor Chris Power is a leading computational astronomer who is having a major impact in his field, working on a broad range of problems in galaxy formation and cosmology.

Chris is leading the development of the Genesis Simulations that will track the birth, growth and the ultimate fate of galaxies from the earliest epoch of galaxy assembly, through the epoch of reionisation to the present-day.

Chris' interests are in dark matter – what is its nature? What kinds of observations will allow us to discriminate between alternative models? How does feedback from stars and black holes (i.e. the deposition of energy and momentum into their surroundings) impact the formation and evolution of galaxies? He also has an interest in scientific high performance computing.

Chris models large N-body simulations (comprising of ~100 billion particles) to construct the most detailed and sophisticated prescriptions for galaxy formation that we have.

Lucie Bakels
University of Western Australia
PhD Student

Adam Batten
Swinburne
PhD Student

Krzysztof Bolejko
University of Tasmania
Affiliate

Garima Chauhan
University of Western Australia
PhD Student

Elena D'Onghia
University of Wisconsin-Madison
Affiliate

Elisabete da Cunha
University of Western Australia
Research Fellow

James Edward Davies
University of Melbourne
PhD Student

Alan Duffy
Swinburne
Associate Investigator

Amir Ebadati Bazkiaei
Macquarie
PhD Student

Christoph Federrath
Australian National University
Associate Investigator

Lilian Garratt-Smithson
University ofWestern Australia
Postdoctoral Researcher

Bradley Greig
University of Melbourne
Research Fellow

Katherine Harborne
University of Western Australia
Postdoctoral Researcher

Anne Hutter
Kapteyn Astronomical Institute
Affiliate

Esteban Jimenez
University of Western Australia
PhD Student

Chiaki Kobayashi
University of Hertfordshire
Affiliate

Mark Krumholz
Australian National University
Associate Investigator

Claudia Lagos
University of Western Australia
Research Fellow

Grace Lawrence
Swinburne
PhD Student

Aaron Lud-low
University of Western Australia
Associate Investigator

Ainulnabilah (Bella) Nasirudin
Curtin University
PhD Student

Danail Obreschkow
University of Western Australia
Associate Investigator

Aaron Robothom
University of Western Australia
Associate Investigator

Stas Shabala
University of Tasmania
Affiliate

Piyush Sharda
Australian National University
PhD Student

Manodeep Sinha
Swinburne
Postdoctoral Researcher

Balu Sreedhar
University of Melbourne
PhD Student

Adam Stevens
University of Western Australia
Affiliate

Philip Taylor
Australian National University
Postdoctoral Researcher

Dian (Pipi) Triani
Swinburne
PhD Student

Stuart Wyithe
University of Melbourne
Chief Investigator

Ellert van der Velden
Swinburne
PhD Student

Adam Watts
The University of Western Australia
PhD Student

Charlotte Welker
McMaster University
Affiliate

Matthew Wilkinson
University of Western Australia
PhD Student

Patrick Yates
The University of Western Australia
PhD Student

BLINDED BY THE LIGHT NO MORE

NASA's James Webb Space Telescope (JWST) will uncover galaxies never before seen by humanity, Australian-led research reveals. The telescope, due to launch in late 2021, is the largest, most powerful and complex space telescope ever built.

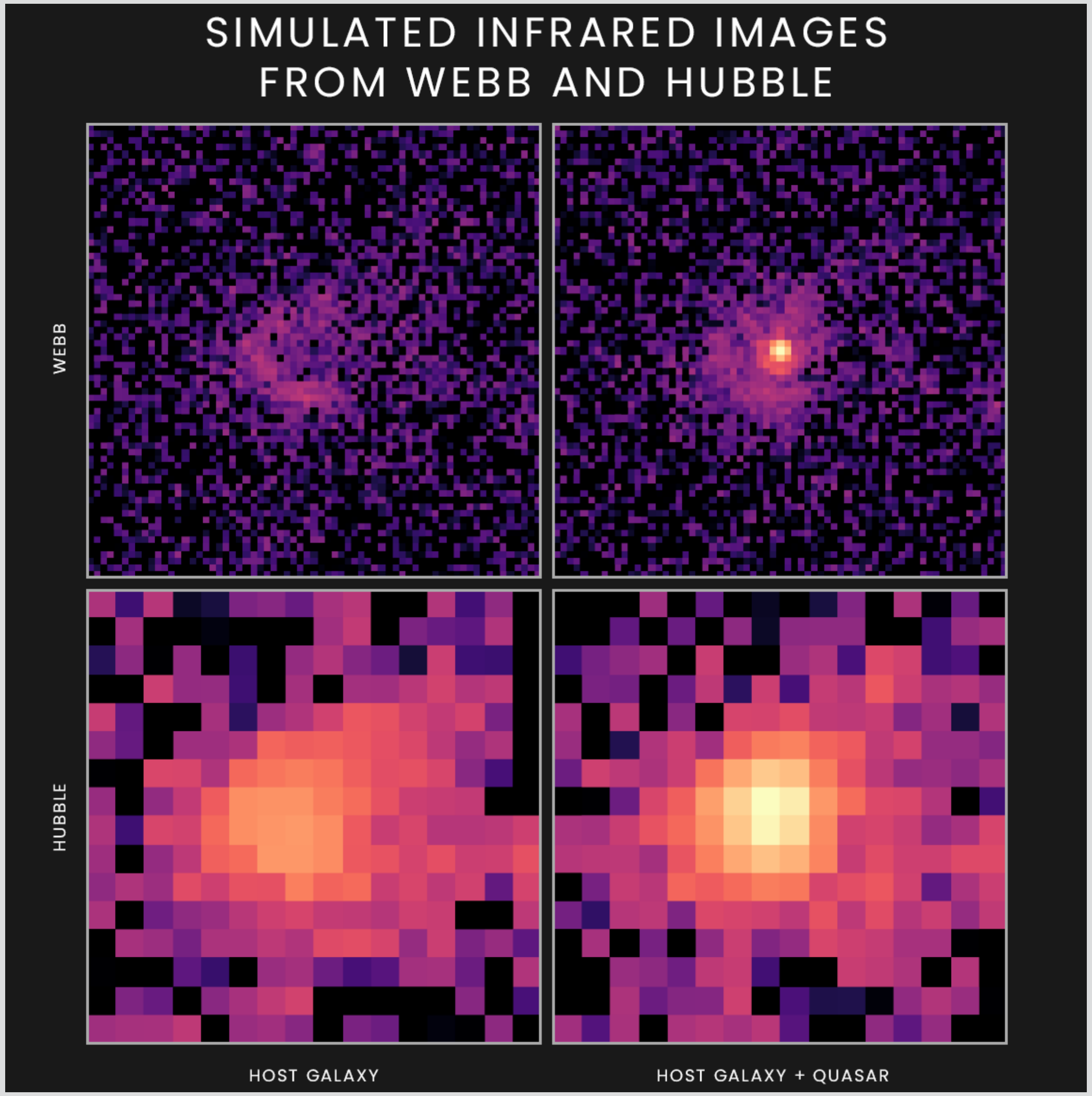
Two new studies led by Madeline Marshall from Australia's Melbourne University and the ARC Centre of Excellence in All Sky Astrophysics in 3 Dimensions (ASTRO 3D) find that JWST will use powerful lights called quasars to reveal currently masked galaxies.

Quasars are the brightest objects in the Universe and among the most energetic. They outshine entire galaxies of billions of stars. In fact, their glare is so intense that astronomers compare it to looking directly into the headlights of an oncoming car and trying to figure out the make and model of the automobile.

"We want to know what kind of galaxies these quasars live in," said Ms Marshall. "That can help us answer questions like: How can black holes grow so big so fast? Is there a relationship between the mass of the galaxy and the mass of the black hole, like we see in the nearby Universe?"

Observing these objects is very difficult with the capabilities of current telescopes. The more distant a galaxy is, the more its light has been stretched to longer wavelengths by the expansion of the Universe. As a result, ultraviolet light from the black hole's accretion disk or the galaxy's young stars gets shifted to infrared wavelengths. The James Webb Space Telescope is an infrared observatory, designed to see this light from the distant Universe.

"Ultimately, JWST's observations should provide new insights into these extreme systems," said ASTRO 3D co-author Stuart Wyithe of the University of Melbourne. "The data it gathers will help us understand how a black hole could grow to weigh a billion times as much as our Sun in just a billion years. These big black holes shouldn't exist so early because there hasn't been enough time for them to grow so massive."



For their research, Ms Marshall and colleagues from Australia, the US, China, Germany, and The Netherlands used the near-infrared capabilities of NASA's Hubble Space Telescope (HST) to study known quasars in hopes of spotting the surrounding glow of their host galaxies, without significant detections. This suggests that dust within the galaxies is obscuring the light of their stars. JWST's infrared detectors will be able to peer through the dust and uncover the hidden galaxies. "Hubble simply doesn't go far enough into the infrared to see the host galaxies. This is where JWST will really excel," said Rogier Windhorst of Arizona State University in Tempe, a co-author on the HST study.

To determine what JWST is expected to see, the team used a state-of-the-art computer simulation called BlueTides, developed by a team led by ASTRO 3D distinguished visitor Tiziana Di Matteo from Carnegie Mellon University in the US. "BlueTides is designed to study the formation and evolution of galaxies and quasars in the first billion years of the Universe's history. Its large cosmic volume and high spatial resolution enables us to study those rare quasar hosts on a statistical basis," said Yueying Ni of Carnegie Mellon University, who ran the BlueTides simulation. It provides good agreement with current observations and allows astronomers to predict what JWST should see.

The team found that the galaxies hosting quasars tended to be smaller than average, spanning only about 1/30 of the diameter of the Milky Way despite containing almost as much mass as our galaxy.

"The host galaxies are surprisingly tiny compared to the average galaxy at that point in time," said Marshall.

The galaxies in the simulation also tended to be forming stars rapidly, up to 600 times faster than the current star formation rate in the Milky Way. "We found that these systems grow very fast," explained Di Matteo. "They're like precocious children – they do everything early on."

The team then used these simulations to determine what JWST's cameras would see if the observatory studied these distant systems. They found that distinguishing the host galaxy from the quasar would be possible, although still challenging due to the galaxy's small size on the sky. "JWST will open up the opportunity to observe these very distant host galaxies for the first time," said Marshall.

The papers are published in The Astrophysical Journal and the Monthly Notices of the Royal Astronomical Society (MNRAS).

DATA INTENSIVE ASTRONOMY (DIA) PROGRAM

The Data Intensive Astronomy Program (DIAP) facilitates better access to tools, technology, infrastructure and training for ASTRO 3D researchers working with large datasets and in High-Performance Computing (HPC) environments. It does this by working with national infrastructure providers, and by the sharing of expertise between ASTRO 3D researchers. As much of the ASTRO 3D science involves world-leading surveys and large data sets, our ability to process our data in a timely and efficient manner is critical to our success.

The DIA Program manages the following key projects:

DATA FLOW AND PROCESS MANAGEMENT

This project aims to analyse data flow requirements of ASTRO 3D surveys and provide support for the implementation of optimised data transfer and storage paths. It develops algorithms and techniques to assist the implementation of pipelines for ASTRO 3D surveys.

ALL-SKY VIRTUAL OBSERVATORY

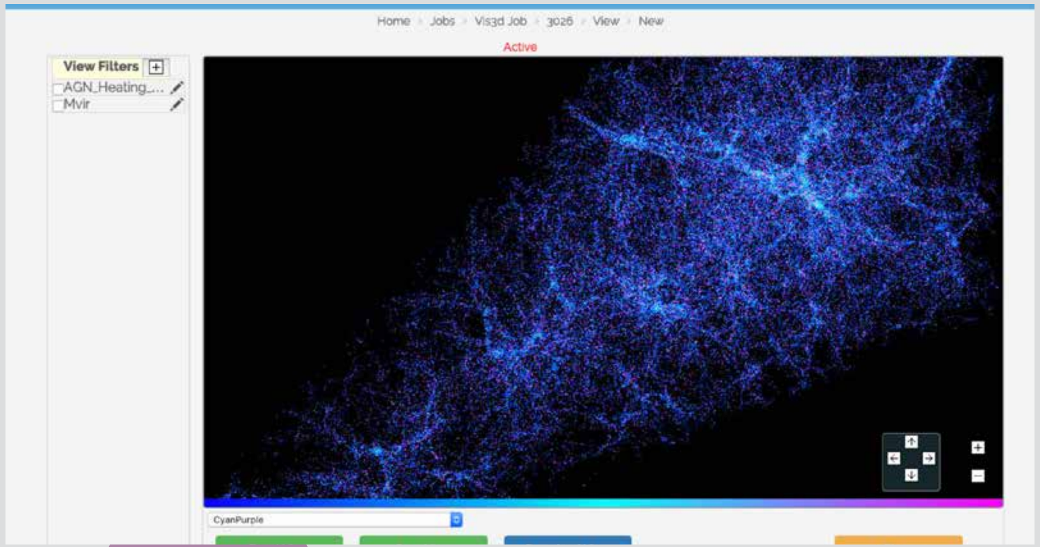
The VO project seeks to promote interoperability between the ASTRO 3D data sets that exist on All-Sky Virtual Observatory (ASVO) nodes, including the Theoretical Astrophysical Observatory (TAO). TAO is an online eResearch laboratory that allows ASTRO 3D researchers to construct their own mock light cones from a range of different simulation and galaxy formation model data, including Genesis, filter the output through virtual telescopes and download the results for their own scientific use.

Highlights from 2020 include the completion of a new backend for the TAO Vis3D interactive data visualisation tool. Currently, there is a basic user interface to the Vis3D tool, but further development of the full user-facing front end will occur in 2021 after the completion of user experience interviews.

Supported by Astronomy Australia Ltd, the AAO Data Central and SkyMapper teams have developed a new initiative, the Australian Optical Data Centre. This provides access to ASTRO 3D survey data, including SAMI, GALAH and MAGPI. During 2020, the Data Central team have provided ASTRO 3D researchers with single authentication and pilot cross-matching capability across multiple ASVO nodes, and have provided visualisation tools.

DIA program team members have also worked with members of the WALLABY and DINGO teams to implement newly developed algorithms for the reduction of ASKAP bandpass calibration errors caused by radio-frequency interference. The appointment of several people to the Australian SKA Regional Centre (AusSRC), including ASTRO 3D AI Karen Lee-Waddell as inaugural Director, has initiated the development of new software for the ASTRO 3D MWA EOR and ASKAP HI projects.

The further engagement of ASTRO 3D with the AusSRC program, the conduct of an updated survey to re-assess DIA needs of ASTRO 3D researchers for the 2nd half of the Centre, and the hiring of two new staff through the new Macquarie University node will provide ASTRO 3D researchers with new data analysis tools and will promote further cross-project collaboration.



The new TAO user interface at https://tao.asvo.org.au

DATA INTENSIVE ASTRONOMY PEOPLE

PROF. LISTER STAVELEY-SMITH

University of Western Australia

Thread Leader: Data Intensive Astronomy

Professor Lister Staveley-Smith is the Science Director at ICRAR/UWA and has over two decades of experience in leading major surveys on new radio telescope facilities and in developing and applying new software and computation techniques.

Lister is coordinating and leading the Data Intensive Astronomy observational teams at UWA, Curtin, AAO and the University of Sydney to ensure a cohesive Data Intensive Astronomy structure that facilitates the analysis of our petabyte-scale datasets.

He is also co-leader of WALLABY, one of three ASKAP surveys which provide a critical, complementary suite of wide and deep coverage of galaxies through space and time.

ASSOC. PROF. RICHARD MCDERMID

Macquarie University

Associate Professor Richard McDermid is an expert in the field of stellar dynamics and stellar populations in galaxies, and combining these to deconstruct galaxy formation histories.

He has pioneered the use of integral field spectroscopy in this area, and developed new techniques to understand the archaeological record of stellar orbits and chemistry in galaxies beyond the Milky Way. These techniques are being applied to ASTRO 3D surveys

Richard is also lead scientist for MAVIS – a major new instrument that Australia is developing for the European Southern Observatory that aims to build on the scientific legacy of ASTRO 3D.

Andy Casey
Monash University
Affilate

Xuelei Chen
Chinese Academy of Sciences
Associate Investigator

Vitaliy Ogarko
University of Western Australia
Postdoctoral Researcher

Manodeep Sinha
Swinburne
Postdoctoral Researcher

Andreas Wicenec
University of Western Australia
Associate Investigator

Tanner Wilson
Monash University
PhD Student

Ivy Wong
CSIRO
Affiliate

Hongwei Xi
Chinese Academy of Sciences
PhD Student

MEMBER HIGHLIGHT

ASSOC. PROFESSOR RICHARD MCDERMID

AFFILIATE AT MACQUARIE UNIVERSITY

I'm Richard, Associate Professor in Astronomy at Macquarie University, working on Galaxy Evolution, the Hector Survey, and Data Intensive Astronomy (DIA).

My research is focused on untangling the intrinsic orbital and chemical structures of distant galaxies from observations such as those from the SAMI and Hector surveys. This work is starting to indicate close connections between the structure of those galaxies and the properties of our own Milky Way galaxy, for example as revealed by the GALAH survey. Working within ASTRO 3D gives me a unique environment for bringing together these different observational perspectives, and confronting them with theoretical expectations from the Genesis simulation team, all within one collaboration.

My group has recently developed a new methodology for combining orbital dynamical models and stellar populations, and applied this to high-quality '3D' integral field spectroscopic observations of galaxies in the Fornax galaxy cluster using the European Southern Observatory (ESO) Very Large Telescope (VLT). Using our novel approach, we found that the age and chemistry of the stars within these galaxies is closely related to the kinds of orbits those stars have, revealing new clues on how these galaxies built up their mass and structure.

Stephen Hawking's 'A Brief History of Time', really got me excited about tackling the Big Questions in science, and astronomy in particular.

I was fortunate to have great maths and physics teachers in high school who nurtured my curiosity and let me borrow their copies of popular science books - most notably Stephen Hawking's 'A Brief History of Time', which really got me excited about tackling the Big Questions in science, and astronomy in particular. I studied undergraduate astrophysics at St Andrews University in Scotland, but it wasn't until my final-year research project, where I got to use the University's 0.94m telescope, that I became convinced I wanted to work in astronomy research.

My other passion at school was geography, and especially getting out into the countryside for fieldwork. So perhaps if I hadn't followed astronomy, I'd be standing in a field or river somewhere taking measurements for geographical science of some kind!

Being an astronomer has given me amazing opportunities to see the world (as well as the Universe!), and interact with people from so many different backgrounds and countries. I also feel a great sense of privilege being able to spend my time thinking about astronomical problems, using the most amazing technologies, and working with extremely talented people, all with a common goal of understanding the Universe a little more than we did before.

In ten years' time I hope to be sitting with my all-important morning coffee reading about the latest astronomical discovery made by a diverse Australian-led international research team using the combined capabilities of the Square Kilometre Array (SKA) and ESO Extremely Large Telescope (ELT), making use of instruments and computer code designed and built with Australian technology know-how, following on from the scientific legacy of ASTRO 3D and subsequent astronomy Centres of Excellence.

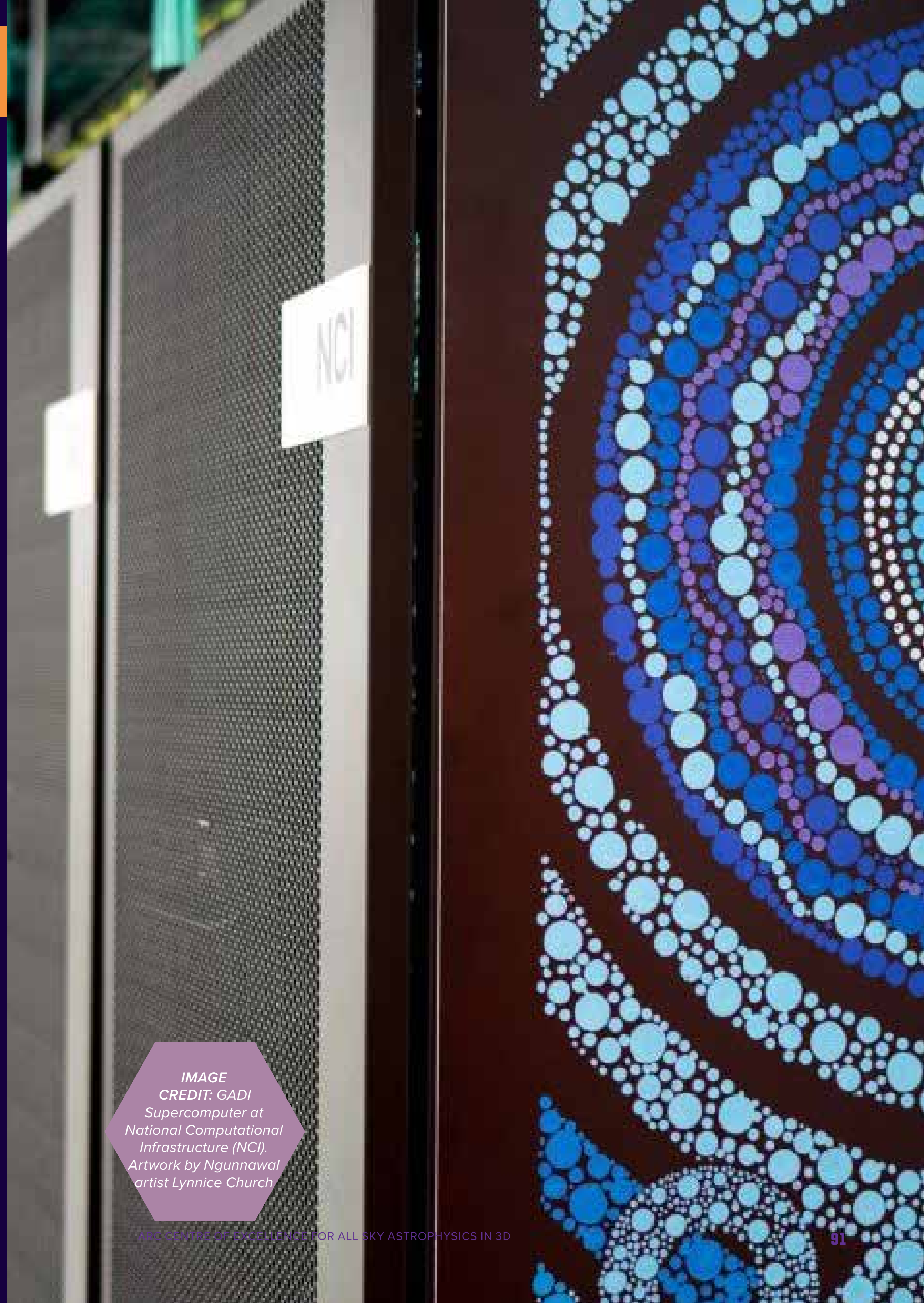


IMAGE CREDIT: *GADI Supercomputer at National Computational Infrastructure (NCI). Artwork by Ngunnawal artist Lynnice Church*

SCIENCE MANAGEMENT COMMITTEE

The Science Management Committee (SMC), chaired by CI Stuart Wyithe, met three times during 2020 to assess the scientific progress against the Centre's goals, evaluate cross-node and cross-project collaborations, and set Key Performance Indicators (KPIs) and milestones for the coming year. The SMC concentrates the Centre's extensive science survey management expertise and is composed of two Theme Leaders, two Thread Leaders, a Collaboration leader, and key CIs and PIs who ensure that all scientific areas of the Centre are represented on the Committee.

2020 Membership:
Chair - CI Stuart Wyithe

Theme Leader (Origin of Matter & the Periodic Table) - CI Elaine Sadler

Theme Leader (Origin of the Ionised Universe) - CI Lisa Kewley

Thread Leader (The Genesis Simulations) - CI Chris Power

Thread Leader (Data Intensive Astronomy) - CI Lister Staveley-Smith

Collaboration Leader - CI Joss Bland-Hawthorn

Key CIs and PIs - CI, AI Kim Vy Tran, CI Cathryn Trott, Julia Bryant and PI Phil Edwards

The SMC is tasked with:

1. Ensuring that ASTRO 3D meets its science goals;

2. Driving the translation of ASTRO 3D science into maximum measurable outcomes; and

3. Maintaining focus on training and supporting early career researchers to lead Australia's future science programs on the next generation telescopes.

At the start of 2020 the success of the second year of ASTRO 3D science in each project was assessed by the SMC against a series of outcome-focused milestones (Activity Plans). Further, the SMC identified areas of both cross-project collaboration and collaboration with international partners.

Overall ASTRO 3D projects were found to have achieved >80% of their set key objectives, with those not achieved being due to a strategic change of direction. Rather than repeat the Work-Plan-focussed assessment, in 2020 the SMC ran a process of science review, focussing on the progress, achievements and opportunities in each ASTRO 3D project, as well as identifying areas of risk, competition and opportunities for collaboration. The review also identified intstances where new opportunities had driven a change in direction from the original ASTRO 3D plan. This review was presented to the International Advisory Board. The outcomes of this review have been fed into other areas of ASTRO 3D governance, including the risk register.

Stuart Wyithe
SMC Chair

EQUITY, DIVERSITY AND INCLUSION COMMITTEE

The ASTRO 3D Equity, Diversity & Inclusion (EDI) Committee is committed to cultivating a sense of belonging for all ASTRO 3D members. We strive to engage with individuals and institutions to identify best practices and empower everyone to make positive change. With some members rotating off in early 2020, Chair Kim-Vy Tran (UNSW) issued an annual call for expressions of interest. The 2020 EDI Committee of 22 members represents the full spectrum of professions and career stages at ASTRO 3D institutes. The EDI Committee holds zoom meetings on the second Wednesday of every month and agendas include links to resources spanning a broad range of topics within the EDI landscape.

The year started on a very positive note with ASTRO 3D named one of the Australian Academy of Science's Women in STEM Decadal Plan Champions. We also updated our "Guidelines for Inclusive Meetings" to include consideration of holding meetings in countries that are LGBTQIA+ friendly. The ASTRO 3D "Guidelines for Inclusive Meetings" are available on the ASTRO 3D website for all to use, and the EDI Committee will revisit the Guidelines annually to incorporate feedback and improvements.

COVID-19

A major focus for the EDI committee in 2020 has been in helping the ASTRO 3D community handle the wide-spread disruption due to COVID-19. In March, we surveyed members on how the COVID-19 pandemic was impacting their lives. An EDI task force led by K. Tran, G. Kacprzak, and J. van de Sande prepared a "Strategies for Adapting to Impact by COVID-19" for the ASTRO 3D community. This report provides guidance on expectations, logistics, and community support to ensure that we do our collective best to support all of our members. The COVID-19 Impact guidelines were posted on the ASTRO 3D website in April 2020.

Black Lives Matter

In May, the systemic racism embedded throughout our societies was brought to the fore and challenged every single one of us to reflect on the continuing injustices experienced by people of colour and Indigenous communities. The EDI committee held two zoom discussions in June and invited all ASTRO 3D members to provide thoughts, strategies, and resources, with the goal of taking positive action. Led by EDI members K. Tran and A. Elagali, the EDI team developed the "Black Lives Matter: ASTRO 3D Action Plan" to:

1. Acknowledge racial inequity in academia.

2. Take steps to combat racial inequity in academia and beyond.

3. Make astronomy more accessible to Black and Indigenous Australians.

The BLM Action Plan was circulated to the ASTRO 3D community for feedback and adopted in

COMMITTEE UPDATES

September 2020. The BLM Action Plan includes a timeline with immediate goals as well as intermediate and long term milestones for the remaining life of this Centre (2024). Key to realising the Action Plan is coordinating efforts across and integrating existing resources at the ASTRO 3D institutes. The EDI committee convened a BLM Task Force that will regularly assess how the ASTRO 3D community is meeting the goals outlined in the Action Plan.

Hiring Guidelines

In the second half of 2020, the EDI committee returned to our original planned milestone for 2020 of developing hiring guidelines that promote equitable and inclusive practices. Led by K. Tran, D. Castle, and I. McCarthy, the EDI committee has drafted hiring guidelines that are divided into three phases: Phase 1 – Preparing to hire; Phase 2 – Hiring Process; and Phase 3 – Post-search Assessment. We have provided a draft version of the hiring guidelines to ASTRO 3D line managers and plan to have a full working version by early 2021. A major component of the hiring guidelines and a point related to BLM is the inclusion of a demographic survey. To help foster and support an inclusive and diverse workforce, we need to determine whether our hiring practices are effective at recruiting people from all groups in our society. The EDI committee developed optional demographic questions to include in the ASTRO 3D climate survey and as part of the hiring guidelines.

Pleiades Award Application

The Astronomical Society of Australia (ASA) has issued a call for applications for the Pleiades Awards which recognises organisations that take active steps to promote equity and inclusion at all levels and across all people in the astronomical community. An EDI task force led by M. Partridge, K. Grasha, and G. Heald prepared the ASTRO 3D application for a Pleiades award which was submitted in December 2020.

Kim Vy-Tran
EDI Committee Chair

SENIOR EARLY CAREER RESEARCHERS COMMITTEE

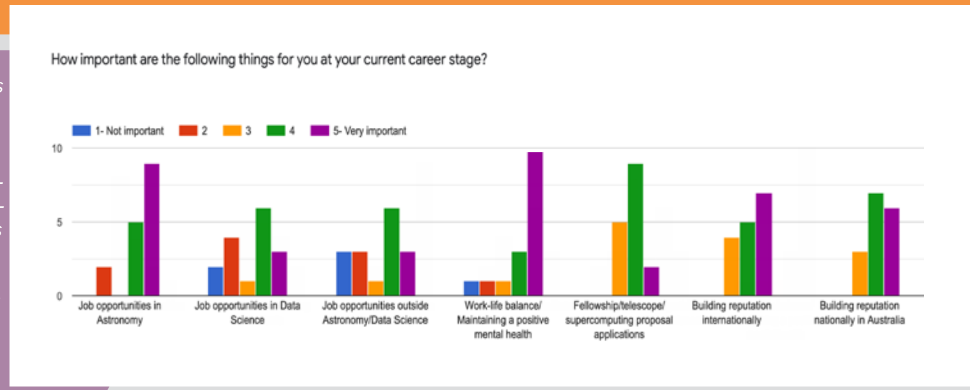
2020 was the Senior ECR Committee's first full year of operation. We have continued our efforts to represent our peers and their needs to the Executive Management Committee. We are particularly grateful to the Executive Management Committee for using unused travel funds for contract extensions, and for their work helping initiate conversations with former astronomers who have moved into other fields.

Towards the end of the year, Bi-Qing For (UWA) and Tiantian Yuan (Swinburne) stepped down from their roles on the committee; we thank them for their contributions over the last 12 months. Replacing them are Andrew Battisti (ANU) and Lilian Garratt-Smithson (UWA), who join existing members Michael Hayden (USyd) and Phil Taylor (ANU).

Looking ahead to 2021, the Senior Postdoc Committee will hold monthly meetings, with a focus on helping the senior postdoc community achieve their career goals. We will hopefully organise workshops to this end as the world returns to normal. The committee will continue to ensure effective and efficient communication between the senior postdoc community and the ASTRO 3D Executive Management Committee.

Phillip Taylor
On behalf of the Senior ECR Committee

Anonymous ECR Survey sent to early career researcher members asking participants to rank items by priority. Graph provided by Dr Kathryn Grasha - Junior ECRs Committee Chair



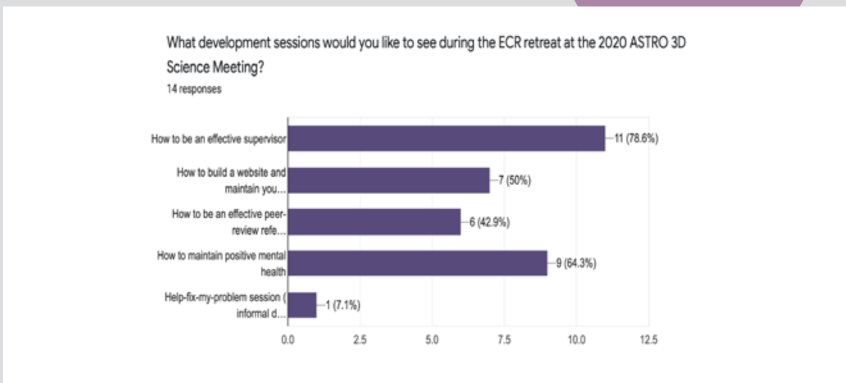
JUNIOR EARLY CAREER RESEARCHERS COMMITTEE

It has been one full calendar year for the ASTRO 3D new Junior ECR Committee. Our philosophical goal for 2020 was the following: how can we best address and make an action plan to identify and solve issues that the junior ECRs of ASTRO 3D are facing in their careers? To identify the issues, we created an anonymous poll sent out to all ASTRO 3D new ECR members with pre-filled and open ended questions. Following the highly ranked leadership training held at the 2019 Annual retreat, we also sought suggestions for training session topics for 2020. The topics "Jobs in Astronomy" and "Work-life balance" ranked the highest priorities to new ECRs (top image). For training sessions, the two most popular suggestions were related to "How to be an effective supervisor" and "Maintaining positive mental health" (bottom image). Due to COVID-19 and subsequent lockdowns, we are planning dedicated day for an in-person ECR retreat on these two topics prior to the 2021 Science Meeting. A one day virtual workshop on how to give effective communication is also being planned for the beginning of 2021.

The Junior ECRs also express concern about building a reputation outside Australia as well as proposal applications. The former has been further brought to light by the lack of international travel resulting from the 2020 pandemic. However, the junior ECRs are still optimistic about the job market and career goal priorities are to remain in astronomical research. ASTRO 3D is introducing the new International Zoom Seminars series where ASTRO 3D students and Postdocs can present and advertise their work to the broader international community. The aim of these seminars will be to help counter the effects of reduced international travel and loss of international exposure during the pandemic.

Kathryn Grasha
On behalf of the Junior ECR Committee

Anonymous ECRSurvey sent to early career researcher members asking participants to rank development sessions by priority. Graph provided by Dr Kathryn Grasha - New ECRs Committee Chair



COMMITTEE UPDATES

STUDENT COMMITTEE

The ASTRO 3D student committee is a body of student representatives, at least one from each node, which works as a liaison between the Executive Management and the students. The role of the student committee is to act as a bridge between the senior staff and the students, be a body where students can bring up their problems or appreciation of ASTRO 3D, organise events for students (e.g. ASTRO 3D student retreat) and forward any new ideas the students might have.

Due to COVID-19, this year has been particularly tough, which has not allowed us to catch-up on the goals we had set for ourselves. On a positive note, we had many students successfully submit their theses this year and publish papers. The virtual writing retreat had very positive reviews from all the attendees and students found it very useful.

The shutting down of telescopes impacted the research of many students leading to a need for research extensions. ASTRO 3D's COVID-19 extensions have been very helpful for finishing students, as they are able to continue their research while they apply for jobs.

During the lockdown imposed by the government, regular zoom sessions were organised by the students and their respective nodes to help cope with the isolation. This included both social and work sessions, which have been well received by students. These were in additon to the ongoing ASTRO 3D zoom seminars and meetings.

The future/near-future goals for the student committee may include workshops for students to cope with a post-COVID-19 crisis, manage their mental health and workshops/seminars for students to show their work to other institutes. We will also try to organise a Student Retreat this year.

Garima Chauhan
On behalf of the Student Committee

SUSTAINABILITY COMMITTEE

The ASTRO 3D Sustainability Committee is driven to introduce lasting changes that will reduce the carbon footprint of astronomy research. We recognise that our research activities emit an unsustainable volume of greenhouse gases. The Committee approaches this as a structural problem: organisational changes are necessary to reduce the carbon emissions of astronomy facilities, and to reduce the expectation of scientists to travel. The Committee meets on the last Wednesday of the month, and the Committee members are representatives or leaders of recently established sustainability committees at the institution-level, and within the Astronomical Society of Australia.

The 2019 ASTRO 3D Annual Retreat occurred at a transition point for astronomy research in Australia. Unprecedented bushfires ravaged the country and blanketed our cities in smoke. Around the same time, Affiliate Investigator Adam Stevens (ICRAR) and others completed a study finding that Australian astronomers contribute five times more emissions than the average human (>37tCO2-e/yr per astronomer). Supercomputers, travel, and telescopes are all broadly considered essential to astronomical research, and they all contribute substantial emissions. With these data, and climate change on our very doorstep, the Annual Retreat represented an opportunity to initiate lasting change.

In 2020 the Committee activities have largely centered around education: educating colleagues about the impact of our normal research activities, and generating knowledge to help mitigate that impact. Our Sustainability Seminars have been key to help educate, and the coming year will include seminars from climate researchers in other ARC CoEs, research that is also underpinned by supercomputers. In collaboration with environmental consultants, the Sustainability Committee has developed detailed and practical guidelines for evaluating suppliers and purchasing products (merchandise, equipment). These guidelines include how to identify the source materials, accreditations, the waste hierarchy, and how to identify the production chain. Modern slavery can be hidden in industrial supply chains: artificially decreasing prices, and increasing emissions through otherwise unnecessary transportation. These purchasing guidelines are applicable for individuals and organisations, and were unanimously recommended by the Executive Committee. In 2021 we aim to produce a guide on how to host a carbon neutral conference, including a review of technology platforms for more effective remote collaboration.

Using data from the KPI reporting from ASTRO 3D members, the Committee has calculated the carbon footprint of all recent travel in ASTRO 3D. These efforts reflect our broader goals for the next two years: measure and mitigate. In 2021 the Committee will develop a detailed carbon accounting for all current and historical ASTRO 3D activities. With these data we will lobby for research facilities that only use renewable energy, nurture effective remote collaboration to reduce travel, and develop strategies to mitigate the impact of necessary travel. Mitigation strategies may include pooling carbon offsets for all Centre travel, or perhaps across all ARC CoEs to leverage economies of scale, to fund activities that have real impact.

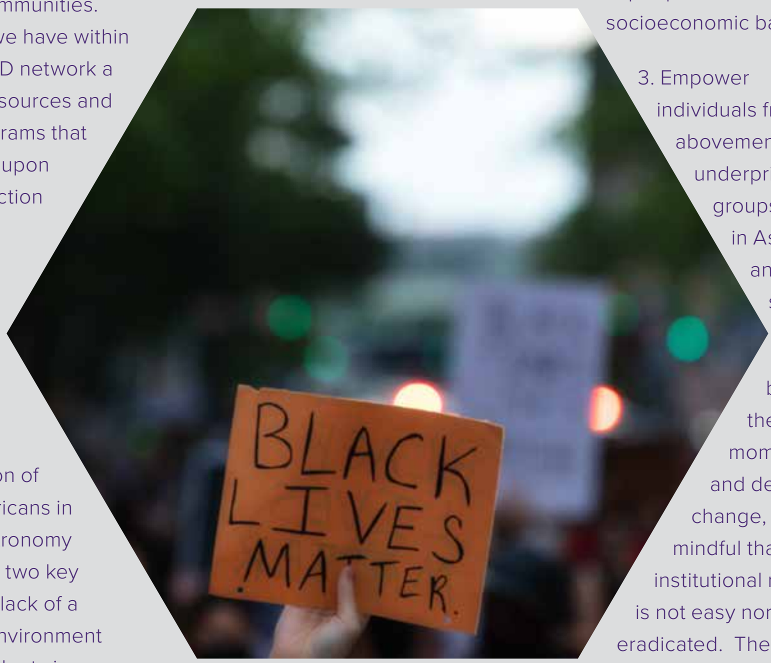
Andy Casey
On behalf of the Sustainability Committee

EQUITY DIVERSITY AND INCLUSION HIGHLIGHT

BLACK LIVES MATTER (BLM) ACTION PLAN

As members of the ASTRO 3D community, we all have the opportunity to help implement the ASTRO 3D BLM Action Plan within our respective institutions as well as across Australia and internationally. It cannot be stressed enough how important it is to have people at every career stage be engaged in working towards dismantling the systemic racial barriers that still exist within academic communities.

Fortunately we have within the ASTRO 3D network a number of resources and existing programs that we can build upon in our BLM Action Plan.



Recent reports identify that the persistent under-representation of African-Americans in physics & astronomy are driven by two key factors are 1) lack of a supportive environment for these students in many departments; and 2) the enormous financial challenges that these students and the programs that support their success face. The ASTRO 3D Black Lives Matter Action Plan addresses these factors with immediate actions to be in place by mid-2021 and with intermediate and long term plans for the remaining life of this Centre. The focus of our immediate actions is on Indigenous and Black communities, whereas the mid and long-term plans expand to encompass marginalised communities and people of colour.

With our BLM Action plan, we will:

1. Educate our community about racial biases and equip ourselves with the tools necessary to combat racial inequities in our institutions and nodes.

2. Engage with marginalised communities and voices, especially Indigenous and Black Australians and people from underprivileged socioeconomic backgrounds.

3. Empower individuals from the abovementioned underprivileged groups to succeed in Astronomy and related sciences.

As we build on the renewed momentum and demands for change, we must be mindful that challenging institutional racism is not easy nor quickly eradicated. The ASTRO 3D BLM Action Plan relies on establishing, strengthening, and sustaining partnerships with universities, schools, and businesses. As a community, we have a long-term vision that is sustainable and continuously empowers marginalised voices, i.e. "this is a marathon and not a sprint".

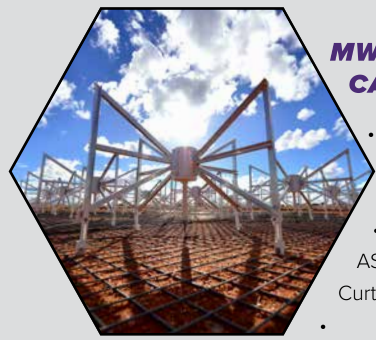
ACTIVITY PLAN 2021

GENESIS SIMULATIONS – CHRIS POWER (UWA)

- Following ASTRO 3Ds investment in the development of SWIFT, in 2021 we will run our ambitious 300 billion particle simulation with NCI, enabling the large volume simulations for needed for ASTRO 3D and galaxy survey and reionisation science
- EAGLE-XL consists of an EAGLE galaxy formation prescription run in a Millennium volume, such that the statistics of galaxy groups and clusters is significantly improved. Colibre focuses on a volume equivalent to the EAGLE high resolution run, but with enhanced resolution and improved models for the physics of the inter-stellar medium. Genesis team members are already embedded in the core EAGLE-XL and Colibre teams. In 2021, we will utilise the next set of state-of-the-art EAGLE-XL galaxy formation simulations to compare with our survey/project datasets.

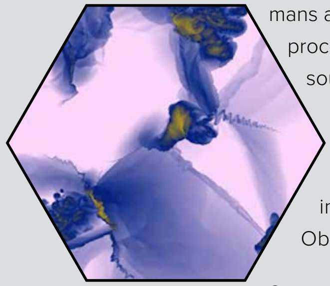
DATA INTENSIVE ASTRONOMY (DIA) – LISTER STAVELEY-SMITH (UWA)

- Macquarie University hosts Astronomy Data Central (ADC) which provides important data curation and data servers for ASTRO 3D optical surveys. In 2021, we will integrate ADC services into a virtual radio/optical/GW/theory centre. ADC will provide in-kind professional software engineering and project resources not present in ASTRO 3D.
- Recent visits by the Canadian and Spanish SKA Science Directors have led to a combined project between CIRADA, and the Spanish and Australian SKA Regional Centre to supply database resources to ASTRO 3D for WALLABY, which is part of the ASTRO 3D project, ASKAP HI surveys. In 2021, this program will add extra DIA resources to ASTRO 3D.
- In 2021, we will exploit extra HPC resources arising from Pawsey and NCI upgrades, HPC verification, extra AAL-purchased HPC cycles and joint ventures with industry. These collaborations create excellent opportunities to increase theory and simulation capacity, and to bolster international competitiveness in the DIA area.



MWA EOR SURVEY – RACHEL WEBSTER (MELBOURNE) AND CATH TROTT (CURTIN)

- The MWA EoR survey team will continue to obtain data on the Murchison Widefield Array, and to analyse this data with the upgraded Pawsey Supercomputer facility.
- The SKA simulation and Science Working Group work will continue with current ASTRO 3D members (Trott, Pindor, Line, Mitchell, McKinley, Barry, Wayth), and a new Curtin 3-year 2021-2023 SKA science research position.
- Additional focus on diffuse emission models (calibration and signal subtraction) and RFI in data (particularly in response to SpaceX and other satellite constellation reflections of Geraldton and Perth DTV and FM radio) will be undertaken.
- Through our strengthened relationship with the LOFAR EoR KSP project (joint SKA work between Koop-



mans and Trott, a cross-node visit from Andre Offringa, and a visit with collaborative data processing by Nichole Barry to ASTRON), we will work more collectively to combine southern and northern hemisphere data and insights.

FIRST STARS PROJECT – GARY DA COSTA (ANU)

The follow-up of extremely metal poor (EMP) candidates will continue with individual star-by-star observing with the ANU 2.3m telescope at Siding Spring Observatory.

Spectra from the 2.3m will be used to perform a full investigation aiming to understand the frequency of carbon enhanced stars as a function of [Fe/H]. Gaia information will be used to supplement spectral information on EMP stars, and to derive a complete chrono-chemo-dynamical picture of stars in the early Galaxy.

There is substantial scope for further follow-up and extension of these kinematic studies through further observations, Gaia eDR3 and DR3, and with modeling.

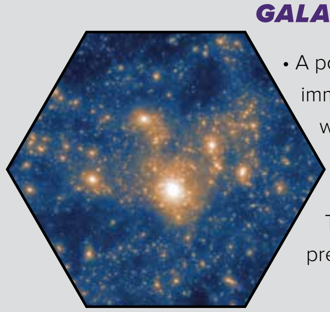
FIRST GALAXIES PROJECT – MICHELE TRENTI (MELBOURNE)

• We will focus primarily on Hubble Space Telescope and ground-based telescope investigations into the chemical and structural properties of first galaxies. This will be complemented by continued theoretical and numerical modelling of galaxy, star, BH and GRB formation at highredshift, in particular aiming at leveraging strategic investment in the design of the SkyHopper space telescope to secure federal funding for construction and later operations. This combined approach will position the First Galaxies theme at the forefront of astrophysical observations from space when JWST is launched in 2021.

• JWST science: Trenti is a co-investigator of the GLASS-ERS program led by Prof. Treu at UCLA which will provide both imaging and spectroscopy of high-z galaxies, and a collaborator on Massimo Stiavelli's GTO program on high-redshift galaxies, which will include medium-deep parallel fields with NIRCAM (short and mid IR imaging) that will be ideal to identify galaxies at z~8-14. ASTRO 3D postdoc Leethochawalit is already contributing to the development of tools for these programs and will continue doing so until the end of her appointment.   When JWST is launched, the First Galaxies project will pivot to fully utilizing GLASS-ERS, including the hire of a new postdoctoral researcher and recruitment of new students for JWST projects.

• SkyHopper mission design: We will support this sub-project into its transition to full external funding and industry engagement/consultancies, delivering large benefits for the end of the Centre and for its next proposed phase.

GALAXY EVOLUTION PROJECT – KIM-VY TRAN (UNSW)



• A postdoctoral researcher will be hired at UNSW to lead the AGEL data analysis, most immediately to handle the 57 hours of VLT observations scheduled for 2021A. Tran will lead the AGEL team with core members at UNSW, Swinburne, and UC Davis, and contributing members across the ASTRO 3D institutes

• At Swinburne, there will be a transition from current CI Glazebrook to D. Fisher. The DUVET survey led by Fisher maps ionised gas in star-forming disks and presents

a complementary new opportunity that will be supported by a PDRA within GE. Bringing new members to the GE Project and leadership ensures that we continue maximizing science opportunities for current and upcoming facilities such as the GMT and the E-ELT.

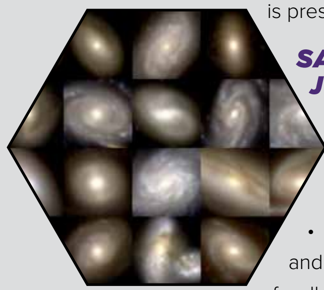
Analysis of all Galaxy Evolution Survey data will continue throughout 2021 with discoveries to be reported as press releases, publications, and social media updates.

ASKAP SURVEYS – ELAINE SADLER (SYDNEY)

• The resources provided by ASTRO 3D have been pivotal in allowing the scientific exploitation of ASKAP HI data. They have also been useful in allowing us to leverage other re-sources such as OzSTAR HPC time, ADACS software development, and international links to the Canadian and Spanish SKA Regional Centres.

• The ongoing ASKAP-X upgrade will improve telescope reliability, and the 2021 Pawsey upgrade will allow our survey teams to remove bottlenecks and accelerate survey progress. Now data is flowing, additional (non-ASTRO 3D-funded) postdocs and students are being committed to the HI surveys.

In 2021, we will further strengthen links with the Genesis simulations team, make follow-up observations with VLBI and we will advertise a USyd ASTRO 3D continuing position (targeted at radio astronomy) to provide permanent career paths for our early career researchers. We will develop ESO/MUSE follow-up proposals for ASKAP sources, propose for deep DECAM time on ASKAP pilot fields and make high-resolution postage stamps for bright galaxies (WALLABY). We will split ASKAP observing bands to maintain band-width but avoid radio-frequency interference (RFI) near 1200 MHz. This RFI comes from Earth-orbiting satellite transmissions, so is present even at the radio-quiet MRO site

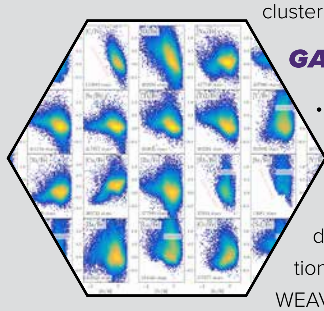


SAMI/HECTOR SURVEYS – SCOTT CROOM (SYDNEY) AND JULIA BRYANT (SYDNEY

• We will use SAMI and then Hector to understand outflows, particularly for all galaxies, not just edge-on galaxies (requires good LSF, multi-comp fitting). Contribute to gas-stellar misalignment work.

• The Hector team will use hydrodynamical simulations to investigate how joint IFU and HI/H2 analyses can be used to place limits on models of star formation and stellar feedback. This will include expanding the SimSpin tool to extract gas properties from simulations, followed by controlled non-cosmological simulations and then cosmological zooms

• In 2021, the team will be beginning its Hector survey, including surveying clusters to large radius to view the cluster transformation process in action over a range of densities. This includes combining stellar populations, kinematics and current star formation rates together to identify the quenching and transformation modes in cluster galaxies.



GALAH - JOSS BLAND-HAWTHORN (SYDNEY)

• The GALAH survey will continue its large program of high spectral resolution observations of stars in the Milky Way using the HERMES instrument on the Anglo-Australian Telescope (AAT). The team has been allocated 200 nights in 2021-2022.

• WEAVE and 4MOST are the next generation of large-scale surveys, currently in development. They are highly multi-plexed, and will take both high and low resolution spectra to carry out a range of Galactic and extragalactic projects simultaneously. WEAVE commissioning will begin this year and is restricted to the northern hemisphere. Our team will engage with these programs to complement the GALAH survey.

• Given the successes of the GALAH survey, in 2021 our team will exploit the recent Gaia EDR3 data release, which significantly improves the kinematic information for stars targeted by GALAH.

2020 VIRTUAL SCIENCE MEETING

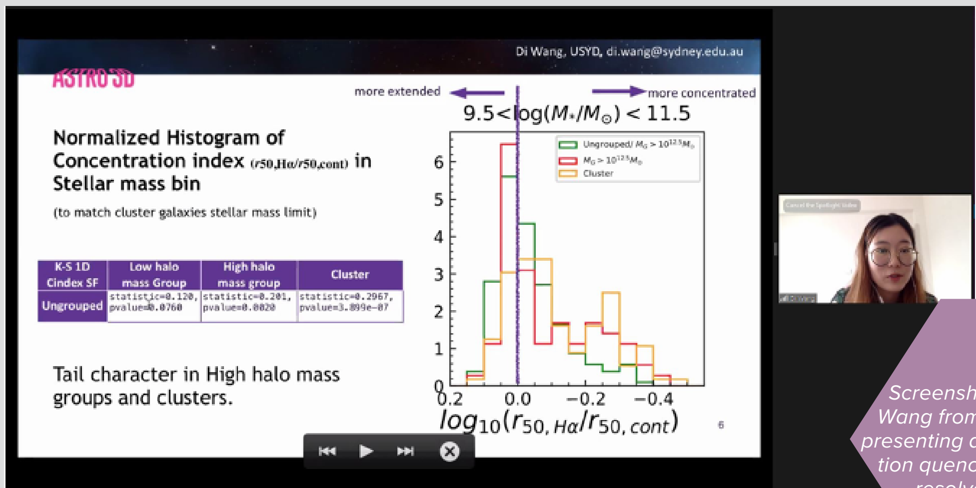
With COVID-19 lockdowns in full effect, we held a Virtual Science Meeting, using Zoom Webinars as the primary platform to deliver the latest updates for our scientific discoveries. Survey and project leads provided overviews and updates, followed by highlight talks by PhD students and Early Career Researchers. The team also received management updates, an overview of the progress within our education and outreach programs, as well as committee updates.

With 108 participants, a many ASTRO 3D researchers had the chance to update their colleagues on their latest results from all of our projects and surveys and contribute to discussions and written Q & A sessions. As a Centre that covers many time zones, including northern hemisphere China, US, and Europe, it is important for our virtual meetings to be accessible across the Centre. All talks and updates as well as the Q & A text were recorded and uploaded to our YouTube, Website and Slack channels to allow those unable to attend in real time to view the talks at a later date. Discussions and Q&A sessions continued on our Slack Channel.

Despite being overseas in many time zones, our International Advisory Board was able to view the science meeting talks, either in real time, or via the recordings.

Highlights included:

- An update on the GALAH Data Release 3 from ANU Postdoc Sven Buder
- A summary of decomposed stellar kinematics of SAMI galaxy bulges and disks by ANU Postdoc Sree Oh
- An update on whether Lyman Continuum galaxies have a homogenous escape fraction by Swinburne PhD student Uros Mestric
- An overview of the discovery of a ring galaxy at high redshift by Swinburne Fellow Tiantian Yuan.
- An update of the first results from the WALLABY pilot survey by UWA AI Tobias Westmeier
- An outline of the MWA Long Baseline Epoch of Reionisation Survey (LoBES) by Curtin Postdoc Christene Lynch
- Predictions from the Blue Tides simulation of host galaxies of z=7 quasars by Melbourne PhD student Madeline Marshall

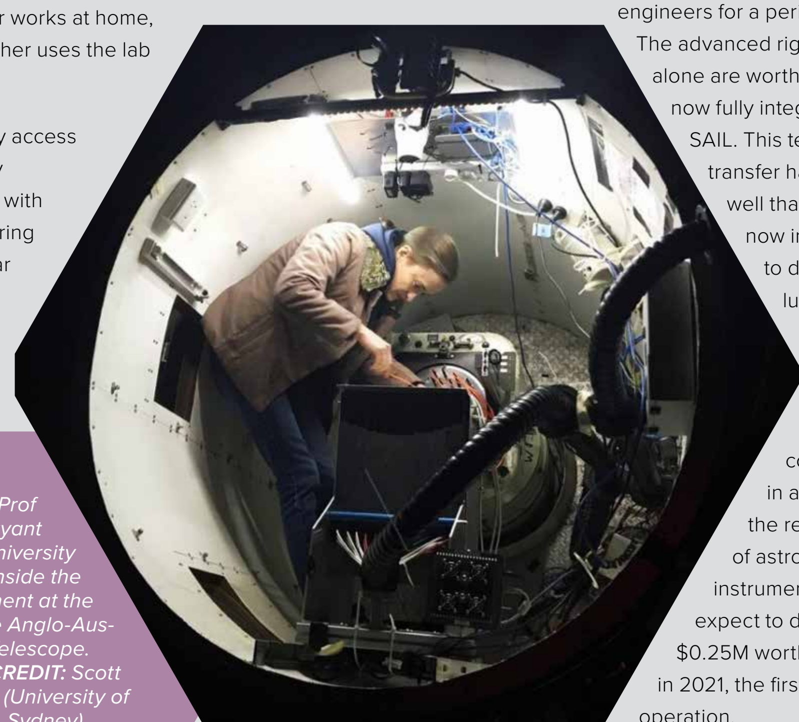


Screenshot of PhD Student Di Wang from University of Sydney presenting an outline of star formation quenching rates in spatially resolved SAMI galaxies.

COMMERCIAL TRANSLATION

This has been a difficult year for lab-based research across the country, as it has been for lab-based teaching across all universities. The Sydney Astrophotonic Instrumentation Laboratory (SAIL) (Director: ASTRO 3D Associate Investigator, Assoc Prof Sergio Leon-Saval and Hector lead Assoc Prof Julia Bryant) at the University of Sydney were under strict protocols to limit the spread of the COVID-19 virus. Typically, this meant limiting one researcher to each lab, or having a rotation system where one researcher works at home, while another uses the lab facilities.

Laboratory access was tightly controlled with mask-wearing and regular cleaning.



*Assoc Prof Julia Bryant from the University of Sydney inside the SAMI instrument at the top end of the Anglo-Australian Telescope. **IMAGE CREDIT:** Scott Croom (University of Sydney)*

COMMERCIAL SUCCESS

A major success was the installation of Subsea Communications Australia into the SAIL labs under the umbrella of an ANFF facility. This company is the leading manufacturer of fibre Bragg gratings, a technology that has revolutionised the field of astrophotonics. Dr Leon-Saval raised $1M to transfer the main systems to the SAIL labs, which was sufficient funding to hire the two lead engineers for a period of 3 years. The advanced rig systems alone are worth $2M and are now fully integrated into SAIL. This technology transfer has gone so well that we are now in a position to deliver on lucrative government, industrial and commercial contracts, in addition to the requirements of astronomical instrumentation. We expect to deliver on $0.25M worth of contracts in 2021, the first year of operation.

COLLABORATION HIGHLIGHTS

Our Centre includes six international partners - University of Washington, Caltech, University of Toronto, the ASTRON Institute in the Netherlands, Oxford University and the Chinese Academy of Sciences. We now have close ties with simulation groups at U..Washington, Harvard, UC Davis and Max Planck Institute, Munich that have specific skills to aid active ASTRO 3D science programs.

Our national partner institutions are CSIRO Astronomy and Space Science (CASS), and the National Computational Infrastructure (NCI). We maintain our strong connection with CASS through the ASKAP surveys. The ASTRO 3D nodes have been collaborating closely with researchers based at the Australian Astronomical Observatory Consortium, particularly through science projects like SAMI and GALAH, and instrument builds like Hector. Furthermore, the AAO Consortium, a collaboration between Macquarie University, the University of Sydney and the Australian National University, has strong links to ASTRO 3D. The most visible aspect of these collaborations in 2020 has been several large teams working together on grant submissions under the ARC LIEF umbrella to fund instruments that will benefit ASTRO 3D and forge closer links with the European Southern Observatory, including a new instrument called MICADO, and the Australian-led MAVIS instrument to be built for the VLT.

In the year of COVID-19, we have maintained close collaborations through regular meetings and with a focus on finishing existing projects, in particular, publishing high-profile science papers. This was mostly achieved through a combination of writing retreats (including a virtual writing retreat) and key investigators in each survey/project directly engaging partners.

This has been our most successful year measured by research output. Of the almost 200 refereed papers published by ASTRO 3D members in 2020, 97% were published in international journals of high impact. Moreover, many of our articles include co-authors from other countries. Predominantly these are countries where we have partner institutes such as in the US (where co-authors are represented on 63% of our papers) and the UK (33%), but also include countries such as Italy (24%) and France (15%). Many projects from earlier years have now matured to the point of producing published work. Taylor (ANU) and Hayden (Sydney) submitted a paper on the COCKATOO suite of simulations that looks at the prevalence of alpha-rich vs. alpha-poor discs in simulated Milky Way analogues. CI Chris Power and the Genesis team has been working with Camilla Correa from Amsterdam. This has enabled a new paper with ICRAR/UWA PhD student Ruby Wright. In addition, new collaborations have emerged based on work with EAGLE and Illustris teams, either exploiting existing datasets or direct collaboration on new projects.

This has been a good year for the GALAH collaboration with the major data release, DR3. An exciting collaboration has emerged between ASTRO 3D PhD student Boquan Chen (U.Sydney), ASTRO 3D Fellow Michael Hayden (U.Sydney), ASTRO 3D Affiliate, Chiaki Kobayashi (University of Hertfordshire) and ASTRO 3D Chief Investigator Amanda Karakas (Monash). Chen is building a chemical evolution model for the Galaxy using their revolutionary new chemical tables; this is to be compared with new GALAH/Gaia data samples.

Swinburne PhD student Garima Chauhan), collaborated with ASTRO 3D Fellow Claudia Lagos (UWA) and ASTRO 3D Associate Investigator Danail Obreschkow (UWA) to produce mock galaxy light cone simulations for the ASKAP HI surveys (WALLABY and DINGO). ASTRO 3D Postdoc, Lilian Garratt-Smithson (UWA) has been leading hydrodynamical simulations to identify analogue galaxy populations in support of ASKAP HI surveys (FLASH) with U'Sydney CI Elaine Sadler and galaxy evolution observing proposals in collaboration with ANU postdoc Kathryn Grasha.

Our collaborations with NCI are underpinning a number of ASTRO 3D flagship projects. CI Joss Bland-Hawthorn and research fellow Thor Tepper-Garcia secured time on the new NCI Gadi supercomputer. Moreover, CIs Power, Croton and Wyithe (UWA, Swinburne and U.Melbourne) successfully engaged with NCI staff to optimize the Genesis simulations for NCI computers that carry the Genesis simulation runs. Power and collaborators at the University of Tasmania and the University of Hertfordshire (UK) were awarded a further 22.5M CPU hours by NCI to conduct research on the effect of propagating jets on the evolution of galaxies.

The Genesis/Bluetides project, led by Chief Investigator, Stuart Wyithe (U.Melbourne), with Tiziana di Matteo (Carnegie Mellon), continued their collaboration with a new paper led by U.Melbourne PhD student Madeline Marshall on predictions of host galaxies around high-redshift quasars. A follow-up paper on predictions specific to JWST was also submitted. U.Melbourne PhD student James Davies published a paper on stacked 21cm galaxy images around high-redshift galaxies. PhD student Kevin Ren published work on stochastic processes as the origin of double power law in the evolution of the quasar luminosity function, in collaboration with AI di Matteo and CI Michele Trenti.

In 2019, the MAGPI collaboration emerged from one of the largest ESO time allocations to be approved with MUSE, the instrument with the highest demand across ESO institutions. A team of early-career ASTRO 3D fellows from across multiple nodes (Caroline Foster - Sydney, Claudia Lagos - UWA, Trevor Mendel - ANU, Emily Wisnioski -ANU, Tiantian Yuan- Swinburne) came together to build a large team of galaxy researchers with the goal of studying the 3D kinematics, chemistry and properties of more than 50 galaxies in a diverse range of environments at z ~ 0.3. The first survey overview paper was started in 2020 and is now well advanced, to be submitted in 2021.

PhD student Joseph Ronniy (Curtin) is working with members of the CHIME and HIRAX collaborations to look at new MWA calibration techniques and a joint generalised framework for performing radio interferometer calibration.

The ASTRO 3D collaborations with the FAST team in China continue. CI Staveley-Smith, Hongwei Xi, Bi-Qing For, working with Bo Peng (NOAC), have secured their first FAST data for the Pilot FAST Ultra-deep survey. CI Bland-Hawthorn and research fellow Thor Tepper-Garcia continue with their simulations in preparation for the FAST HI survey, in collaboration with FAST Project Scientist, ASTRO 3D Partner Investigator Professor Di Li.

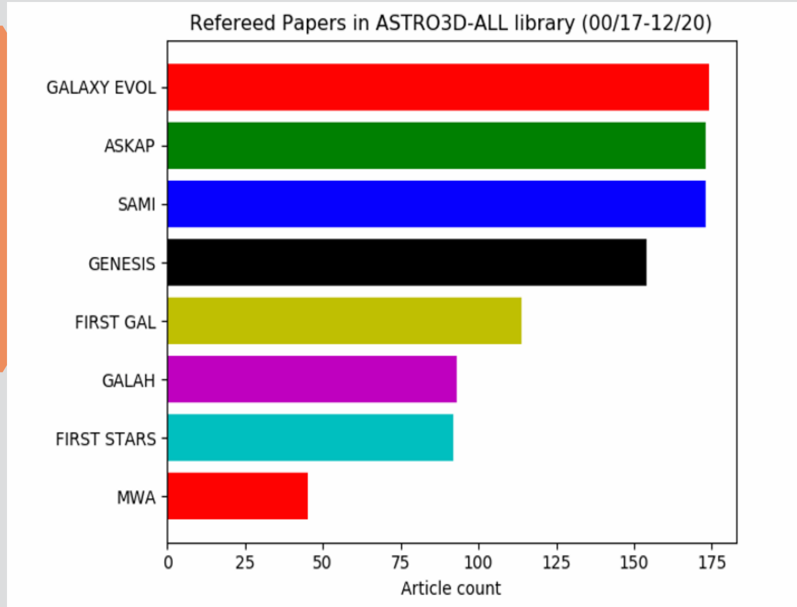
While the SAMI Galaxy Survey is complete, the SAMI project continues to motivate collaborations across ASTRO 3D. Sukyoung Yi and PhD Khim visited from Korea in January 2020 that led to a new SAMI team paper. Just before the virus hit in March, Francesco Belfiore (INAF, Italy) also visited to discuss new collaborations. The ongoing collaboration building around the Hector Galaxy Survey continues as they strive to deliver the instrument in 2021.

In February 2020, there was a special in-person workshop to bring the ESO and ASTRO 3D communities together. This was a well attended meeting with the science organizing committee chaired by ASTRO 3D Fellow Claudia Lagos(UWA) and ASTRO 3D Associate Investigator Aaron Robotham (UWA).

In December 2020, ASTRO 3D Associate Investigators, Jesse van de Sande and Nic Scott ran a successful virtual conference on "Linking the Galactic and Extragalactic", (https://extragalactic-milkyways.org). This was a remarkable meeting that displayed a unique format to engage speakers from around the world, in two separated time slots to deal with the time zone problem. This led to a new collaboration between the GALAH team and the WINDS survey. team based in Chile (PI Bland-Hawthorn).

CROSS-NODE AND CROSS-PROJECT COLLABORATION

The number of refereed papers by ASTRO 3D researchers in each (primary) project.

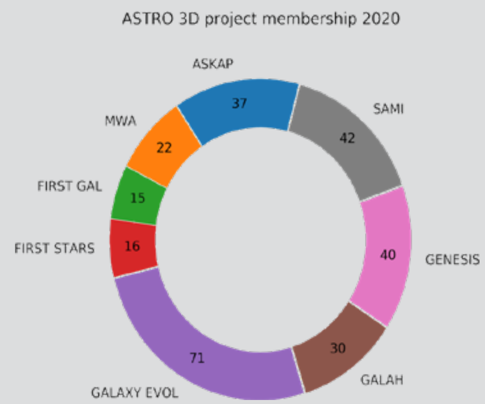


Understanding the evolution of matter from the Big Bang to the present day is a necessarily ambitious task that demands united expertise from world-leading astronomers. ASTRO 3D is organised into many scientific projects that share this pioneering goal of understanding the cosmos, with researchers situated at institutions (nodes) across Australia and beyond. Fostering collaboration between geographic nodes and scientific projects is central to achieving ASTRO 3D's mission, and its legacy.

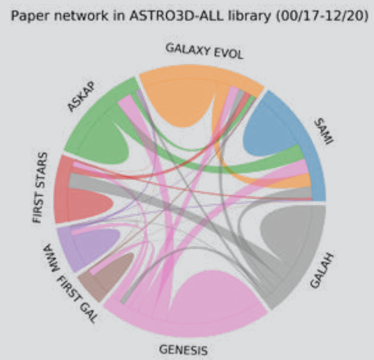
The peer-reviewed publications authored by ASTRO 3D researchers demonstrates strong collaboration across nodes and projects. The number of publications from ASTRO 3D surveys and projects, with no single project dominating over any other (bar graph above). These publications largely reflect ASTRO 3D's membership per (primary) project (see right top), emphasising strong scientific outputs from all projects and researchers. While MWA continues observations and calibration efforts with more papers in preparation, the data collected so far already surpasses best limits on measuring the reionisation of the cosmos, peering far back into the early Universe.

Astronomy is often siloed between theory and observational research, or between radio or optical research, stifling innovation and scientific advancement. However, the author network of ASTRO 3D publications show strong cross-collaboration (see right centre). Here every ASTRO 3D project has refereed publications with authors across projects, and chord thickness represents publication count. The Genesis (theory) project has crucial links with all observational projects. ASKAP (radio) is crucial for galaxy evolution and the SAMI survey. Milky Way stars (GALAH) underpins work on distant galaxies, and the first stars and galaxies. This kind of cross-collaboration is crucial for properly understanding the Cosmos, but is rarely possible without the support of a collaborative Centre.

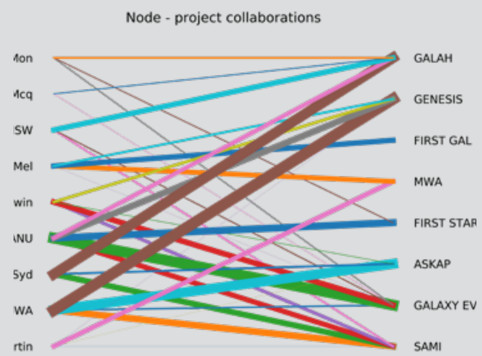
No project is housed at a particular node; nodes have researchers with expertise in many projects (see right bottom). This helps foster collaboration both within institutions (across projects) and across institutions (within projects). While the expertise at some nodes underpin a project (e.g., Curtin and University of Melbourne on the MWA, or the University of Western Australia on ASKAP), other nodes are powerhouses of activity: the Australian National University, the Universities of Sydney, Melbourne, and Western Australia, and Swinburne, have thick lines connecting to many projects. Similarly, the Galaxy Evolution and SAMI survey unite every single node. First Galaxies, the Genesis project, and the GALAH survey, all link nearly every node. These cross-node and cross-project publications are a strong reflection of the collaborative and productive nature in ASTRO 3D.



Number of ASTRO 3D researchers per (primary) project. Most ASTRO 3D researchers work across multiple projects, so only the primary project is shown here.



Interdependence and collaboration of ASTRO 3D projects as measured by publications between projects. Chord thickness represents the number of publications.



The collaborations between nodes (left) and projects (right), as measured by scientific publications. Line thickness is proportional to unique publications by node members on a project.

2020 ALL NODES DAY

COVID-19 impacted our ability to hold our in-person annual retreat. Travel restrictions and on-going lockdowns in Victoria meant that getting together to give updates, do training and build on our collaborative relationships needed to be moved online. This took the form of a Virtual All Nodes Day hosted on Zoom Webinars. We had over 100 attendees with many nodes sharing a lunch event.

Director Lisa Kewley gave an overview of the Centre's 2020 achievements, CI Stuart Wyithe outlined the major science discoveries, COO Ingrid McCarthy updated everyone on our operational progress, and Senior Education and Outreach Coordinator Dr Delese Brewster summarised our Education and Outreach program progess.

Project and Survey progress updates were given by Chris Power (Genesis), Lister Staveley-Smith and Richard McDermid (Data Intensive Astronomy), Rachel Webster (MWA EoR), Gary Da Costa (First Stars), Kim-Vy Tran (Galaxy Evolution), Scott Croom (SAMI/Hector) and Joss Bland-Hawthorn (GALAH).

We received updates from each of our committee representatives (Equity, Diversity & Inclusion, Students, Junior ECRs, Senior ECRs, Sustainability and Awards).

Following the virtual seminars, all nodes joined together for node-specific discussions. Highlights include:

ANU members met to discuss a virtual ASTRO 3D visitors program using video conferencing during international travel restrictions. Director Lisa Kewley gave an update on the current and future initiatives to increase the gender diversity. Sree Oh led a discussion on travel funding allocation. Additionally, Sven Buder introduced a plan to host a post-COVID-19 international conference in 2021.

The Swinburne node had a 30-minute coffee break with virtual prizes, where CI Karl Glazebrook won a prize with a photo of his gorgeous puppies.

The University of Melbourne node had an enjoyable virtual meeting, discussing the proposed 2023 astronomy Centre of Excellence proposal. Bart Pindor provided an update on the MWA EoR activities. Simon Mutch discussed the recent Genesis updates, including Bluetides and 21cm MC based projects, as well as plans for combining the large Genesis box with the new MCMC merger tree extension code developed by Yisheng Qui in order to make a large volume, high dynamic range simulation with Meraxes.

ASTRO 3D Director Lisa Kewley opens the Virtual Science Meeting via Zoom Webinar

EDUCATION PROGRAMS

SCIENTISTS TAKING ASTRONOMY TO REGIONAL SCHOOLS (STARS)

Due to COVID-19, there was a hiatus in delivering telescopes to regional schools in 2020. In January, ASTRO 3D Associate Investigator Dr Brad Tucker and Education Affiliate Matt Dodds featured in three, short instructional videos, recorded by ANU Media, on using an 8" Dobsonian telescope. These videos are on the ASTRO 3D YouTube channel and are proving very popular

In 2020, in partnership with the Research School of Astronomy and Astrophysics at ANU, we applied for an Australian Federal Government Maker grant to expand the Regional Telescopes in Schools program, called Scientists Taking Astronomy to Regional Schools (STARS). ASTRO 3D was awarded $85,000 to deliver the STARS program between January 2021 and April 2022. This funding will allow ASTRO 3D AI Brad Tucker and PhD students to visit dozens of primary and secondary school students in rural, regional and remote Australia where they will conduct workshops, star-gazing evenings, and show students how to operate the telescopes and accessories provided. They will also learn how to record data for research projects. Teachers and students will be supported through technical information, curriculum resources and student projects ideas on our website.

*Dr Brad Tucker and Matt Dodds filming intructional video on using an 8" Dobsonian tele-scope. **IMAGE CREDIT:** Ingrid McCarthy*

*Student using tele-scope. **IMAGE CREDIT:** Ingrid McCarthy*

SPIRIT IN SCHOOLS REMOTE INTERNET TELESCOPE PROGRAM

SPIRIT in Schools is a joint ASTRO 3D-ICRAR program to engage Western Australian students from underrepresented demographics in STEM and astronomy through a practical astronomy project.

In 2020, SPIRIT went online, and included teacher professional learning sessions to support students in designing, implementing, and completing an astronomy project using SPIRIT.

ASTRO 3D supports the SPIRIT Image of the Year competition. Students who have used the SPIRIT telescopes throughout 2020 can create colour images of objects of their choice and submit them for judging. The winning photo (below) will be included in the annual astrophotography exhibition at Perth Astrofest in February 2021.

VIRTUAL WORK EXPERIENCE PROGRAM

Swinburne Node Education and Outreach Officer, Emma Barnet developed a pilot virtual work experience program that was operated during school holidays. We operated three online work experience programs, with over 50 students participating. Each two-day program involved the students doing a research task with a supervisor, receiving an introduction to python programming and Q&A career sessions with astronomers.

In 2021, we will develop a full week-long virtual work experience program that can be operated at all nodes. This program will include research modules of ASTRO 3D projects with instructions and discussion points for the students and guidelines for the astronomy supervisors. Virtual work experience programs enable rural, regional and remote students to participate in programs that may not be otherwise available to them.

'A nice pair' by Yuta Uemoto. 2019 SPIRIT Image of the Year winner.

EDUCATION PROGRAMS

PHYSICS DEPTH STUDY

In 2020, ASTRO 3D ran a successful one-day virtual astronomy and astrophysics Depth Study program for Year 12 NSW students at Siding Spring Observatory in line with the NSW physics curriculum. Over 400 Year 12 students from 50 NSW schools participated in the Depth Study via Zoom Webinars. Students listened to engaging presentations from ASTRO 3D researchers, built a spectroscope, and learned how to take photos of spectra with a smartphone. Topics covered included the nature of light, nucleosynthesis in stars, oxygen in the Universe and spinning galaxies. The students finished the day with an online quiz. Before the Depth Study, 14.5% of the students were planning to study physics at university. After the Depth Study, this increased to 19.7%.

"Thanks again for your fantastic workshop last week. The students really enjoyed it and said they felt "like adults" attending a "conference"."

INDIGENOUS WORK EXPERIENCE PROGRAM

The Indigenous Work Experience Program (IWEX) is a unique astronomy education opportunity that will encourage Aboriginal and Torres Strait Islander Year 10 students interested in astronomy to consider further study and possible career options in the field. Bringing together a group of these students who share an interest, gives them the opportunity to network, create connections and develop relationships that can continue after the program.

The 5-day pilot program at Mt Stromlo Observatory is under development and will take place in mid-2021. It will cater for Aboriginal and Torres Strait Islander students from NSW and the ACT.

The program will be supported by both the NSW Department of Education and ACT Education Directorate and be administered as part of their formal workplace learning program.

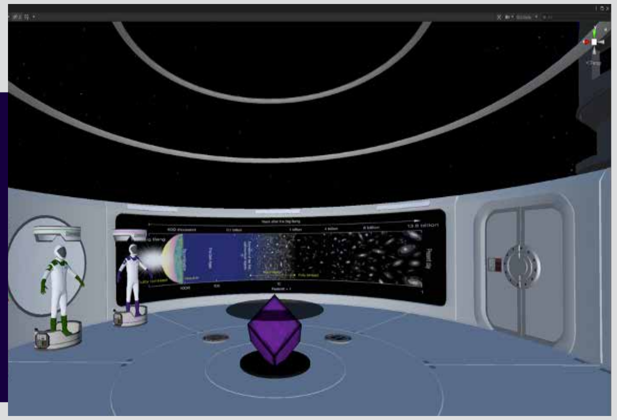
Screenshot from YouTube of Matt Dodds' videoed instructions on building your own spectograph

EDUCATION PROGRAMS

VIRTUAL REALITY (VR) EDUCATION MODULE

ASTRO 3D is committed to inspiring school students to study Science, Technology, Engineering and Mathematics (STEM). There is a particular need for teacher resources linked to the Year 10 Science Australian Curriculum, to help explain complex astronomical concepts and theories on the origin of the Universe.

Stage 1: Transporter Room, portal to the Universe



In collaboration with the Deakin University CADET Virtual Reality (VR) Laboratory, ASTRO 3D is developing an innovative, immersive and interactive VR package based on ASTRO 3D research. It will incorporate mathematics, digital technologies and the science that will assist student understanding of the data intensive science that they can't 'touch', and promote deep learning.

The VR program is overseen by a Science Steering Committee of ASTRO 3D astronomers as well as an Education Steering Committee of teachers and educators. These committees provide vital input to ensure that our program is scientifically accurate, aligns with the curriculum and is accessible to students and teachers.

The VR design stage is complete with the program now in the development phase. An overview of the structure and contents of the VR module is given in the table below.

Students will be astronomers working for the Universe 3D Taskforce. The first phase—development version of the transporter room—has been completed and tested on the Oculus Quest headset.

Activities will be developed and tested in sequence. The final modeule is expected to be completed in 2021.

An overview of the structure and contents of the VR module .

Overview

Activity name	Summary	Level of user involvement	Collaboration in VR	Atomic/astronomical level
Universe 3D Transporter Room 'Waiting Room' – familiar space where users can adapt to being in VR, investigate tools, user interfaces and learn about what they need to do to complete activities.				
The oldest light	Exploring the first 400,000 years of the Universe. Investigating its transformation from a hot, dense plasma to a transparent Universe when the light from the Cosmic Microwave Background travelled freely through the Universe.	Experiential/Inquiry	Single	Atomic
Exploring atoms in the neutral Universe	Manipulating and measuring hydrogen, helium, lithium, beryllium atoms and their isotopes.	Inquiry	Up to group of three. Each user could investigate a different atom	Atomic
Detection of the 21cm neutral hydrogen emission line	Identifying and measuring the redshifted 21cm signal.	Inquiry	Single	Atomic and astronomical
Experiencing the Epoch of Reionisation	Experiencing the EoR simulation through observing new stars form and the bubbles of ionised gas getting larger and larger until the Universe becomes transparent.	Experiential/Inquiry	Single or pair	Atomic and astronomical
Ionise neutral hydrogen	Creating ionised hydrogen atoms by 'blasting off' the electrons with UV blasters.	Game	Up to group of 3	Atomic

MEDIA HIGHLIGHT

DARK SKY SURVEY

Scientists asked all Australians to step outside on the longest night of the year to help them measure light pollution around the country.

Thousands of people joined the Australasian Dark Sky Alliance on Australia's longest night, Sunday 21 June 2020, to help researchers create a map of Australia's darkest skies, and learn about light pollution and its effect on people, animals, and astronomy.

"Their observations helped map how light pollution varies across Australia's cities and regions, and made the GUINNESS WORLD RECORD™ for 'Most users to take an online environmental sustainability lesson in 24 hours'," said Marnie Ogg, CEO and founder of the Australasian Dark Sky Alliance.

"The Australian night sky is amazing. Our galaxy, The Milky Way, is painted across the sky. It's a view that encourages us to wonder what's out there, amongst the billions of stars. It's a view that encourages kids to take up science and physics. But most Australians can't see it, their view of the sky is blinded by light pollution," says astronomer Professor Lisa Kewley, director of the ARC Centre of Excellence in All Sky Astrophysics in 3 Dimensions (ASTRO 3D) who supported the project.

"Light pollution doesn't just disrupt our view of The Milky Way. It disturbs wildlife, disrupt people's sleep, and represents wasted electricity," said Marnie.

"The information collected will help councils plan for darker skies and create opportunities for tourism," said Marnie. "Dark sky parks and tours are already popping up around the country."

"The observations will help us understand how light at night affects wildlife," said wildlife ecologist Dr Jen Martin from The University of Melbourne.

"For example, light pollution from cities distracts bogong moths as they migrate from Queensland to Victoria's alpine regions. If they don't arrive on time, the endangered mountain pygmy possums that depend on them for food will starve."

The project was supported by the Australian Government Department of Agriculture, Water and the Environment, which produced The National Light Pollution Guidelines for Wildlife. Other supporters included ASTRO 3D, AstroNZ, Bintel, ICRAR, Globe at Night, Unihedron, ANU, the International Dark Sky Alliance, Laing Simmons & Young, Waiheke Island Dark Sky Park and Dark Sky Traveller.

OUTREACH AND ENGAGEMENT

ASTROFEST, PERTH

Perth's annual Astrofest was held on the 29 February showcasing almost every astronomy-related group in Perth and attracting thousands of visitors over four hours. The ASTRO 3D stall, crewed by our Curtin and UWA staff and students, showcased our Epoch of Bubbles and CMB Maze activities. Some ASTRO 3D members were outside the pavillion with the telescopes, showing how radio telescopes work.

*ASTROFEST Participant enjoying the Epoch of Bubbles display. **IMAGE CREDIT:** Teresa Slaven-Blair*

COMMEMORATIVE COIN SERIES ON INDIGENOUS ASTRONOMY

ASTRO 3D AI and Education and Outreach officer Duane Hamacher (U.Melbourne) lead the development of the Royal Australian Mint's series on Indigenous Astronomy. The commemorative coins celebrate the astronomical knowledge and traditions of Aboriginal and Torres Strait Islander people. Three coins make up the series, and two were released in 2020. The 'Emu in the Sky' coin features Wiradjuri (NSW) artwork, and 'The Seven Sisters' coin features Yamaji (WA) artwork. The third and final coin will be released March 2021.

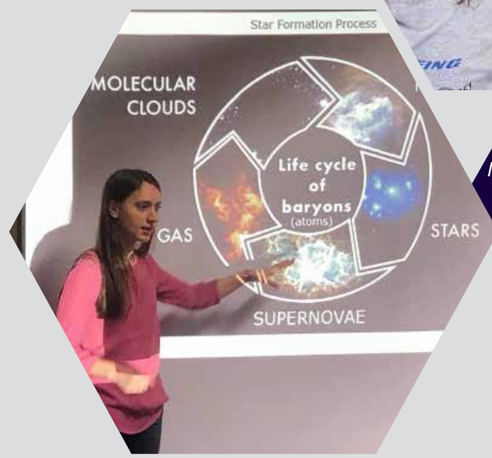
'The Seven Sisters" (above) and 'Emu in the Sky' (right) coins from the Indigenous commemorative coin series.

YMCA SPACE SQUAD

Our collaboration with the YMCA Canberra Space Squad continued in 2020. The school holiday program immerses 12–15 year-old students in space exploration and astronomy sessions and activities for five days.

In January 2020, the students visited Mt Stromlo Observatory where ASTRO 3D Senior Education and Outreach Coordinator, Dr Delese Brewster coordinates a tour of the facilities. In 2020, students received a presentation on how ASTRO 3D GALAH and SAMI researchers collect spectral information on the chemical composition of stars and galaxies. We led students in an activity to build a cardboard spectroscope, view spectra from various gas discharge tubes and take pictures using their smart devices.

For the July and October programs, ASTRO 3D Honours student Ella Wang and Post-Doc Dr Katie Grasha went to the Space Squad headquarters to deliver presentations and help with activities.



Images by Matt Dodds and Dr Delese Brewster

ASTRO IN THE HOME - VIDEO SERIES

As a response to the COVID-19 lockdowns, Swinburne University node E&O Officer Emma Barnett created a video series, called ASTRO in the Home.

ASTRO 3D astronomers film themselves 'at home' demonstrating a fun, engaging, hands-on astronomy-related activity people could do within their own homes, and describe how the activity relates to their ASTRO 3D research.

We launched the series at the start of National Science Week (15th-23rd August) with a new video released each day on the ASTRO 3D YouTube channel and promoted via social media.

By the end of December 2020, ASTRO 3D had released twelve videos covering a range of ASTRO 3D science with an average of 200 views per video. We will continue ASTRO in the Home as a regular series, with more videos planned for 2021.

All 3 images are screen-shots taken from the videos on YouTube.

EPOCH OF BUBBLES - VIDEO

Whilst working from home, Teresa Slaven-Blair (Outreach Officer at Curtin University) created an engaging explainer video on how to run her Epoch of Bubbles activity at home. This is a simple bubble art activity that links the structures of air bubbles to the regions of ionised hydrogen that formed around the first stars and galaxies during the Epoch of Reionisation. Teresa describes what equipment is needed, how to create the bubbles and how to 'capture' the bubbles on the activity sheet. Also provided is an explanation of how this is an analogy of the Epoch of Reionisation. Try it out at home!

Screenshot from Teresa Slaven-Blair's Epoch of Bubbles Video

Screenshot from Q&ARC Video.

#QANDARC VIDEO

ASTRO 3D participated in the collaborative Centres of Excellence social media video series, QandARC. The series is a collection of videos focused on ASTRO 3D early career researchers. Post-Docs Nichole Barry (UMelb), Sree Oh (ANU) and Sven Buder (ANU) discuss the goals of ASTRO 3D research, their research, what inspired them to become astronomers and the best part of being part of ASTRO 3D.

MENTORING PROGRAM

The ASTRO 3D Mentoring Program continued in 2020, utilising the Mentorloop platform to match mentors and mentees, according to their science, their career stage, and their interests in areas such as data science, careers outside astronomy and work/life balance.

Our mentoring program is voluntary and complements mentoring programs that exist within the node universities. In 2020, 25 people participated in our mentoring program, with 4 mentors, 6 mentees and 15 people with dual roles as mentor and mentee.

Nearly 75% of participants had reached the “Levelling Up” stage of the program and the Mentoring Quality Score from the participants was 4.6/5, which is well above average for similar industries.

Most participants met via Zoom or other video conferencing software, however, over 1/3 of them met up in person during the year.

I really enjoy chatting to my mentor, and it’s nice to have someone that I can discuss my career plans with. It’s definitely a worthwhile scheme, and I’m glad I’m involved in it.

My mentor has given me interview practise and also lots of useful career tips.

While the vast majority (82%) of participants did not create a formal plan, those that did, generally stuck to it (60%). Some participants indicated that although they did not create a formal “action plan”, they did set targets for each meeting, which they then discussed.

The majority of participants in 2020 (63%) felt that the mentoring program was helping with their career, and 71% felt it was a positive experience.

Most participants (80%) felt the existing informal structure through Mentorloop was helpful.

Our mentoring program will continue in 2021. Existing participants can continue, with either their existing mentor or get a new one. New participants are currently being called for.

MEDIA AND SOCIAL MEDIA

During 2020, despite COVID-19 restrictions, ASTRO 3D and its members had great media coverage, in print, radio, TV and online.

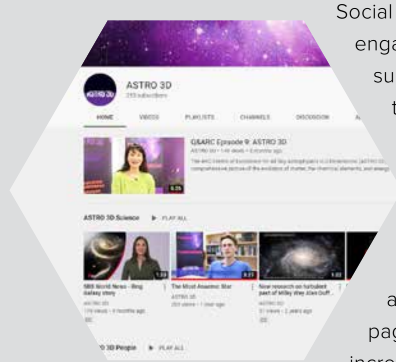
WEBSITE

January 2020 saw the launch of an updated website www.astro3d.org.au following a survey and feedback from our members. It was further refreshed in September. We continue to add new content, especially to our News section, but also to continually update the static pages with up to date information on people, science, education/outreach and committees.

COMMUNICATIONS TRAINEES

As part of our commitment to providing our members with transferrable skills training, 2020 saw our first Communications Trainees. Comprising of PhD students, postdoctoral researchers and ASTRO 3D Fellows, the seven Trainees undertook training in science writing by Science in Public, using social media by Brand Rebellion and publishing blog posts on our website by Education and Outreach Officer Tash Marshall. They have been contributing to our News content and also sharing their news content on social media. We will continue our communication trainee program in 2021.

SOCIAL MEDIA AND MEDIA



Social media engagement grew substantially, with the Centre’s Twitter audience growing to 1008 followers (228 new followers in 2020) and our Facebook page “Likes” increasing 184 from 345 to 529.

We had a series of videos in 2020 during the COVID-19 shutdown called “ASTRO in the Home” which featured ASTRO 3D members showing activities that people can do in their own home. The most popular videos include Modelling the Solar System in Your Backyard and Measuring the Speed of Light with Chocolate.

Centre Director, Lisa Kewley has had a busy year for media appearances on behalf of the Centre. Press releases for her Diversity in Astronomy paper were picked up by many media outlets, She has also given interviews for JJJ national radio, ABC national radio and a live TV interview on ABC National News.

Associate Investigator Brad Tucker was also popular in the media, with TV interviews on ABC, Sky News, 7:30, Good Morning Britain, Sunrise, radio interviews on ABC, 2CC Canberra, 6PR Perth, 4BC Brisbane, 2GB Sydney and many public outreach and school talks, including our Scientists Taking Telescopes to Regional Schools program (STARS). There was substantial interest from the media following the media release on STARS. Interviews were conducted with local and regional ABC radio, including Mt Isa, Bendigo and Bowral.

RESEARCH TRAINING AND PROFESSIONAL DEVELOPMENT

ASTRO 3D Research training programs are focused on both research skills and other professional skills needed to develop an exceptional team of researchers and students.

WALLABY BUSY WEEK

The WALLABY team held a successful busy week at ICRAR's UWA node in Perth during the first week of March to discuss outstanding technical and organisational issues in preparation for the WALLABY pilot survey which is currently under way on ASKAP. Participants addressed a wide range of different topics including the presentation of the first full-scale WALLABY HI images at full sensitivity in the direction of the Hydra galaxy cluster. This marks an important milestone for the project, with the scientific analysis of the pilot data expected to start soon.

PROPOSAL WRITING WORKSHOP

CIs Deanne Fisher and Emma Ryan-Weber co-organised the 10-13 March proposal writing workshop at Swinburne with Luca Cortese coordinating the UWA end. ASTRO 3D members from Swinburne, Melbourne, UNSW, UQ and UWA. met over zoom in the Melbourne afternoon (Perth Morning). A total of 15 (mostly ESO) proposals were reviewed. Informal feedback noted the highlight of the workshop was access to the pool of reviewers on the other side of the country.

MAGPI

The MAGPI team held a successful inaugural remote busyweek on 14-17 April. Members joined in from across Australia and Europe to hear the survey status, science updates and hold strategic discussions. Sessions were recorded and posted on the wiki for those unable to attend. Participants worked remotely and came up with innovative ways to collaborate remotely.

WRITING RETREATS

A group of 11 writers from ANU and UNSW attended the ACT-NSW Galaxy Evolution Writing Retreat in Bateman's Bay week 13-17 July. With goal-setting, mentoring, peer review groups and distraction free writing sessions, the retreat was incredibly productive.

VIRTUAL WRITING RETREAT

A one week Virtual Writing Retreat facilitated by Dr Beth Beckman was held via Zoom 23-27 November. Dr Beckman ran daily 20 min presentations with expert guest speakers and group goal/report meetings. Individual zoom advice sessions were also held between partcipants and the facilitator.

AUSTRALIA-ESO - THE BUILD-UP OF GALAXIES THROUGH MULTIPLE TRACERS AND FACILITIES

The workshop/conference ESOz-2020 brought together 120 researchers across the world (with 57% Australia-based and 43% based abroad) to discuss the build-up of baryons across multiple tracers and facilities. The conference aimed for greater collaboration across surveys from multiple facilities to achieve a truly panchromatic view of baryons in the Universe. Talks spanned a range of topics from instruments, surveys and simulations, and from the Milky-Way to nearby galaxies, all the way to the epoch of reionisation.

Participants at the Build-up of Galaxies conference

CONFERENCE HIGHLIGHT

LINKING THE GALACTIC & EXTRAGALACTIC

In early December 2020, ASTRO 3D ran the virtual conference "Linking the Galactic and Extragalactic: stellar dynamics and stellar populations of the Milky Way and its siblings". The meeting consisted of four key topics: the stellar dynamics and populations of the Milky Way and the stellar dynamics and populations of extragalactic galaxies, as well as an extra topic dedicated to comparing the different disciplines. Due to COVID-19 the in-person conference was transformed into a virtual meeting.

We adopted an experimental format with:

- Pre-recorded contributed talks, made available a week before the online meeting.
- An online Slack forum for questions and discussions about the pre-recorded talks.
- 2 days with live invited talks and four discussion sessions led by the SOC via Zoom.

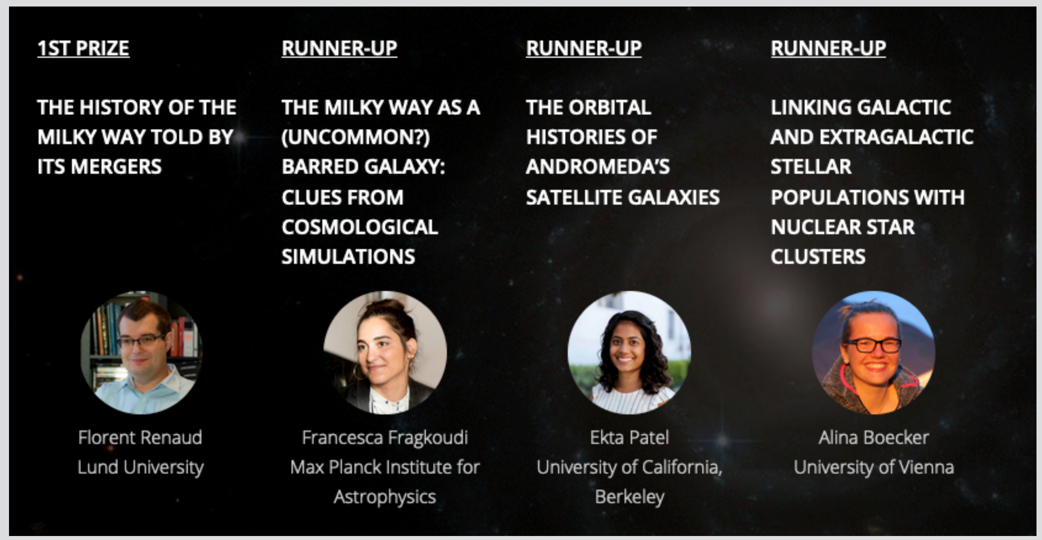
The online live sessions consisted of two sessions a day: one at 8-10am and one at 8-10pm Australian Eastern Daylight Time, accommodating various international timezones. We were pleased to see a nearly 50/50 (46/54-M/F) gender representation amongst contributed speakers that emerged naturally from the abstract rankings from the SOC, based on anonymised abstracts only (no identifying information on the authors). Amongst invited speakers we reached a 45/55 M/F ratio in terms of gender representation.

With more than a 140 unique viewers for the pre-recorded talks, an average of ~80 people who joined the live sessions, and over 2100 messages sent through slack, the meeting was an immense success. One of the key goals was to bring together Galactic and Extragalactic astronomers, and we felt that we have been successful in gathering a large and diverse group of people, as well as creating an atmosphere where everybody felt comfortable sharing their results.

The ~40 contributed and nine invited talks are now publicly available, and you can find the recorded talks on the virtual meeting page here: https://extragalactic-milkyways.org/virtual_meeting/

This website, with all of its content, will be available for at least another year.

Jesse Van de Sande - Conference Co-Organiser



2020 INVITED AND CONTRIBUTED TALKS

(includes conferences, workshops, colloquia, and poster presentations)

TALK TITLE	SPEAKER	LOCATION	WHEN
An order of magnitude improvement: lessons from MWA EoR analyses	Nichole Barry	Sexten, Italy	January
Near Field Cosmology and Large-scale Structure	Jonathan Bland-Hawthorn	Leiden, Netherlands	January
Hector and the spin alignment of galaxies	Jonathan Bland-Hawthorn	Leiden, Netherlands	January
The GALAH survey and chemodynamics of the Milky Way	Sven Buder	Uppsala Sweden	January
Measuring MWA Beam Shapes Using Communication Satellites	Aman Chokshi	Indore, India	January
Better Stellar Modeling: Numerical Tools and Techniques for the Modern Observational Landscape	Meridith Joyce	Tokyo, Japan	January
Star Formation, AGN, and Shocks in LIRGs	Lisa Kewley	Honolulu, Hawai'i	January
The current astrophysical understanding of the progenitors of binary mergers seen by LIGO	Ilya Mandel	Schloss Ringberg, Germany	January
Galactic archaeology in the Milky Way and beyond	Sarah Martell	Cambridge/ Guikdford, UK	January
MWA EoR project update	Benjamin McKinley	Indore, India	January
MWA Observations in the EDGES Band	Bart Pindor	Sesto, Italy	January
Bayesian inference in astronomy, past, present, and future.	Sanjib Sharma	Hyderabad, India	January
Special Session: Maunakea Spectroscopic Explorer	Kim-Vy Tran	Honolulu, Hawai'i, USA	January
The MWA EoR Program Update and New Results	Cathryn Trott	Sesto, Italy	January
The impact of environment on galaxy dynamics as observed with SAMI and Hector	Jesse van de Sande	Leiden, Netherlands	january
Galaxies and Reionization	Stuart Wyithe	Sesto, Italy	January
Resolving Distant Galaxies through Strong Gravitational Lensing	Tiantian Yuan	Chongqing, China	January
Neutral gas in the host galaxies of the brightest explosions in the Universe	Maryam Arabsalmani	Perth, Australia	February
The Intergalactic Dispersion Measure in the EAGLE Simulations	Adam Batten	Perth, Australia	February

Continued

TALK TITLE	SPEAKER	LOCATION	WHEN
MAGPHYS+photo-z	Andrew Battisti	Perth, Australia	February
How HI populates haloes: Simulations vs Observations	Garima Chauhan	Perth, Australia	February
ALMA unveils the dust properties of galaxies at cosmic noon	Elisabete da Cunha	Perth, Australia	February
Molecular vs Ionised gas kinematics in turbulent, gas-rich galaxies	Marianne Girard	Perth, Australia	February
Improved stellar models for photoionisation modelling	Kathryn Grasha	Perth, Australia	February
Mass assembly history of massive galaxies at 2<z<4	Anshu Gupta	Perth, Australia	February
Intergalactic Plasma: a way back to go forward	Duane Hamacher	Melbourne, Australia	February
Star Formation Histories for a z~2 Proto-Cluster with PROSPECTOR	Anishya Harshan	Perth, Australia	February
Massive Star Evolution	Alexander Heger	Canberra, Australia	February
Tracing outflows and accretion using OVI absorption	Glenn Kacprzak	Perth, Australia	February
Panchromatic emission of galaxies in simulations	Claudia Lagos	Perth, Australia	February
Updates on compact-object binaries	Ilya Mandel	Canberra, Australia	February
Lithium-rich giants in the GALAH survey	Sarah Martell	Sydney, Australia	February
Understanding Gas Flows in-and-around Galaxies	Hasti Nateghi	Perth, Westen Australia.	February
Seismology of Lithium Rich Giants	Alexander Obradovic	Sydney, Australia	February
Decomposed stellar kinematics of galaxy bulges and disks	Sree Oh	Leiden, Nethelands	February
Mapping Outflows in Starbursting Disk Galaxies	Bronwyn Reichardt Chu	Perth, Australia	February
ASKAP HI deep survey (DINGO)	Jonghwan Rhee	Perth, Australia	February
Deep Investigation of Neutral Gas Origins	Kristof Rozgonyi	Daedeok-gu, Korea	February
Neutral Hydrogen in the Distant Universe	Elaine Sadler	Perth, Australia	February
Extragalactic Archaeology	Nicholas Scott	Sydney, Australia	February
How do high redshift galaxies sustain higher star formation rates?	Piyush Sharda	Perth, Australia	February

Continued

2020 INVITED AND CONTRIBUTED TALKS

(includes conferences, workshops, colloquia, and poster presentations)

TALK TITLE	SPEAKER	LOCATION	WHEN
2MTF Final Data Release and WALLABY Early Science	Lister Staveley-Smith	Cape Town, South Africa	February
2MTF and WALLABY	Lister Staveley-Smith	Stellenbosch, South Africa	February
The evolution of galaxies' multi-phase gas reservoirs by environment	Adam Stevens	Perth, Australia	February
The critical importance of mock-observing simulated galaxies' gas	Adam Stevens	Perth, Australia via Zoom to Daejon, Korea	February
ZFOURGE & MOSEL: Tracking Galaxy Growth at Cosmic Noon	Kim-Vy Tran	Massachusetts, USA	February
ZFIRE: How Galaxy Evolution Depends on Environment at z~2	Kim-Vy Tran	Massachusetts, USA	February
The impact of environment on galaxy dynamics as observed with SAMI and Hector	Jesse van de Sande	Leiden, The Netherlands	February
The build-up of mass and angular momentum in galaxies across morphology and environment with SAMI	Jesse van de Sande	Groningen, The Netherlands	February
The zoo of galaxy components	Jesse van de Sande	Leiden, The Netherlands	February
Comparing 3D spectroscopic observations with galaxies from cosmological hydrodynamical simulations	Jesse van de Sande	Leiden, The Netherlands	February
HI-selected galaxy group at z=0.45	Simon Weng	Perth, Australia	February
Follow up talks	Tanner Wilson	Sydney, Australia	February
The WALLABY survey	Ivy Wong	Stellenbosch, South Africa	February
The physics of gas accretion onto halos and galaxies: insight from cosmological simulations	Ruby Wright	Perth, Australia	February
"The physics of gas accretion onto halos and galaxies: insight from cosmological simulations"	Ruby Wright	Perth, Australia	February
Connecting supernovae with their progenitors from a different perspective	Katie Auchettl	Melbourne, Australia	March
WALLABY data validation	Bi-Qing For	Perth, Australia	March
Global-signal detection with radio interferometers	Benjamin McKinley	Perth Australia	March

Continued

TALK TITLE	SPEAKER	LOCATION	WHEN
Constraining nucleosynthesis in CEMP-s progenitors using Fluorine	Aldo Mura	Concepción, Chile	March
Fluorine in different stellar populations	Aldo Mura	La Serena, Chile	March
Accurate abundances for SMSS 1605-1443 ([Fe/H] = -6)	Thomas Nordlander	Concepción, Chile	March
ESO proposals - Phase 1	Emma Ryan-Weber	Melbourne, Australia	March
The impact of magnetic field strength on theprimordial initial mass function	Piyush Sharda	Concepción, Chile	March
Primordial versus present-day IMF: the competition between radiation feedback and magnetic fields.	Piyush Sharda	Concepción, Chile	March
Simulations overview for WALLABY	Adam Stevens	Perth, Australia	March
Modelling and separating the power sources of emission lines: star formation, AGN and shocks	Adam Thomas	Bento Gonçalves, Brazil	March
FOURGE & MOSEL: Tracking Galaxy Growth at Cosmic Noon	Kim-Vy Tran	Virtual	March
SoFiA 2 – The WALLABY Source Finding Pipeline	Tobias Westmeier	Perth, Australia	March
Using mass-metallicity relations from quiescent galaxies to constrain stellar feedback models	Nicha Leethochawalit	Melbourne, Australia	April
SAMI galaxy survey: the stellar population gradients of central galaxies	Giulia Santucci	Sydney, Australia	April
The First Large Absorption Survey in HI: Status update	James Richard Allison	Virtual	May
Panchromatic evolution of galaxies	Claudia Lagos	Leiden, The Netherlands	May
Summary of simulation progress 2019-2020	Claudia Lagos	Copenhaguen, Denmark	May
Angular momentum in galaxies in the EAGLE simulations	Claudia Lagos	Leiden, The Netherlands	May
LoBES: The Long Baseline Epoch of Reionisation Survey	Christene Lynch	Virtual	May
Gravitational-wave astronomy	Ilya Mandel	Virtual	May
HPC Simulations of the Early Universe	Simon Mutch	Warsaw, Poland	May
Deep Investigation of Neutral Gas Origin	Jonghwan Rhee	Virtual	May

Continued

2020 INVITED AND CONTRIBUTED TALKS

(includes conferences, workshops, colloquia, and poster presentations)

TALK TITLE	SPEAKER	LOCATION	WHEN
Velocity dispersion of stars in the Milky Way	Sanjib Sharma	Virtual	May
WALLABY	Lister Staveley-Smith	Groningen, The Netherlands	May
Stellar angular momentum distribution linked to galaxy morphology	Sarah Sweet	Brisbane Australia	May
The MWA EoR program - A3D meeting Introduction and overview - ICRAR Board	Cathryn Trott	Perth, Australia	May
WALLABY Pilot Survey Update	Tobias Westmeier	Virtual	May
Cosmic Ring of Fire	Tiantian Yuan	Virtual	May
Scaling relations between galaxy structure and their stellar population	Tania Barone	Remote	June
Searching for the first galaxies with primordial hydrogen in the Epoch of Reionisation	Nichole Barry	Sydney, Australia	June
The structure race: 21 cm power spectrum analysis from the Murchison Widefield Array	Nichole Barry	Remote	June
MAGPHYS+photo-z	Andrew Battisti	Remote	June
Galactic phase-spiral evolution due to a disc-crossing perturber	Jonathan Bland-Hawthorn	Remote	June
The atomic hydrogen-halo mass relation as a probe of feedback physics	Garima Chauhan	Leiden, Netherlands	June
On the physical connection between galaxy structure, star formation and gas content in nearby galaxies: the xGASS view	Luca Cortese	Remote	June
Improving stellar models as inputs for photionization modelling	Kathryn Grasha	United States	June
New stellar models with variable abundances	Kathryn Grasha	Leiden, Netherlands	June
Interpreting recent LOFAR upper limits on reionisation	Bradley Greig	Remote	June
Chemodynamics of the Milky Way	Michael Hayden	Remote	June
Chemical Evolution with Radial Mixing	Michael Hayden	Remote	June
Probing Neural Networks for science: What is it they are learning?	Colin Jacobs	Melbourne, Australia	June

Continued

TALK TITLE	SPEAKER	LOCATION	WHEN
Standing on the shoulders of giants: New mass and distance estimates for a Orionis through a combination of evolutionary, asteroseismic, and hydrodynamical simulations with MESA	Meridith Joyce	Remote	June
The MAGPI Survey: Mapping the evolution of resolved galaxy properties over the past 4 billion years	Trevor Mendel	Remote	June
Decomposed Stellar Kinematics of Galaxy Bulges and Disks	Sree Oh	Washington, USA	June
Linking gas and star formation throughout cosmic time	Sambit Roychowdhury	Remote	June
ASKAP Surveys overview	Elaine Sadler	Remote	June
Impact of magnetic fields on Pop III IMF	Piyush Sharda	Remote	June
GALAH: Lithium in GALAH Stars	Jeffrey Simpson	Sydney, Australia	June
Understanding our Galaxy: charting a path forward	Lorenzo Spina	Remote	June
The descendants of compact passive and massive galaxies at z~0: Lessons learnt from comparing 3D spectroscopic observations with galaxies from cosmological hydrodynamical simulations	Jesse van de Sande	Remote	June
K-CLASH: Evidence of ram pressure stripping in galaxy cluster members at intermediate redshift	Sam Vaughan	Remote	June
K-CLASH: Disc strangulation and ram-pressure stripping in cluster galaxies at $0.3 < z < 0.6$	Sam Vaughan	Remote	June
Spatial Resolving Galaxy Environmental Quenching in SAMI Galaxy Survey	Di Wang	Remote	June
FLASH and MUSE	Simon Weng	Remote	June
WALLABY Pilot Survey Update	Tobias Westmeier	Remote	July
The impact of environment on the dynamics of gas reservoirs in galaxies	Adam Watts	Virtual - European Astronomical Society Annual Meeting	July
The impact of environment on the dynamics of gas reservoirs in galaxies	Adam Watts	ASA AGM	August
A new era of photonic spectrographs: tutorial	Jonathan Bland-Hawthorn	Sydney, Australia	August
MWA Beam Measurements Using ORBCOMM Satellites	Jack Line	Remote	August

Continued

2020 INVITED AND CONTRIBUTED TALKS

(includes conferences, workshops, colloquia, and poster presentations)

TALK TITLE	SPEAKER	LOCATION	WHEN
Intensity Mapping with a Phased Array Feed	Lister Staveley-Smith	Perth, Australia	August
The resolved dynamics and metallicity of galaxies across cosmic time	Emily Wisnioski	Perth, Australia	September
Triggering Swift Target of Opportunity Observations.	Katie Auchettl	Melbourne, Australia	September
Using supernova remnants to probe stellar death	Katie Auchettl	Birmingham, UK	September
YSE vetting of PanSTARRs data using the QUB website	Katie Auchettl	Melbourne, Australia	September
IGM Attenuation Bias for Lyman Continuum Detected Galaxies at z > 3.0	Robert Bassett	Melbourne, Australia	September
Galactic seismology: a new era	Jonathan Bland-Hawthorn	Mullard Space Science Laboratory, U Surrey	September
A New Perspective on the Assembly of Mass	Danail Obreschkow	MIT, USA	September
Mapping Outflows in Starbursting Disk Galaxies with DUVET	Bronwyn Reichardt Chu	Remote	September
Spatially-resolved galaxy angular momentum	Sarah Sweet	Perth, Western Australia	September
Sweeping Away the Dust: Understanding the Evolution of Attenuation up to the Peak of Cosmic Star Formation	Andrew Battisti	Baltimore, MA USA	October
Probing the nature of dark matter with strong gravitational lensing	Dorota Bayer	Perth, Australia	October
Probing the nature of dark matter with strong gravitational lensing	Dorota Bayer	Melbourne, Australia	October
Spatially resolved direct method metallicities in the SAMI Galaxy Survey	Alex Cameron	Remote	October
DEVILS Synergies with MAGPI	Caroline Foster	Remote	October
New metallicity calibrations across cosmic time	Kathryn Grasha	Remote	October
DEVILS – At the Forefront of CGM Studies?	Glenn Kacprzak	Aarhus	October
The impact of evolved stars on the chemical evolution of the Universe	Amanda Karakas	Remote	October
Global sky signal measurements with the EDA-2	Benjamin McKinley	Sydney, Australia	October

Continued

TALK TITLE	SPEAKER	LOCATION	WHEN
Trying to solve the lithium problems of dwarfs and giants	Jeffrey Simpson	Remote	October
Investigating dust origin in galaxies using Dusty SAGE	Dian (Pipit) Triani	London, England (virtual)	October
Pursuing the Faint 21cm Epoch of Reionisation Signal using the MWA	Nichole Barry	virtual	November
The Worldwide Race: Using the 21 cm Signal to Detect the Epoch of Reionisation	Nichole Barry	Caltech, LA, USA	November
Galactic seismology: evolution of the phase spiral across the Galactic disc	Jonathan Bland-Hawthorn	Virtual	November
Galactic seismology: what triggered the disc waves?	Jonathan Bland-Hawthorn	Columbia University, NY	November
Galactic seismology: evolution of the phase spiral in the Milky Way	Jonathan Bland-Hawthorn	Caltech	November
Galactic seismology: evolution of giant waves across the Galaxy	Jonathan Bland-Hawthorn	Bengaluru, India	November
The Stromlo Stellar Tracks: non-scaled solar abundances for massive stars	Kathryn Grasha	Virtual	November
How large massive galaxies stops forming stars?	Anshu Gupta	Melbourne, Australia	November
LoBES: The Long Baseline Epoch of Reionsation Survey	Christene Lynch	Virtual	November
Detecting the redshifted 21-cm signal with an interferometer	Benjamin McKinley	Online	November
Ram Pressure Stripping of ESO501-G075	Tristan Reynolds	Perth, Australia	November
ASKAP Surveys Overview	Elaine Sadler	Online	November
Data Intensive Astronomy	Lister Staveley-Smith	Perth, Australia	November
ACAMAR overview	Lister Staveley-Smith	Perth, Australia	November
Simulation science pervading WALLABY projects	Adam Stevens	Online from Perth, Australia	November
The Search for Hydrogen: Detecting the EoR through the 21cm line	Cathryn Trott	NCRA, Pune, India	November
Extracting stellar labels of individual stars from MUSE observations	Zixian Wang	Canberra, Australia	November
The MWA Cross-Pipeline Study: Observational vs. Analysis Systematics	Nichole Barry	virtual	December

Continued

2020 OTHER PRESENTATIONS

(includes industry and government briefings)

TALK TITLE	SPEAKER	LOCATION	WHEN
Hector - a new multi-object integral field spectrograph instrument for the Anglo-Australian Telescope	Julia Bryant	Online conference	December
Mapping electron temperature in galaxies with [OIII]4363	Alex Cameron	Sydney, Australia (online via Zoom)	December
Cartography of the Milky Way	Michael Hayden	Sydney Australia	December
New MWA Epoch of Reionization Power Spectrum Measurements of the EoR1 field	Mahsa Rahimi	Virtual zoom meeting	December
Chemodynamics of the Milky Way as revealed by large observational surveys	Sanjib Sharma	Virtual meeting,	December
Milky Way Analogues with BlueMUSE	Jesse van de Sande	University of Melbourne, Australia	December
A toy model of galaxy evolution inspired by stellar metallicity measurements from the SAMI survey	Sam Vaughan	Sydney, Australia	December
Extracting stellar parameters of individual stars from MUSE observations.	Zixian Wang	Sydney, Australia	December

Screenshot of an ASTRO 3D Director's video update. Held monthly over zoom for ASTRO 3D Members.

TALK TITLE	SPEAKER	LOCATION	WHEN
Careers in Physics	Kim-Vy Tran	Texas A&M University, College Station, Texas, USA	January
Carbon emissions in astronomy	Adam Stevens	Perth, Australia via Zoom to Madrid, Spain; Paris, France; Heidelberg, Germany	January
Black Holes and Dark Matter	Rachel Webster	Melbourne, Australia	January
TESS.ninja	Andy Casey	Sydney, Australia	February
ESO Users Committee Representative update	Caroline Foster	Canberra, Australia, via zoom	February
Creating Inclusive Events	Ingrid McCarthy	Adelaide, Australia	February
General STEM discussion	Simon Mutch	Melbourne, Australia	February
Remote sensing from space - Italy-Australia cooperative opportunities	Michele Trenti	Adelaide, Australia	February
Thinking beyond Python	Christopher Jordan	Sydney, Australia	February
Inclusive and respectful workplaces: attracting and retaining our STEM workforce	Lisa Kewley	Adelaide, Australia	February
Thinking beyond Python	Nic Scott	Sydney, Australia	February
Towards a Zero-Waste Life	Phil Taylor	Canberra, Australia	February
Introduction to software development	Ellert van der Velden	Sydney/Melbourne, Australia	February
A Short History of the Universe	Rachel Webster	Adelaide, Australia	February
Closing the gap - full workforce gender modelling for STEM in Australia	Lisa Kewley	Canberra, Australia	March
Carbon emissions in astronomy	Adam Stevens	Perth, Australia	March
How stars that should not exist help explain the origin of the elements	Andy Casey	Virtual	May
The impact of COVID19 on carers	Caroline Foster	Virtual	May
ESO Users Committee update	Caroline Foster	Virtual	May
Fundamental relations for velocity dispersion of stars.	Sanjib Sharma	Berlin, Germany	May
Towards a Zero Waste Life	Phil Taylor	Perth, Australia	May

Continued

TALK TITLE	SPEAKER	LOCATION	WHEN
Carbon emissions of Australian astronomers	Adam Stevens	Virtual	June
Gender Diversity	Lisa Kewley	ANU College of Science - Executive	July
ARC talk on Gender Diversity	Lisa Kewley	Remote via Zoom	July
Panel member for Managing Careers during a Pandemic - Career pathways: Jobs in Academia	Caroline Foster	Virtual	August
Diversity in STEMM	Lisa Kewley	Virtual	September
ASTRO 3D	Lisa Kewley	Virtual	September
The NCA mid-term review	Lister Staveley-Smith	Perth, Australia	September
Update from Australia	Lister Staveley-Smith	Perth, Australia	November
Software Telescopes: Astronomy in the Era of the Square Kilometre Array	Cathryn Trott	Perth, Australia	December

Screenshot of an ASTRO 3D Executive Management Committee Meeting. Held monthly over zoom.

2020 PUBLIC LECTURES, OUTREACH AND SCHOOL TALKS

SUBJECT	SPEAKER	EVENT	LOCATION	WHEN
TV interview	Elisabete da Cunha	Portuguese public broadcaster RTP, show “Hora dos Portugueses”	Perth, Australia	January
Telescope Tales	Caroline Foster	Mark Moran Aged care facility in Vaucluse talk	Sydney, Australia	January
Careers in Physics	Kim-Vy Tran	Texas A&M University, College Station	Texas, USA	January
Black Holes and Dark Matter	Rachel Webster	Lyceum Club	Melbourne, Australia	January
Rocking the Cradle – Black Holes and Young Radio Galaxies	James Richard Allison	Oxford University Space Science and Astronomy Society	Oxford, United Kingdom	Feburary
EoR experiments	James Kariuki Chege	Astrofest	Perth, Australia	Feburary
Galaxy evolution crash course	Caroline Foster	Sutherland Astronomical Society Inc	Sydney, Australia	February
A 3D view of Galaxies	Brent Groves	Astrofest	Perth, Australia	February
Public Talk	Ilya Mandel	Mornington Peninsula Astronomical Society	Mornington, Australia	February
SPIRIT 101 for the Classroom	Gregory Rowbotham	Ongoing Education	Perth, Australia	February
Writing Strategies for Scientists	Kim-Vy Tran	Harvard-Smithsonian Center for Astrophysics	Massachusetts, USA	February
Being Captain of Your PhD	Kim-Vy Tran	Harvard-Smithsonian Center for Astrophysics	Massachusetts, USA	February
Astrofest	Cathryn Trott	Astrofest	Perth, Australia	February
Dutch: Alles over Sterrenkunde (Everything about Astronomy)	Jesse van de Sande	School Talk	Balbrug, The Netherlands	February
Feature article on my journey and work in Astronomy and Astrophysics.	Lisa Kewley	University of Adelaide’s Alumni magazine Lumen	Canberra, Australia	March
Gravitational Lensing and the Hubble Space Telescope	Lisa Kewley	Googong Anglican School Talk	Queanbeyan, Australia	March

Continued

2020 PUBLIC LECTURES, OUTREACH AND SCHOOL TALKS

SUBJECT	SPEAKER	EVENT	LOCATION	WHEN
Beyond our Earth	Lisa Kewley	Beyond our Earth Documentary Series	Canberra, Australia	March
Modelling The Evolution Of Double Neutron Stars	Ilya Mandel	Online Newspaper Space Australia	Online	March
A Cosmic History Lesson	Chris Power	School Talk	Perth, Australia	March
Cosmos Computing PD for Teachers	Gregory Rowbotham	Ongoing Education	Carnamah, Australia	March
Astrophysics - Career & Research	Emma Ryan-Weber	ASTRO 3D propsoal writing workshop	Melbourne, Australia	March
The discovery of the mini moon shows us just how dynamic our Universe is	Dian (Pipit) Triani	SBS Indonesian Radio	Melbourne, Australia	March
WA science and industry leaders put their heads together to search for the first stars and galaxies	Cathryn Trott	West Australian newspaper	Perth, Australi	March
On the impact of COVID-19 on women in academia compared to men	Andy Casey	Washington Post Article	Online	April
From Wolfe Creek to Tunguska - Meteorites in Cultural Traditions	Duane Hamacher	Royal Society of Victoria	Melbourne, Australia	April
Beteigeuze in Australischen Überlieferungen (Betelgeuse in Australian lore)	Duane Hamacher	Laika und Freunde (German Science Magazine)	Online	April
Unravelling Mystery Black Holes	Ilya Mandel	Source for Phs. org article	Online	April
Pluto, the oddball - livestream with Dr David Gozzard	Gregory Rowbotham	ICRAR/ASTRO3D Astronomy Wednesday	Perth, Australia	April
Twinkle, Twinkle, Baby black hole - Kat Ross livestream	Gregory Rowbotham	ICRAR/ASTRO3D Astronomy Wednesday	Perth, Australia	April
Coins and constellations on 94.7 FM The Pulse,	Duane Hamacher	n/a	Melbourne, Australia	June

Continued

SUBJECT	SPEAKER	EVENT	LOCATION	WHEN
Journey of Galaxies	Anishya Harshan	U3A video conferencing series	Sydney, Australia	June
ICRAR/ASTRO3D Astronomy Wednesday	Gregory Rowbotham	n/a	Perth, Australia	June
The elements of life: from supernovae to planets	Katie Auchettl	July Lectures in Physics	Melbourne, Australia	July
Giant Telescopes	Matthew Colless	Young Stars	Canberra Australia	July
Discussing 3 astronomy related news and answering callers' questions.	Caroline Foster	ABC Radio Evening	ABC Sydney Radio	July
Galaxy's DNA	Giulia Santucci	UNSW Science Postgraduate Research Showcase	Sydney, Australia	July
Spatial Resolving Galaxy Environmental Quenching in The SAMI Galaxy Survey	Di Wang	USYD SIFA morning tea	Sydney, Australia	July
First Stars, GALAH, and Spectroscopy	Xi Wang	Space Squad	Canberra, Australia	July
Astro in the Home YouTube video	Emma Barnett	National Science Week	Melbourne, Australia	August
Women in science	Jonathan Bland-Hawthorn	Careers day - Ascham Girls	Sydney, Australia	August
Astro in the Home: Doppler Redshift with Slinkies	Alex Cameron	Astro in the Home YouTube Series	Online	August
Stargazers for National Science Week	Kirsten Gottschalk	N/A	Perth, Australia	August
ASTEROIDS HONOUR FIRST NATIONS ASTRONOMY	Duane Hamacher	Radio Adelaide 101.5	Adelaide, Australia	August
From 7809 Marcialangton to 7630 Yidumduma: 5 asteroids named after Aboriginal and Torres Strait Islander people	Duane Hamacher	n/a	Melbourne, Australia	August

Continued

2020 PUBLIC LECTURES, OUTREACH AND SCHOOL TALKS

SUBJECT	SPEAKER	EVENT	LOCATION	WHEN
Indigenous Astronomy	Duane Hamacher	National Science Week	Melbourne, Australia	August
Why are Astronomers deleting galaxies from their data?	Jack Line	An interview with Scitech for an online article	Perth, Australia	August
STEM Careers	Cathryn Trott	Halleybury College STEM Careers Series	Perth, Australia	August
The Man Who Knew Infinity Panel Discussion	Ingrid McCarthy	National Film and Sound Archive Scienc Week event	Canberra, Australia	August
Measure the speed of light with chocolate	Chandrashekar Murugeshan	Astro in the Home, YouTube series	Melbourne, Australia	August
Exploring Quasars with Ice Cream	Keven Ren	Astro in the Home, YouTube series	Melbourne, Australia	August
SPIRIT 101 Professional Development	Gregory Rowbotham	Southern River College	Perth, Australia	August
Make and break a rainbow with spectroscopy	Emma Ryan-Weber	Astro in the Home, YouTube series	Melbourne, Australia	August
Australia's Original Astronomers	Duane Hamacher	Passport (Podcast)	Los Angeles, USA	September
New coins celebrate Indigenous astronomy, the stars, and the dark spaces between them	Duane Hamacher	The Conversation	Melbourne, Australia	September
SPIRIT Online remote internet PD	Gregory Rowbotham	n/a	Perth, Australia	September
SPIRIT PD Online	Gregory Rowbotham	Esperance Senior High School	Perth, Australia	September
Bannister Creek PS Camp stargazing event	Cathryn Trott	Bannister Creek PS Camp stargazing	Perth, Australia	September
SPIRIT PD	Gregory Rowbotham	School talk	Esperance, Australia	November
Giant Waves across the Milky Way	Jonathan Bland-Hawthorn	ASSA AGM (astronomical society)	Adelaide	December

2020 INTERNATIONAL VISITS

WHO	INSTITUTION/FACILITY VISITED	WHERE	WHEN
Sven Buder	Max Planck Institute for Astronomy++	Heidelberg, Germay,	January
Sven Buder	Stockholm University	Stockholm, Sweden	January
Meridith Joyce	Institute for the Physics and Mathematics of the Universe	Tokyo, Japan	January
Jonathan Bland-Hawthorn	University of Leiden	Lieden, Netherlands	January
Jonathan Bland-Hawthorn	University of Oxford	Oxford, UK	January
Nichole Barry	Sexten Center for Astrophysics	Sexten, Italy	January
Karl Glazebrook	Keck observatory remote observing	Waimea, HI, USA	January
Duane Hamacher	University of Basque Country	Bilbao, Spain	January
Melanie Hampel	Konkoly Observatory	Budapest, Hungary	January
Lisa Kewley	London college, Amsterdam College	Oxford, London UK	January
Sarah Martell	University of Surrey	Guildford, UK	January
Sarah Martell	University of Cambridge	Cambridge, UK	January
Benjamin McKinley	Indian Institute of Technology Indore (IITI)	Indore, India	January
Jesse van de Sande	Leiden Observatory, Leiden University, Kapteyn Astronomical Institute, University of Groningen	Leiden, Groningen, The Netherlands	January
Luca Casagrande	Case Western Reserve University	Cleveland, USA	February
Lister Staveley-Smith	The Stellenbosch Institute for Advanced Study	Stellenbosch, South Africa	February
Sree Oh	Lorentz Center	Leiden, Netherlands	February
Piyush Sharda	Universidad de Concepción, Chile	Concepción, Chile	March

2020 PUBLICATIONS

1. Acebron, A., Zitrin, A., Coe, D., Mahler, G., Sharon, K., Oguri, M., Bradač, M., Bradley, L. D., Frye, B., Forman, C. J., Strait, V., Su, Y., Umetsu, K., Andrade-Santos, F., Avila, R. J., Carrasco, D., Cerny, C., Czakon, N. G., Dawson, W. A., Fox, C., Hoag, A. T., Huang, K.-H., Johnson, T. L., Kikuchihara, S., Lam, D., Lovisari, L., Mainali, R., Nonino, M., Oesch, P. A., Ogaz, S., Ouchi, M., Past, M., Paterno-Mahler, R., Peterson, A., Ryan, R. E., Salmon, B., Stark, D. P., Toft, S., Trenti, M., Vulcani, B., Welch, B. (2020) "RELICS: A Very Large (θE ~ 40″) Cluster Lens—RXC J0032.1+1808", The Astrophysical Journal, 898, 6.

2. Acharyya, A., Krumholz, M. R., Federrath, C., Kewley, L. J., Goldbaum, N. J., Sharp, R. (2020) "Quantifying the effects of spatial resolution and noise on galaxy metallicity gradients", Monthly Notices of the Royal Astronomical Society, 495, 3819.

3. Algera, H. S. B., Smail, I., Dudzevičiūtė, U., Swinbank, A. M., Stach, S., Hodge, J. A., Thomson, A. P., Almaini, O., Arumugam, V., Blain, A. W., Calistro-Rivera, G., Chapman, S. C., Chen, C.-C., da Cunha, E., Farrah, D., Leslie, S., Scott, D., van der Vlugt, D., Wardlow, J. L., van der Werf, P. (2020) "An ALMA Survey of the SCUBA-2 Cosmology Legacy Survey UKIDSS/UDS Field: The Far-infrared/Radio Correlation for High-redshift Dusty Star-forming Galaxies", The Astrophysical Journal, 903, 138.

4. Allison, J. R., Sadler, E. M., Bellstedt, S., Davies, L. J. M., Driver, S. P., Ellison, S. L., Huynh, M., Kapińska, A. D., Mahony, E. K., Moss, V. A., Robotham, A. S. G., Whiting, M. T., Curran, S. J., Darling, J., Hotan, A. W., Hunstead, R. W., Koribalski, B. S., Lagos, C. D. P., Pettini, M., Pimbblet, K. A., Voronkov, M. A. (2020) "FLASH early science - discovery of an intervening H I 21-cm absorber from an ASKAP survey of the GAMA 23 field", Monthly Notices of the Royal Astronomical Society, 494, 3627.

5. Amarsi, A. M., Lind, K., Osorio, Y., Nordlander, T., Bergemann, M., Reggiani, H., Wang, E. X., Buder, S., Asplund, M., Barklem, P. S., Wehrhahn, A., Skúladóttir, Á., Kobayashi, C., Karakas, A. I., Gao, X. D., Bland-Hawthorn, J., de Silva, G. M., Kos, J., Lewis, G. F., Martell, S. L., Sharma, S., Simpson, J. D., Zucker, D. B., Čotar, K., Horner, J., GALAH Collaboration (2020) "The GALAH Survey: non-LTE departure coefficients for large spectroscopic surveys", Astronomy and Astrophysics, 642, A62.

6. Arabsalmani, M., Renaud, F., Roychowdhury, S., Arumugam, V., Floc'h, E. L., Bournaud, F., Cormier, D., Zwaan, M. A., Christensen, L., Pian, E., Madden, S., Levan, A. (2020) "Local Starburst Conditions and Formation of GRB 980425/SN 1998bw within a Collisional Ring", The Astrophysical Journal, 899, 165.

7. Aravena, M., Boogaard, L., Gónzalez-López, J., Decarli, R., Walter, F., Carilli, C. L., Smail, I., Weiss, A., Assef, R. J., Bauer, F. E., Bouwens, R. J., Cortes, P. C., Cox, P., da Cunha, E., Daddi, E., Díaz-Santos, T., Inami, H., Ivison, R., Novak, M., Popping, G., Riechers, D., van der Werf, P., Wagg, J. (2020) "The ALMA Spectroscopic Survey in the Hubble Ultra Deep Field: The Nature of the Faintest Dusty Star-forming Galaxies", The Astrophysical Journal, 901, 79.

8. Armillotta, L., Krumholz, M. R., Di Teodoro, E. M. (2020) "The life cycle of the Central Molecular Zone - II. Distribution of atomic and molecular gas tracers", Monthly Notices of the Royal Astronomical Society, 493, 5273.

9. Audcent-Ross, F. M., Meurer, G. R., Audcent, J. R., Ryder, S. D., Wong, O. I., Phan, J., Williamson, A., Kim, J. H. (2020) "The radial distribution of supernovae compared to star formation tracers", Monthly Notices of the Royal Astronomical Society, 492, 848.

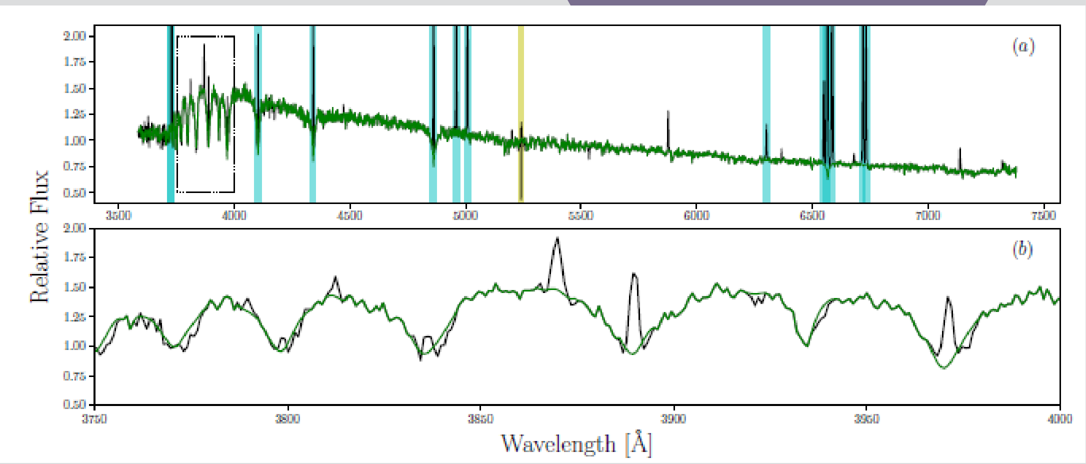
10. Barat, D., D'Eugenio, F., Colless, M., Sweet, S. M., Groves, B., Cortese, L. (2020) "SHαDE: survey description and mass-kinematics scaling relations for dwarf galaxies", Monthly Notices of the Royal Astronomical Society, 498, 5885.

11. Baratella, M., D'Orazi, V., Carraro, G., Desidera, S., Randich, S., Magrini, L., Adibekyan, V., Smiljanic, R., Spina, L., Tsantaki, M., Tautvaišienė, G., Sousa, S. G., Jofré, P., Jiménez-Esteban, F. M., Delgado-Mena, E., Martell, S., Van der Swaelmen, M., Roccatagliata, V., Gilmore, G., Alfaro, E. J., Bayo, A., Bensby, T., Bragaglia, A., Franciosini, E., Gonneau, A., Heiter, U., Hourihane, A., Jeffries, R. D., Koposov, S. E., Morbidelli, L., Prisinzano, L., Sacco, G., Sbordone, L., Worley, C., Zaggia, S., Lewis, J. (2020) "The Gaia-ESO Survey: a new approach to chemically characterising young open clusters. I. Stellar parameters, and iron-peak, α-, and proton-capture elements", Astronomy and Astrophysics, 634, A34.

12. Barnes, A. T., Longmore, S. N., Dale, J. E., Krumholz, M. R., Kruijssen, J. M. D., Bigiel, F. (2020) "Which feedback mechanisms dominate in the high-pressure environment of the central molecular zone?", Monthly Notices of the Royal Astronomical Society, 498, 4906.

13. Barone, T. M., D'Eugenio, F., Colless, M., Scott, N. (2020) "Gravitational Potential and Surface Density Drive Stellar Populations. II. Star-forming Galaxies", The Astrophysical Journal, 898, 62.

Figure 2 from Barone et al (2020) (no. 13): The rest-frame original spectrum for galaxy spec-0541-51959-0600 (black line) and the spectrum used for the stellar population template fitting (green line) that has gas emission lines, sky lines, and discrepant pixels masked. Panel (a) shows the entire wavelength range, panel (b) shows a close-up of the region covering the higher order Balmer lines (indicated by a black dotted box in panel a). The cyan regions are emission lines explicitly masked using the pPXF function determine_goodpixels, and the yellow region is the 5577 sky line that is also explicitly masked. Any remaining emission lines or discrepant pixels are identied and masked by the CLEAN function in pPXF, which iteratively rejects pixels that deviate more than 3 from the best-t and rets until no further pixels are clipped (Cappellari et al. 2002). The higher-order Balmer lines are not explicitly masked, because not all spectra have emission in these regions. However as shown in panel (b), the method used effectively identifes remaining emission lines and masks them, recovering the shape of the underlying absorption feature.



2020 PUBLICATIONS

14. Battisti, A. J., Cunha, E. da ., Shivaei, I., Calzetti, D. (2020) "The Strength of the 2175 Å Feature in the Attenuation Curves of Galaxies at 0.1 < z < 3", The Astrophysical Journal, 888, 108.

15. Bellstedt, S., Robotham, A. S. G., Driver, S. P., Thorne, J. E., Davies, L. J. M., Lagos, C. del P., Stevens, A. R. H., Taylor, E. N., Baldry, I. K., Moffett, A. J., Hopkins, A. M., Phillipps, S. (2020) "Galaxy And Mass Assembly (GAMA): a forensic SED reconstruction of the cosmic star formation history and metallicity evolution by galaxy type", Monthly Notices of the Royal Astronomical Society, 498, 5581.

16. Bian, F., Kewley, L. J., Groves, B., Dopita, M. A. (2020) "What drives the redshift evolution of strong emission line ratios?", Monthly Notices of the Royal Astronomical Society, 493, 580.

17. Borsato, N. W., Martell, S. L., Simpson, J. D. (2020) "Identifying stellar streams in Gaia DR2 with data mining techniques", Monthly Notices of the Royal Astronomical Society, 492, 1370.

18. Botelho, R. B., Milone, A. de C., Meléndez, J., Alves-Brito, A., Spina, L., Bean, J. L. (2020) "Carbon, isotopic ratio 12C/13C, and nitrogen in solar twins: constraints for the chemical evolution of the local disc", Monthly Notices of the Royal Astronomical Society, 499, 2196.

19. Bravo, M., Lagos, C. del P., Robotham, A. S. G., Bellstedt, S., Obreschkow, D. (2020) "From rest-frame luminosity functions to observer-frame colour distributions: tackling the next challenge in cosmological simulations", Monthly Notices of the Royal Astronomical Society, 497, 3026.

20. Burkhart, B., Appel, S. M., Bialy, S., Cho, J., Christensen, A. J., Collins, D., Federrath, C., Fielding, D. B., Finkbeiner, D., Hill, A. S., Ibáñez-Mejía, J. C., Krumholz, M. R., Lazarian, A., Li, M., Mocz, P., Mac Low, M.-M., Naiman, J., Portillo, S. K. N., Shane, B., Slepian, Z., Yuan, Y. (2020) "The Catalogue for Astrophysical Turbulence Simulations (CATS)", The Astrophysical Journal, 905, 14.

21. Byler, N., Kewley, L. J., Rigby, J. R., Acharyya, A., Berg, D. A., Bayliss, M., Sharon, K. (2020) "A Comparison of UV and Optical Metallicities in Star-forming Galaxies", The Astrophysical Journal, 893, 1.

22. Carleo, I., Gandolfi, D., Barragán, O., Livingston, J. H., Persson, C. M., Lam, K. W. F., Vidotto, A., Lund, M. B., D'Angelo, C. V., Collins, K. A., Fossati, L., Howard, A. W., Kubyshkina, D., Brahm, R., Oklopčić, A., Mollière, P., Redfield, S., Serrano, L. M., Dai, F., Fridlund, M., Borsa, F., Korth, J., Esposito, M., Díaz, M. R., Nielsen, L. D., Hellier, C., Mathur, S., Deeg, H. J., Hatzes, A. P., Benatti, S., Rodler, F., Alarcon, J., Spina, L., Santos, Â. R. G., Georgieva, I., García, R. A., González-Cuesta, L., Ricker, G. R., Vanderspek, R., Latham, D. W., Seager, S., Winn, J. N., Jenkins, J. M., Albrecht, S., Batalha, N. M., Beard, C., Boyd, P. T., Bouchy, F., Burt, J. A., Butler, R. P., and 63 colleagues (2020) "The Multiplanet System TOI-421", The Astronomical Journal, 160, 114.

23. Casagrande, L. (2020) "Connecting the Local Stellar Halo and Its Dark Matter Density to Dwarf Galaxies via Blue Stragglers", The Astrophysical Journal, 896, 26.

24. Casali, G., Spina, L., Magrini, L., Karakas, A. I., Kobayashi, C., Casey, A. R., Feltzing, S., Van der Swaelmen, M., Tsantaki, M., Jofré, P., Bragaglia, A., Feuillet, D., Bensby, T., Biazzo, K., Gonneau, A., Tautvaišienė, G., Baratella, M., Roccatagliata, V., Pancino, E., Sousa, S., Adibekyan, V., Martell, S., Bayo, A., Jackson, R. J., Jeffries, R. D., Gilmore, G., Randich, S., Alfaro, E., Koposov, S. E., Korn, A. J., Recio-Blanco, A., Smiljanic, R., Franciosini, E., Hourihane, A., Monaco, L., Morbidelli, L., Sacco, G., Worley, C., Zaggia, S. (2020) "The Gaia-ESO survey: the non-universality of the age-chemical-clocks-metallicity relations in the Galactic disc", Astronomy and Astrophysics, 639, A127.

25. Cavecchi, Y., Galloway, D. K., Goodwin, A. J., Johnston, Z., Heger, A. (2020) "The efficiency of nuclear burning during thermonuclear (Type I) bursts as a function of accretion rate", Monthly Notices of the Royal Astronomical Society, 499, 2148.

26. Cañas, R., Lagos, C. del P., Elahi, P. J., Power, C., Welker, C., Dubois, Y., Pichon, C. (2020) "From stellar haloes to intracluster light: the physics of the Intra-Halo Stellar Component in cosmological hydrodynamical simulations", Monthly Notices of the Royal Astronomical Society, 494, 4314.

27. Chan, C., Müller, B., Heger, A. (2020) "The impact of fallback on the compact remnants and chemical yields of core-collapse supernovae", Monthly Notices of the Royal Astronomical Society, 495, 3751.

28. Chang, Y.-Y., Le Floc'h, E., Juneau, S., da Cunha, E., Salvato, M., Dekel, A., Civano, F., Marchesi, S., Suh, H., Wang, W.-H. (2020) "Unveiling Sizes of Compact AGN Hosts with ALMA", The Astrophysical Journal, 888, 44.

29. Chauhan, G., Lagos, C. del P., Stevens, A. R. H., Obreschkow, D., Power, C., Meyer, M. (2020) "The physical drivers of the atomic hydrogen-halo mass relation", Monthly Notices of the Royal Astronomical Society, 498, 44.

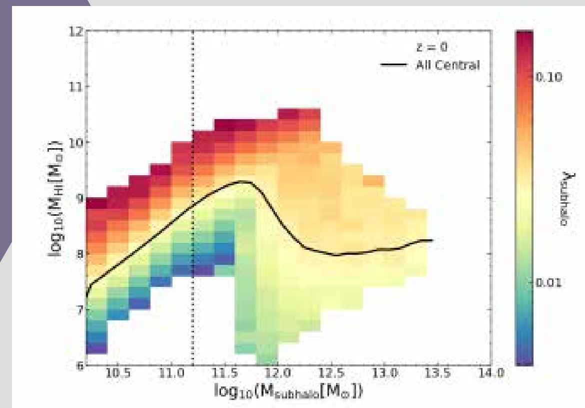
30. Chen, B., D'Onghia, E., Alves, J., Adamo, A. (2020) "Discovery of new stellar groups in the Orion complex. Towards a robust unsupervised approach", Astronomy and Astrophysics, 643, A114.

31. Chen, X., Wang, J., Kong, X., Catinella, B., Shao, L., Mo, H. (2020) "The growth of bulges and discs in relatively H I-rich galaxies: indication from H I scaling relations", Monthly Notices of the Royal Astronomical Society, 492, 2393.

32. Churchill, C. W., Evans, J. L., Stemock, B., Nielsen, N. M., Kacprzak, G. G., Murphy, M. T. (2020) "Mg II Absorbers in High-resolution Quasar Spectra. I. Voigt Profile Models", The Astrophysical Journal, 904, 28.

33. Cole, J., Bezanson, R., van der Wel, A., Bell, E., D'Eugenio, F., Franx, M., Gallazzi, A., van Houdt, J., Muzzin, A., Pacifici, C., van de Sande, J., Sobral, D., Straatman, C., Wu, P.-F. (2020) "Stellar Kinematics and Environment at z ~ 0.8 in the LEGA-C Survey: Massive Slow Rotators Are Built First in Overdense Environments", The Astrophysical Journal, 890, L25.

Figure 10 from Chauhan et al (2020) (no. 29): The H_I content of central galaxies as a function of their subhalo mass at z = 0. Bins are coloured by the median subhalo's spin parameter, as labelled in the colour bar. The solid black line shows the median H_I mass as a function of the mass of the subhalo, Msubhalo. Subhaloes with higher spin parameters are H_I-richer than their counterparts up to $M_{subhalo}$ ~10^{12}M , after which the trend is almost completely lost at the transition and high mass regions.



34. Collacchioni, F., Lagos, C. D. P., Mitchell, P. D., Schaye, J., Wisnioski, E., Cora, S. A., Correa, C. A. (2020) “The effect of gas accretion on the radial gas metallicity profile of simulated galaxies”, Monthly Notices of the Royal Astronomical Society, 495, 2827.

35. Cook, R. H. W., Cortese, L., Catinella, B., Robotham, A. (2020) “xGASS: the role of bulges along and across the local star-forming main sequence”, Monthly Notices of the Royal Astronomical Society, 493, 5596.

36. Cook, R. H. W., Seymour, N., Spekkens, K., Hurley-Walker, N., Hancock, P. J., Bell, M. E., Callingham, J. R., For, B.-Q., Franzen, T. M. O., Gaensler, B. M., Hindson, L., Johnston-Hollitt, M., Kapińska, A. D., Morgan, J., Offringa, A. R., Procopio, P., Staveley-Smith, L., Wayth, R. B., Wu, C., Zheng, Q. (2020) “Searching for dark matter signals from local dwarf spheroidal galaxies at low radio frequencies in the GLEAM survey”, Monthly Notices of the Royal Astronomical Society, 494, 135.

37. Corcho-Caballero, P., Ascasibar, Y., López-Sánchez, Á. R. (2020) “A single galaxy population? Statistical evidence that the star-forming main sequence might be the tip of the iceberg”, Monthly Notices of the Royal Astronomical Society, 499, 573.

38. Cordoni, G., Milone, A. P., Marino, A. F., Da Costa, G. S., Dondoglio, E., Jerjen, H., Lagioia, E. P., Mastrobuono-Battisti, A., Norris, J. E., Tailo, M., Yong, D. (2020) “Gaia and Hubble Unveil the Kinematics of Stellar Populations in the Type II Globular Clusters ω Centauri and M22”, The Astrophysical Journal, 898, 147.

39. Cortese, L., Catinella, B., Cook, R. H. W., Janowiecki, S. (2020) “xGASS: passive discs do not host unexpectedly large reservoirs of cold atomic hydrogen”, Monthly Notices of the Royal Astronomical Society, 494, L42.

40. D’Eugenio, F., van der Wel, A., Wu, P.-F., Barone, T. M., van Houdt, J., Bezanson, R., Straatman, C. M. S., Pacifici, C., Muzzin, A., Gallazzi, A., Wild, V., Sobral, D., Bell, E. F., Zibetti, S., Mowla, L., Franx, M. (2020) “Inverse stellar population age gradients of post-starburst galaxies at z = 0.8 with LEGA-C”, Monthly Notices of the Royal Astronomical Society, 497, 389.

41. Davies, R. L., Förster Schreiber, N. M., Lutz, D., Genzel, R., Belli, S., Shimizu, T. T., Contursi, A., Davies, R. I., Herrera-Camus, R., Lee, M. M., Naab, T., Price, S. H., Renzini, A., Schruba, A., Sternberg, A., Tacconi, L. J., Übler, H., Wisnioski, E., Wuyts, S. (2020) “From Nuclear to Circumgalactic: Zooming in on AGN-driven Outflows at z ~ 2.2 with SINFONI”, The Astrophysical Journal, 894, 28.

42. Davé, R., Crain, R. A., Stevens, A. R. H., Narayanan, D., Saintonge, A., Catinella, B., Cortese, L. (2020) “Galaxy cold gas contents in modern cosmological hydrodynamic simulations”, Monthly Notices of the Royal Astronomical Society, 497, 146.

43. de Blok, W. J. G., Athanassoula, E., Bosma, A., Combes, F., English, J., Heald, G. H., Kamphuis, P., Koribalski, B. S., Meurer, G. R., Román, J., Sardone, A., Verdes-Montenegro, L., Bigiel, F., Brinks, E., Chemin, L., Fraternali, F., Jarrett, T., Kleiner, D., Maccagni, F. M., Pisano, D. J., Serra, P., Spekkens, K., Amram, P., Carignan, C., Dettmar, R.-J., Gibson, B. K., Holwerda, B. W., Józsa, G. I. G., Lucero, D. M., Oosterloo, T. A., Ramaila, A. J. T., Ramatsoku, M., Sheth, K., Walter, F., Wong, O. I., Zijlstra, A. A., Bloemen, S., Groot, P. J., Le Poole, R., Klein-Wolt, M., Körding, E. G., McBride, V. A., Paterson, K., Pieterse, D. L. A., Vreeswijk, P., Woudt, P. A. (2020) “MeerKAT HI commissioning observations of MHONGOOSE galaxy ESO 302-G014”, Astronomy and Astrophysics, 643, A147.

44. de Graaff, A., Bezanson, R., Franx, M., van der Wel, A., Bell, E. F., D’Eugenio, F., Holden, B., Maseda, M. V., Muzzin, A., Pacifici, C., van de Sande, J., Sobral, D., Straatman, C. M. S., Wu, P.-F. (2020) “Tightly Coupled Morpho-kinematic Evolution for Massive Star-forming and Quiescent Galaxies across 7 Gyr of Cosmic Time”, The Astrophysical Journal, 903, L30.

45. Deeley, S., Drinkwater, M. J., Sweet, S. M., Diaz, J., Bekki, K., Couch, W. J., Forbes, D. A., Bland-Hawthorn, J., Bryant, J. J., Croom, S., Cortese, L., Lawrence, J. S., Lorente, N., Medling, A. M., Owers, M., Richards, S. N., van de Sande, J. (2020) “The SAMI galaxy survey: a range in S0 properties indicating multiple formation pathways”, Monthly Notices of the Royal Astronomical Society, 498, 2372.

46. du Buisson, L., Marchant, P., Podsiadlowski, P., Kobayashi, C., Abdalla, F. B., Taylor, P., Mandel, I., de Mink, S. E., Moriya, T. J., Langer, N. (2020) “Cosmic rates of black hole mergers and pair-instability supernovae from chemically homogeneous binary evolution”, Monthly Notices of the Royal Astronomical Society, 499, 5941.

47. Duchesne, S. W., Johnston-Hollitt, M., Zhu, Z., Wayth, R. B., Line, J. L. B. (2020) “Murchison Widefield Array detection of steep-spectrum, diffuse, non-thermal radio emission within Abell 1127”, Publications of the Astronomical Society of Australia, 37, e037.

48. Dudzevičiūtė, U., Smail, I., Swinbank, A. M., Stach, S. M., Almaini, O., da Cunha, E., An, F. X., Arumugam, V., Birkin, J., Blain, A. W., Chapman, S. C., Chen, C.-C., Conselice, C. J., Coppin, K. E. K., Dunlop, J. S., Farrah, D., Geach, J. E., Gullberg, B., Hartley, W. G., Hodge, J. A., Ivison, R. J., Maltby, D. T., Scott, D., Simpson, C. J., Simpson, J. M., Thomson, A. P., Walter, F., Wardlow, J. L., Weiss, A., van der Werf, P. (2020) “An ALMA survey of the SCUBA-2 CLS UDS field: physical properties of 707 sub-millimetre galaxies”, Monthly Notices of the Royal Astronomical Society, 494, 3828.

49. Easter, P. J., Ghonge, S., Lasky, P. D., Casey, A. R., Clark, J. A., Hernandez Vivanco, F., Chatziioannou, K. (2020) “Detection and parameter estimation of binary neutron star merger remnants”, Physical Review D, 102, 043011.

50. Eldridge, J. J., Stanway, E. R., Breivik, K., Casey, A. R., Steeghs, D. T. H., Stevance, H. F. (2020) “Weighing in on black hole binaries with BPASS: LB-1 does not contain a 70 M black hole”, Monthly Notices of the Royal Astronomical Society, 495, 2786.

51. Elmegreen, B. G., Adamo, A., Boquien, M., Bournaud, F., Calzetti, D., Cook, D. O., Dale, D. A., Duc, P.-A., Elmegreen, D. M., Fensch, J., Grasha, K., Kim, H., Kahre, L., Messa, M., Ryon, J. E., Sabbi, E., Smith, L. J. (2020) “Spatial Segregation of Massive Clusters in Dwarf Galaxies”, The Astrophysical Journal, 888, L27.

52. Feuillet, D. K., Feltzing, S., Sahlholdt, C. L., Casagrande, L. (2020) “The SkyMapper-Gaia RVS view of the Gaia-Enceladus-Sausage - an investigation of the metallicity and mass of the Milky Way’s last major merger”, Monthly Notices of the Royal Astronomical Society, 497, 109.

53. Fogasy, J., Knudsen, K. K., Drouart, G., Lagos, C. D. P., Fan, L. (2020) “SMM J04135+10277: a distant QSO-starburst system caught by ALMA”, Monthly Notices of the Royal Astronomical Society, 493, 3744.

54. Fox, A. J., Frazer, E. M., Bland-Hawthorn, J., Wakker, B. P., Barger, K. A., Richter, P. (2020) “Kinematics of the Magellanic Stream and Implications for Its Ionization”, The Astrophysical Journal, 897, 23.

2020 PUBLICATIONS

55. Fridlund, M., Livingston, J., Gandolfi, D., Persson, C. M., Lam, K. W. F., Stassun, K. G., Hellier, C., Korth, J., Hatzes, A. P., Malavolta, L., Luque, R., Redfield, S., Guenther, E. W., Albrecht, S., Barragan, O., Benatti, S., Bouma, L., Cabrera, J., Cochran, W. D., Csizmadia, S., Dai, F., Deeg, H. J., Esposito, M., Georgieva, I., Grziwa, S., González Cuesta, L., Hirano, T., Jenkins, J. M., Kabath, P., Knudstrup, E., Latham, D. W., Mathur, S., Mullally, S. E., Narita, N., Nowak, G., Olofsson, A. O. H., Palle, E., Pätzold, M., Pompei, E., Rauer, H., Ricker, G., Rodler, F., Seager, S., Serrano, L. M., Smith, A. M. S., Spina, L., Subjak, J., Tenenbaum, P., Ting, E. B., Vanderburg, A., and 4 colleagues (2020) "The TOI-763 system: sub-Neptunes orbiting a Sun-like star", Monthly Notices of the Royal Astronomical Society, 498, 4503.

56. Fujimoto, Y., Krumholz, M. R., Inutsuka, S.-ichiro . (2020) "Distribution and kinematics of 26Al in the Galactic disc", Monthly Notices of the Royal Astronomical Society, 497, 2442.

57. Fujimoto, Y., Krumholz, M. R., Inutsuka, S.-. ichiro ., Boss, A. P., Nittler, L. R. (2020) "Formation and evolution of the local interstellar environment: combined constraints from nucleosynthetic and X-ray data", Monthly Notices of the Royal Astronomical Society, 498, 5532.

58. Fuller, S., Lemaux, B. C., Bradač, M., Hoag, A., Schmidt, K. B., Huang, K., Strait, V., Mason, C., Treu, T., Pentericci, L., Trenti, M., Henry, A., Malkan, M. (2020) "Spectroscopically Confirmed Lyα Emitters from Redshift 5 to 7 behind 10 Galaxy Cluster Lenses", The Astrophysical Journal, 896, 156.

59. Gao, X., Lind, K., Amarsi, A. M., Buder, S., Bland-Hawthorn, J., Campbell, S. W., Asplund, M., Casey, A. R., de Silva, G. M., Freeman, K. C., Hayden, M. R., Lewis, G. F., Martell, S. L., Simpson, J. D., Sharma, S., Zucker, D. B., Zwitter, T., Horner, J., Munari, U., Nordlander, T., Stello, D., Ting, Y.-S., Traven, G., Wittenmyer, R. A., GALAH Collaboration (2020) "The GALAH survey: a new constraint on cosmological lithium and Galactic lithium evolution from warm dwarf stars", Monthly Notices of the Royal Astronomical Society, 497, L30.

60. Gentry, E. S., Madau, P., Krumholz, M. R. (2020) "Momentum injection by clustered supernovae: testing subgrid feedback prescriptions", Monthly Notices of the Royal Astronomical Society, 492, 1243.

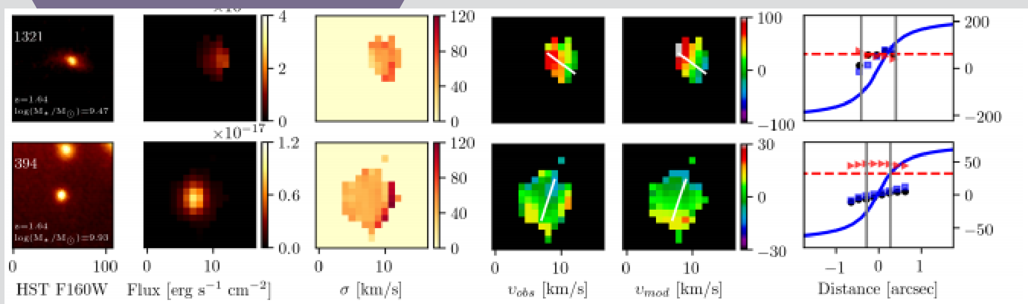
61. Genzel, R., Price, S. H., Übler, H., Förster Schreiber, N. M., Shimizu, T. T., Tacconi, L. J., Bender, R., Burkert, A., Contursi, A., Coogan, R., Davies, R. L., Davies, R. I., Dekel, A., Herrera-Camus, R., Lee, M.-J., Lutz, D., Naab, T., Neri, R., Nestor, A., Renzini, A., Saglia, R., Schuster, K., Sternberg, A., Wisnioski, E., Wuyts, S. (2020) "Rotation Curves in z ˜ 1-2 Star-forming Disks: Evidence for Cored Dark Matter Distributions", The Astrophysical Journal, 902, 98.

62. Ghosh, A., Mertens, F., Bernardi, G., Santos, M. G., Kern, N. S., Carilli, C. L., Grobler, T. L., Koopmans, L. V. E., Jacobs, D. C., Liu, A., Parsons, A. R., Morales, M. F., Aguirre, J. E., Dillon, J. S., Hazelton, B. J., Smirnov, O. M., Gehlot, B. K., Matika, S., Alexander, P., Ali, Z. S., Beardsley, A. P., Benefo, R. K., Billings, T. S., Bowman, J. D., Bradley, R. F., Cheng, C., Chichura, P. M., DeBoer, D. R., Acedo, E. de L., Ewall-Wice, A., Fadana, G., Fagnoni, N., Fortino, A. F., Fritz, R., Furlanetto, S. R., Gallardo, S., Glendenning, B., Gorthi, D., Greig, B., Grobbelaar, J., Hickish, J., Josaitis, A., Julius, A., Igarashi, A. S., Kariseb, M., Kohn, S. A., Kolopanis, M., Lekalake, T., Loots, A., MacMahon, D., and 23 colleagues (2020) "Foreground modelling via Gaussian process regression: an application to HERA data", Monthly Notices of the Royal Astronomical Society, 495, 2813.

63. Gillman, S., Tiley, A. L., Swinbank, A. M., Harrison, C. M., Smail, I., Dudzevičiūtė, U., Sharples, R. M., Cortese, L., Obreschkow, D., Bower, R. G., Theuns, T., Cirasuolo, M., Fisher, D. B., Glazebrook, K., Ibar, E., Mendel, J. T., Sweet, S. M. (2020) "From peculiar morphologies to Hubble-type spirals: the relation between galaxy dynamics and morphology in star-forming galaxies at z ˜ 1.5", Monthly Notices of the Royal Astronomical Society, 492, 1492.

64. Girard, M., Mason, C. A., Fontana, A., Dessauges-Zavadsky, M., Morishita, T., Amorín, R., Fisher, D. B., Jones, T., Schaerer, D., Schmidt, K. B., Treu, T., Vulcani, B. (2020) "The KMOS Lens-Amplified Spectroscopic Survey (KLASS): kinematics and clumpiness of low-mass galaxies at cosmic noon", Monthly Notices of the Royal Astronomical Society, 497, 173.

From Figure A1 from Girard et al (2020) (no. 64): HST/WFC3 F160W near-infrared images, Ha, [OIII] or [OII] flux in erg s−1 cm−2maps, velocity dispersion maps, observed velocity maps, and velocity maps from the kinematic models of 2 galaxies from KLASS. The white lines in the velocity maps indicate the major axis. In the right panels, the black circles and blue squares represent the rotation curves extracted on the major axis of the observed velocity maps and velocity maps from the kinematicmodels, respectively. The blue solid lines show the intrinsic rotation curves from the models (corrected for the inclination). The vertical grey lines indicate the value of the effective radius obtained with GalPaK3D. The red triangles and red dashed lines represent the velocity dispersion profiles and the intrinsic velocity dispersion obtained from the kinematic models, respectively (*original figure from paper shows 42 galaxies)*



65. Giraud, J., Lindsay, M., Jessell, M., Ogarko, V. (2020) "Towards plausible lithological classification from geophysical inversion: honouring geological principles in subsurface imaging", Solid Earth, 11, 419.

66. González-López, J., Novak, M., Decarli, R., Walter, F., Aravena, M., Carilli, C., Boogaard, L., Popping, G., Weiss, A., Assef, R. J., Bauer, F. E., Bouwens, R., Cortes, P. C., Cox, P., Daddi, E., Cunha, E. da ., Díaz-Santos, T., Ivison, R., Magnelli, B., Riechers, D., Smail, I., van der Werf, P., Wagg, J. (2020) "The ALMA Spectroscopic Survey in the HUDF: Deep 1.2 mm Continuum Number Counts", The Astrophysical Journal, 897, 91.

67. Grasha, K., Darling, J., Leroy, A. K., Bolatto, A. D. (2020) "The evolution of neutral hydrogen over the past 11 Gyr via H I 21 cm absorption", Monthly Notices of the Royal Astronomical Society, 498, 883.

68. Greig, B., Mesinger, A., Koopmans, L. V. E. (2020) "Reionisation and cosmic dawn astrophysics from the Square Kilometre Array: impact of observing strategies", Monthly Notices of the Royal Astronomical Society, 491, 1398.

69. Griffin, A. J., Lacey, C. G., Gonzalez-Perez, V., Lagos, C. del P., Baugh, C. M., Fanidakis, N. (2020) "AGNs at the cosmic dawn: predictions for future surveys from a ΛCDM cosmological model", Monthly Notices of the Royal Astronomical Society, 492, 2535.

2020 PUBLICATIONS

70. Grimmett, J. J., Karakas, A. I., Heger, A., Müller, B., West, C. (2020) "The chemical evolution of iron-peak elements with hypernovae", Monthly Notices of the Royal Astronomical Society, 496, 4987.

71. Gullberg, S. R., Hamacher, D. W., Martín-Lopez, A., Mejuto, J., Munro, A. M., Orchiston, W. (2020) "A cultural comparison of the 'dark constellations' in the Milky Way", Journal of Astronomical History and Heritage, 23, 390.

72. Guo, K., Cortese, L., Obreschkow, D., Catinella, B., van de Sande, J., Croom, S. M., Brough, S., Sweet, S., Bryant, J. J., Medling, A., Bland-Hawthorn, J., Owers, M., Richards, S. N. (2020) "The SAMI Galaxy Survey: the contribution of different kinematic classes to the stellar mass function of nearby galaxies", Monthly Notices of the Royal Astronomical Society, 491, 773.

73. Gupta, A., Tran, K.-V., Cohn, J., Alcorn, L. Y., Yuan, T., Rodriguez-Gomez, V., Harshan, A., Forrest, B., Kewley, L. J., Glazebrook, K., Straatman, C. M., Kacprzak, G. G., Nanayakkara, T., Labbé, I., Papovich, C., Cowley, M. (2020) "MOSEL Survey: Tracking the Growth of Massive Galaxies at 2 < z < 4 Using Kinematics and the IllustrisTNG Simulation", The Astrophysical Journal, 893, 23.

74. Hamacher, D. W. (2020) "Native American traditions of Meteor Crater, Arizona: fact, fiction or appropriation?", Journal of Astronomical History and Heritage, 23, 375.

75. Hamacher, D. W., Fuller, R. S., Leaman, T. M., Bosun, D. (2020) "Solstice and solar position observations in Australian Aboriginal and Torres Strait Islander traditions", Journal of Astronomical History and Heritage, 23, 89.

76. Harborne, K. E., Power, C., Robotham, A. S. G. (2020) "SIMSPIN - Constructing mock IFS kinematic data cubes", Publications of the Astronomical Society of Australia, 37, e016.

77. Harborne, K. E., van de Sande, J., Cortese, L., Power, C., Robotham, A. S. G., Lagos, C. D. P., Croom, S. (2020) "Recovering λR and V/σ from seeing-dominated IFS data", Monthly Notices of the Royal Astronomical Society, 497, 2018.

Figure 4 from Hamacher et al (2020) (no. 75): The Wurdi Youang stone arrangement and the hypothesised solar alignments, from Norris et al. (2013). The point where the lines converges is the best vantage point for observing the solar markers.

78. Harshan, A., Gupta, A., Tran, K.-V., Alcorn, L. Y., Yuan, T., Kacprzak, G. G., Nanayakkara, T., Glazebrook, K., Kewley, L. J., Labbé, I., Papovich, C. (2020) "ZFIRE: Measuring Electron Density with [O II] as a Function of Environment at z = 1.62", The Astrophysical Journal, 892, 77.

79. Hasan, F., Churchill, C. W., Stemock, B., Mathes, N. L., Nielsen, N. M., Finlator, K., Doughty, C., Croom, M., Kacprzak, G. G., Murphy, M. T. (2020) "Evolution of C IV Absorbers. I. The Cosmic Incidence", The Astrophysical Journal, 904, 44.

80. Hayden, M. R., Bland-Hawthorn, J., Sharma, S., Freeman, K., Kos, J., Buder, S., Anguiano, B., Asplund, M., Chen, B., De Silva, G. M., Khanna, S., Lin, J., Horner, J., Martell, S., Ting, Y.-S., Wyse, R., Zucker, D., Zwitter, T. (2020) "The GALAH survey: chemodynamics of the solar neighbourhood", Monthly Notices of the Royal Astronomical Society, 493, 2952.

81. Haydon, D. T., Fujimoto, Y., Chevance, M., Kruijssen, J. M. D., Krumholz, M. R., Longmore, S. N. (2020) "An uncertainty principle for star formation - V. The influence of dust extinction on star formation rate tracer lifetimes and the inferred molecular cloud lifecycle", Monthly Notices of the Royal Astronomical Society, 497, 5076.

82. Haydon, D. T., Kruijssen, J. M. D., Chevance, M., Hygate, A. P. S., Krumholz, M. R., Schruba, A., Longmore, S. N. (2020) "An uncertainty principle for star formation - III. The characteristic emission time-scales of star formation rate tracers", Monthly Notices of the Royal Astronomical Society, 498, 235.

83. Hinkle, J. T., Holoien, T. W.-S., Shappee, B. J., Auchettl, K., Kochanek, C. S., Stanek, K. Z., Payne, A. V., Thompson, T. A. (2020) "Examining a Peak-luminosity/Decline-rate Relationship for Tidal Disruption Events", The Astrophysical Journal, 894, L10.

84. Hodge, J. A., da Cunha, E. (2020) "High-redshift star formation in the Atacama large millimetre/submillimetre array era", Royal Society Open Science, 7, 200556.

85. Hodgson, T., Johnston-Hollitt, M., McKinley, B., Vernstrom, T., Vacca, V. (2020) "Low(er) frequency follow-up of 28 candidate, large-scale synchrotron sources", Publications of the Astronomical Society of Australia, 37, e032.

86. Holland-Ashford, T., Lopez, L. A., Auchettl, K. (2020) "Spatially Resolved Study of Recombining Plasma in W49B Using XMM-Newton", The Astrophysical Journal, 903, 108.

87. Holoien, T. W.-S., Auchettl, K., Tucker, M. A., Shappee, B. J., Patel, S. G., Miller-Jones, J. C. A., Mockler, B., Groenewald, D. N., Hinkle, J. T., Brown, J. S., Kochanek, C. S., Stanek, K. Z., Chen, P., Dong, S., Prieto, J. L., Thompson, T. A., Beaton, R. L., Connor, T., Cowperthwaite, P. S., Dahmen, L., French, K. D., Morrell, N., Buckley, D. A. H., Gromadzki, M., Roy, R., Coulter, D. A., Dimitriadis, G., Foley, R. J., Kilpatrick, C. D., Piro, A. L., Rojas-Bravo, C., Siebert, M. R., Velzen, S. van . (2020) "The Rise and Fall of ASASSN-18pg: Following a TDE from Early to Late Times", The Astrophysical Journal, 898, 161.

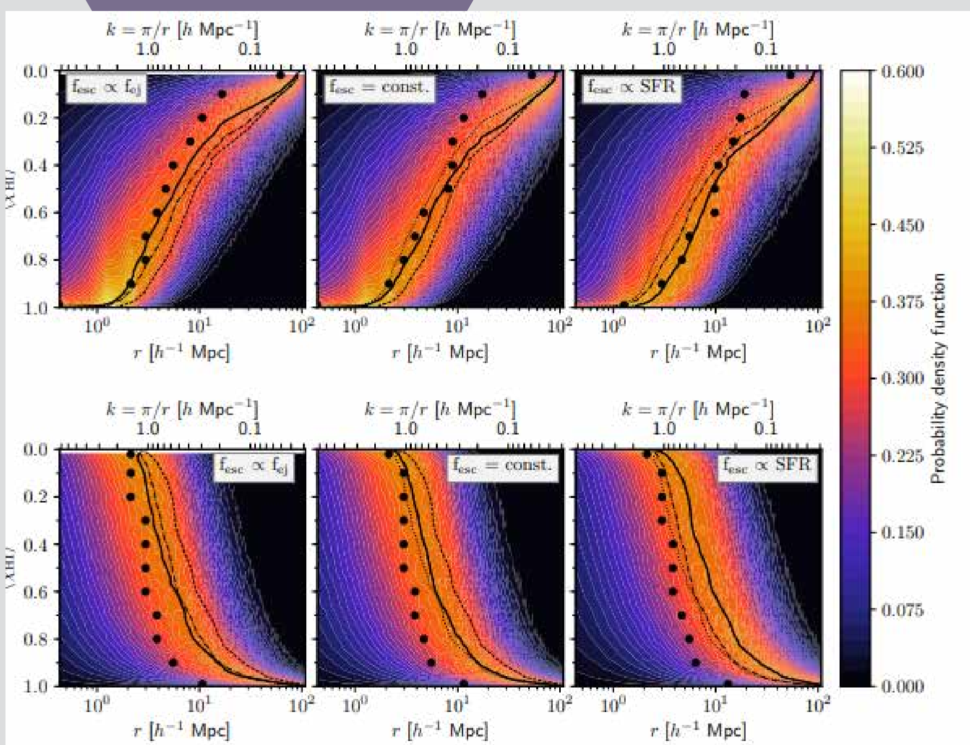
88. Hu, W., Catinella, B., Cortese, L., Staveley-Smith, L., Lagos, C. del P., Chauhan, G., Oosterloo, T., Chen, X. (2020) "The cosmic atomic hydrogen mass density as a function of mass and galaxy hierarchy from spectral stacking", Monthly Notices of the Royal Astronomical Society, 493, 1587.

89. Hung, T., Foley, R. J., Ramirez-Ruiz, E., Dai, J. L., Auchettl, K., Kilpatrick, C. D., Mockler, B., Brown, J. S., Coulter, D. A., Dimitriadis,

G., Holoien, T. W.-S., Law-Smith, J. A. P., Piro, A. L., Rest, A., Rojas-Bravo, C., Siebert, M. R. (2020) "Double-peaked Balmer Emission Indicating Prompt Accretion Disk Formation in an X-Ray Faint Tidal Disruption Event", The Astrophysical Journal, 903, 31.

90. Hutter, A., Watkinson, C. A., Seiler, J., Dayal, P., Sinha, M., Croton, D. J. (2020) "The 21 cm bispectrum during reionisation: a tracer of the ionisation topology", Monthly Notices of the Royal Astronomical Society, 492, 653.

Figure 4 from Hutter et al (2020) (no. 90): Top: Probability density distribution (PDF) for the sizes of the ionised regions. Bottom: PDF for the sizes of the neutral regions. In each panel, colour encodes the amplitude of the PDF, while the solid black line shows the evolution of the maximum of the PDF throughout reionisation. Black dots mark the maxima of the respective granulometry size distribution shown in Fig. A1. For comparison, we plot the maxima of the PDFs of the other two f_{esc} models in each panel, i.e. thin dotted, dash-dotted and dashed lines correspond to the ejected, constant and SFR f_{esc} models, respectively.



91. Inami, H., Decarli, R., Walter, F., Weiss, A., Carilli, C., Aravena, M., Boogaard, L., Gonzaĺez-López, J., Popping, G., da Cunha, E., Bacon, R., Bauer, F., Contini, T., Cortes, P. C., Cox, P., Daddi, E., Díaz-Santos, T., Kaasinen, M., Riechers, D. A., Wagg, J., van der Werf, P., Wisotzki, L. (2020) "The ALMA Spectroscopic Survey in the Hubble Ultra Deep Field: Constraining the Molecular Content at log(M*/M) ˜ 9.5 with CO Stacking of MUSE-detected z ˜ 1.5 Galaxies", The Astrophysical Journal, 902, 113.

92. Issac, N., Tej, A., Liu, T., Varricatt, W., Vig, S., Ishwara Chandra, C. H., Schultheis, M., Nandakumar, G. (2020) "Multiwavelength investigation of extended green object G19.88-0.53: revealing a protocluster", Monthly Notices of the Royal Astronomical Society, 497, 5454.

93. Izzo, L., Auchettl, K., Hjorth, J., De Colle, F., Gall, C., Angus, C. R., Raimundo, S. I., Ramirez-Ruiz, E. (2020) "Broad-line type Ic SN 2020bvc. Signatures of an off-axis gamma-ray burst afterglow", Astronomy and Astrophysics, 639, L11.

94. Janowiecki, S., Catinella, B., Cortese, L., Saintonge, A., Wang, J. (2020) "xGASS: cold gas content and quenching in galaxies below the star-forming main sequence", Monthly Notices of the Royal Astronomical Society, 493, 1982.

95. Ji, A. P., Li, T. S., Hansen, T. T., Casey, A. R., Koposov, S. E., Pace, A. B., Mackey, D., Lewis, G. F., Simpson, J. D., Bland-Hawthorn, J., Cullinane, L. R., Da Costa, G. S., Hattori, K., Martell, S. L., Kuehn, K., Erkal, D., Shipp, N., Wan, Z., Zucker, D. B. (2020) "The Southern Stellar Stream Spectroscopic Survey (S5): Chemical Abundances of Seven Stellar Streams", The Astronomical Journal, 160, 181.

96. Joseph, R. C., Trott, C. M., Wayth, R. B., Nasirudin, A. (2020) "Calibration and 21-cm power spectrum estimation in the presence of antenna beam variations", Monthly Notices of the Royal Astronomical Society, 492, 2017.

97. Joseph, R. C., Trott, C. M., Wayth, R. B., Nasirudin, A. (2020) "Erratum: calibration and 21-cm power spectrum estimation in the presence of antenna beam variations", Monthly Notices of the Royal Astronomical Society, 493, 4077.

98. Joyce, M., Leung, S.-C., Molnár, L., Ireland, M., Kobayashi, C., Nomoto, K. (2020) "Standing on the Shoulders of Giants: New Mass and Distance Estimates for Betelgeuse through Combined Evolutionary, Asteroseismic, and Hydrodynamic Simulations with MESA", The Astrophysical Journal, 902, 63.

99. Kaasinen, M., Walter, F., Novak, M., Neeleman, M., Smail, I., Boogaard, L., Cunha, E. da ., Weiss, A., Liu, D., Decarli, R., Popping, G., Diaz-Santos, T., Cortés, P., Aravena, M., Werf, P. van . der ., Riechers, D., Inami, H., Hodge, J. A., Rix, H.-W., Cox, P. (2020) "A Comparison of the Stellar, CO, and Dust-continuum Emission from Three Star-forming HUDF Galaxies at z ~ 2", The Astrophysical Journal, 899, 37.

100. Karovicova, I., White, T. R., Nordlander, T., Casagrande, L., Ireland, M., Huber, D., Jofré, P. (2020) "Fundamental stellar parameters of benchmark stars from CHARA interferometry. I. Metal-poor stars", Astronomy and Astrophysics, 640, A25.

101. Katsianis, A., Gonzalez, V., Barrientos, D., Yang, X., Lagos, C. D. P., Schaye, J., Camps, P., Trčka, A., Baes, M., Stalevski, M., Blanc, G. A., Theuns, T. (2020) "The high-redshift SFR-M* relation is sensitive to the employed star formation rate and stellar mass indicators: towards addressing the tension between observations and simulations", Monthly Notices of the Royal Astronomical Society, 492, 5592.

102. Kern, N. S., Parsons, A. R., Dillon, J. S., Lanman, A. E., Liu, A., Bull, P., Ewall-Wice, A., Abdurashidova, Z., Aguirre, J. E., Alexander, P., Ali, Z. S., Balfour, Y., Beardsley, A. P., Bernardi, G., Bowman, J. D., Bradley, R. F., Burba, J., Carilli, C. L., Cheng, C., DeBoer, D. R., Dexter, M., de Lera Acedo, E., Fagnoni, N., Fritz, R., Furlanetto, S. R., Glendenning, B., Gorthi, D., Greig, B., Grobbelaar, J., Halday, Z., Hazelton, B. J., Hewitt, J. N., Hickish, J., Jacobs, D. C., Julius, A., Kerrigan, J., Kittiwisit, P., Kohn, S. A., Kolopanis, M., La Plante, P., Lekalake, T., MacMahon, D., Malan, L., Malgas, C., Maree, M., Martinot, Z. E., Matsetela, E., Mesinger, A., Molewa, M., Morales, M. F., and 17 colleagues (2020) "Mitigating Internal Instrument Coupling for 21 cm Cosmology. II. A Method Demonstration with the Hydrogen Epoch of Reionisation Array", The Astrophysical Journal, 888, 70.

103. Khim, D. J., Yi, S. K., Dubois, Y., Bryant, J. J., Pichon, C., Croom, S. M., Bland-Hawthorn, J., Brough, S., Choi, H., Devriendt, J., Groves, B., Owers, M. S., Richards, S. N., van de Sande, J., Sweet, S. M. (2020) "Star-Gas Misalignment in Galaxies. I. The Properties of Galaxies from the Horizon-AGN Simulation and Comparisons to SAMI", The Astrophysical Journal, 894, 106.

104. Kim, S., Contini, E., Choi, H., Han, S., Lee, J., Oh, S., Kang, X., Yi, S. K. (2020) "YZiCS: On the Mass Segregation of Galaxies in Clusters", The Astrophysical Journal, 905, 12.

105. Klitsch, A., Zwaan, M. A., Smail, I., Péroux, C., Biggs, A. D., Chen, C.-C., Ivison, R. J., Popping, G., Lagos, C., Béthermin, M., Swinbank, A. M., Hamanowicz, A., Dutta, R. (2020) "ALMACAL VII: first interferometric number counts at 650 µm", Monthly Notices of the Royal Astronomical Society, 495, 2332.

106. Kobayashi, C., Karakas, A. I., Lugaro, M. (2020) "The Origin of Elements from Carbon to Uranium", The Astrophysical Journal, 900, 179.

107. Kool, E. C., Reynolds, T. M., Mattila, S., Kankare, E., Pérez-Torres, M. A., Efstathiou, A., Ryder, S., Romero-Cañizales, C., Lu, W., Heikkilä, T., Anderson, G. E., Berton, M., Bright, J., Cannizzaro, G., Eappachen, D., Fraser, M., Gromadzki, M., Jonker, P. G., Kuncarayakti, H., Lundqvist, P., Maeda, K., McDermid, R. M., Medling, A. M., Moran, S., Reguitti, A., Shahbandeh, M., Tsygankov, S., U, V., Wevers, T. (2020) "AT 2017gbl: a dust obscured TDE candidate in a luminous infrared galaxy", Monthly Notices of the Royal Astronomical Society, 498, 2167.

108. Koposov, S. E., Boubert, D., Li, T. S., Erkal, D., Da Costa, G. S., Zucker, D. B., Ji, A. P., Kuehn, K., Lewis, G. F., Mackey, D., Simpson, J. D., Shipp, N., Wan, Z., Belokurov, V., Bland-Hawthorn, J., Martell, S. L., Nordlander, T., Pace, A. B., De Silva, G. M., Wang, M.-Y., S5 Collaboration (2020) "Discovery of a nearby 1700 km s-1 star ejected from the Milky Way by Sgr A*", Monthly Notices of the Royal Astronomical Society, 491, 2465.

109. Koribalski, B. S., Staveley-Smith, L., Westmeier, T., Serra, P., Spekkens, K., Wong, O. I., Lee-Waddell, K., Lagos, C. D. P., Obreschkow, D., Ryan-Weber, E. V., Zwaan, M., Kilborn, V., Bekiaris, G., Bekki, K., Bigiel, F., Boselli, A., Bosma, A., Catinella, B., Chauhan, G., Cluver, M. E., Colless, M., Courtois, H. M., Crain, R. A., de Blok, W. J. G., Dénes, H., Duffy, A. R., Elagali, A., Fluke, C. J., For, B.-Q., Heald, G., Henning, P. A., Hess, K. M., Holwerda, B. W., Howlett, C., Jarrett, T., Jones, D. H., Jones, M. G., Józsa, G. I. G., Jurek, R., Jütte, E., Kamphuis, P., Karachentsev, I., Kerp, J., Kleiner, D., Kraan-Korteweg, R. C., López-Sánchez, Á. R., Madrid, J., Meyer, M., Mould, J., Murugeshan, C., and 20 colleagues (2020) "WALLABY - an SKA Pathfinder HI survey", Astrophysics and Space Science, 365, 118.

110. Krefting, N., Sajina, A., Lacy, M., Nyland, K., Farrah, D., Darvish, B., Duivenvoorden, S., Duncan, K., Gonzalez-Perez, V., del P. Lagos, C., Oliver, S., Shirley, R., Vaccari, M. (2020) "The Role of Environment in Galaxy Evolution in the SERVS Survey. I. Density Maps and Cluster Candidates", The Astrophysical Journal, 889, 185.

111. Kritcher, A. L., Swift, D. C., Döppner, T., Bachmann, B., Benedict, L. X., Collins, G. W., DuBois, J. L., Elsner, F., Fontaine, G., Gaffney, J. A., Hamel, S., Lazicki, A., Johnson, W. R., Kostinski, N., Kraus, D., MacDonald, M. J., Maddox, B., Martin, M. E., Neumayer, P., Nikroo, A., Nilsen, J., Remington, B. A., Saumon, D., Sterne, P. A., Sweet, W., Correa, A. A., Whitley, H. D., Falcone, R. W., Glenzer, S. H. (2020) "A measurement of the equation of state of carbon envelopes of white dwarfs", Nature, 584, 51.

112. Krumholz, M. R., Crocker, R. M., Xu, S., Lazarian, A., Rosevear, M. T., Bedwell-Wilson, J. (2020) "Cosmic ray transport in starburst galaxies", Monthly Notices of the Royal Astronomical Society, 493, 2817.

113. Krumholz, M. R., Ireland, M. J., Kratter, K. M. (2020) "Dynamics of small grains in transitional discs", Monthly Notices of the Royal Astronomical Society, 498, 3023.

114. Krumholz, M. R., McKee, C. F. (2020) "How do bound star clusters form?", Monthly Notices of the Royal Astronomical Society, 494, 624.

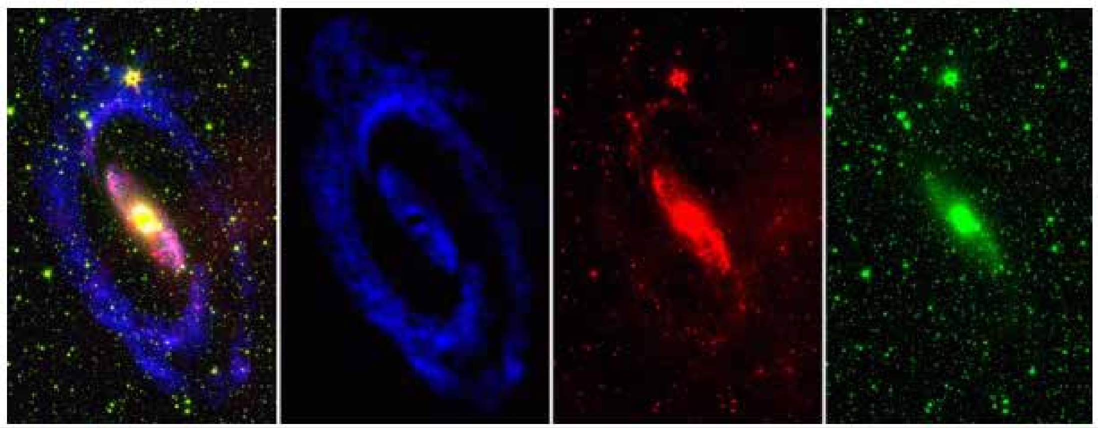
115. Kuo, C. Y., Hsiang, J. Y., Chung, H. H., Constantin, A., Chang, Y.-Y., Cunha, E. da ., Pesce, D., Chien, W. T., Chen, B. Y., Braatz, J. A., Zaw, I., Matsushita, S., Lin, J. C. (2020) "A More Efficient Search for H2O Megamaser Galaxies: The Power of X-Ray and Mid-infrared Photometry", The Astrophysical Journal, 892, 18.

116. Lagos, C. del P., da Cunha, E., Robotham, A. S. G., Obreschkow, D., Valentino, F., Fujimoto, S., Magdis, G. E., Tobar, R. (2020) "Physical properties and evolution of (sub-)millimetre-selected galaxies in the galaxy formation simulation SHARK", Monthly Notices of the Royal Astronomical Society, 499, 1948.

117. Li, J., Obreschkow, D., Lagos, C., Cortese, L., Welker, C., Džudžar, R. (2020) "Angular momentum-related probe of cold gas deficiencies", Monthly Notices of the Royal Astronomical Society, 493, 5024.

118. Lin, J., Asplund, M., Ting, Y.-S., Casagrande, L., Buder, S., Bland-Hawthorn, J., Casey, A. R., De Silva, G. M., D'Orazi, V., Freeman, K. C., Kos, J., Lind, K., Martell, S. L., Sharma, S., Simpson, J. D., Zwitter, T., Zucker, D. B., Minchev, I., Čotar, K., Hayden, M., Horner, J., Lewis, G. F., Nordlander, T., Wyse, R. F. G., Žerjal, M. (2020)

Figure 11 from Koribalski et al (2020) (no. 109): The inner disk of the nearby Circinus Galaxy as observed by the ATCA in H i (blue) and the Spitzer Space Telescope at 8µm (red; warm dust) and 3.4µm (green; stars). The three-colour composite image is shown on the left, emphasizing the need for multi-wavelength observations in studying galaxies. For details see For et al. (2012) and Koribalski et al. (2018).



2020 PUBLICATIONS

"The GALAH survey: temporal chemical enrichment of the galactic disc", Monthly Notices of the Royal Astronomical Society, 491, 2043.

119. Line, J. L. B., Mitchell, D. A., Pindor, B., Riding, J. L., McKinley, B., Webster, R. L., Trott, C. M., Hurley-Walker, N., Offringa, A. R. (2020) "Modelling and peeling extended sources with shapelets: A Fornax A case study", Publications of the Astronomical Society of Australia, 37, e027.

120. List, F., Elahi, P. J., Lewis, G. F. (2020) "Lux Ex Tenebris: The Imprint of Annihilating Dark Matter on the Intergalactic Medium during Cosmic Dawn", The Astrophysical Journal, 904, 153.

121. Liu, F., Yong, D., Asplund, M., Wang, H. S., Spina, L., Acuña, L., Meléndez, J., Ramírez, I. (2020) "Detailed chemical compositions of planet-hosting stars - I. Exploration of possible planet signatures", Monthly Notices of the Royal Astronomical Society, 495, 3961.

122. Lugaro, M., Cseh, B., Világos, B., Karakas, A. I., Ventura, P., Dell'Agli, F., Trappitsch, R., Hampel, M., D'Orazi, V., Pereira, C. B., Tagliente, G., Szabó, G. M., Pignatari, M., Battino, U., Tattersall, A., Ek, M., Schönbächler, M., Hron, J., Nittler, L. R. (2020) "Origin of Large Meteoritic SiC Stardust Grains in Metal-rich AGB Stars", The Astrophysical Journal, 898, 96.

123. Lutz, K. A., Kilborn, V., Catinella, B., Cortese, L., Brown, T. H., Koribalski, B. (2020) "The H IX galaxy survey. III. The gas-phase metallicity in H I eXtreme galaxies", Astronomy and Astrophysics, 635, A69.

124. Magg, M., Nordlander, T., Glover, S. C. O., Hansen, C. J., Ishigaki, M., Heger, A., Klessen, R. S., Kobayashi, C., Nomoto, K. (2020) "A minimum dilution scenario for supernovae and consequences for extremely metal-poor stars", Monthly Notices of the Royal Astronomical Society, 498, 3703.

125. Mandel, I., Müller, B. (2020) "Simple recipes for compact remnant masses and natal kicks", Monthly Notices of the Royal Astronomical Society, 499, 3214.

126. Marshall, M. A., Mechtley, M., Windhorst, R. A., Cohen, S. H., Jansen, R. A., Jiang, L., Jones, V. R., Wyithe, J. S. B., Fan, X., Hathi, N. P., Jahnke, K., Keel, W. C., Koekemoer, A. M., Marian, V., Ren, K., Robinson, J., Röttgering, H. J. A., Ryan, R. E., Scannapieco, E., Schneider, D. P., Schneider, G., Smith, B. M., Yan, H. (2020) "Limits to Rest-frame Ultraviolet Emission from Far-infrared-luminous $z \sim 6$ Quasar Hosts", The Astrophysical Journal, 900, 21.

127. Marshall, M. A., Mutch, S. J., Qin, Y., Poole, G. B., Wyithe, J. S. B. (2020) "Dark-ages reionisation and galaxy formation simulation - XVIII. The high-redshift evolution of black holes and their host galaxies", Monthly Notices of the Royal Astronomical Society, 494, 2747.

128. Marshall, M. A., Ni, Y., Di Matteo, T., Wyithe, J. S. B., Wilkins, S., Croft, R. A. C., Kuusisto, J. K. (2020) "The host galaxies of $z = 7$ quasars: predictions from the BLUETIDES simulation", Monthly Notices of the Royal Astronomical Society, 499, 3819.

129. McLeod, A. F., Kruijssen, J. M. D., Weisz, D. R., Zeidler, P., Schruba, A., Dalcanton, J. J., Longmore, S. N., Chevance, M., Faesi, C. M., Byler, N. (2020) "Stellar Feedback and Resolved Stellar IFU Spectroscopy in the Nearby Spiral Galaxy NGC 300", The Astrophysical Journal, 891, 25.

130. Mendel, J. T., Beifiori, A., Saglia, R. P., Bender, R., Brammer, G. B., Chan, J., Förster Schreiber, N. M., Fossati, M., Galametz, A., Momcheva, I. G., Nelson, E. J., Wilman, D. J., Wuyts, S. (2020) "The Kinematics of Massive Quiescent Galaxies at $1.4 < z < 2.1$: Dark Matter Fractions, IMF Variation, and the Relation to Local Early-type Galaxies", The Astrophysical Journal, 899, 87.

131. Metha, B., Trenti, M. (2020) "One star, two stars, or both? Investigating metallicity-dependent models for gamma-ray burst progenitors with the IllustrisTNG simulation", Monthly Notices of the Royal Astronomical Society, 495, 266.

132. Meyer, R. A., Kakiichi, K., Bosman, S. E. I., Ellis, R. S., Laporte, N., Robertson, B. E., Ryan-Weber, E. V., Mawatari, K., Zitrin, A. (2020) "The role of galaxies and AGN in reionizing the IGM - III. IGM-galaxy cross-correlations at $z \sim 6$ from eight quasar fields with DEIMOS and MUSE", Monthly Notices of the Royal Astronomical Society, 494, 1560.

133. Meštrić, U., Ryan-Weber, E. V., Cooke, J., Bassett, R., Sawicki, M., Faisst, A. L., Kakiichi, K., Inoue, A. K., Rafelski, M., Prichard, L. J., Arnouts, S., Moutard, T., Coupon, J., Golob, A., Gwyn, S. (2020) "Outside the Lyman-break box: detecting Lyman continuum emitters at $3.5 < z < 5.1$ with CLAUDS", Monthly Notices of the Royal Astronomical Society, 494, 4986.

134. Morishita, T., Stiavelli, M., Trenti, M., Treu, T., Roberts-Borsani, G. W., Mason, C. A., Hashimoto, T., Bradley, L., Coe, D., Ishikawa, Y. (2020) "SuperBoRG: Exploration of Point Sources at $z \sim 8$ in HST Parallel Fields", The Astrophysical Journal, 904, 50.

135. Mura-Guzmán, A., Yong, D., Abate, C., Karakas, A., Kobayashi, C., Oh, H., Chun, S.-H., Mace, G. (2020) "Constraining nucleosynthesis in two CEMP progenitors using fluorine", Monthly Notices of the Royal Astronomical Society, 498, 3549.

136. Murphy, S. J., Lawson, W. A., Onken, C. A., Yong, D., Da Costa, G. S., Zhou, G., Mamajek, E. E., Bell, C. P. M., Bessell, M. S., Feinstein, A. D. (2020) "THOR 42: A touchstone ~24 Myr-old

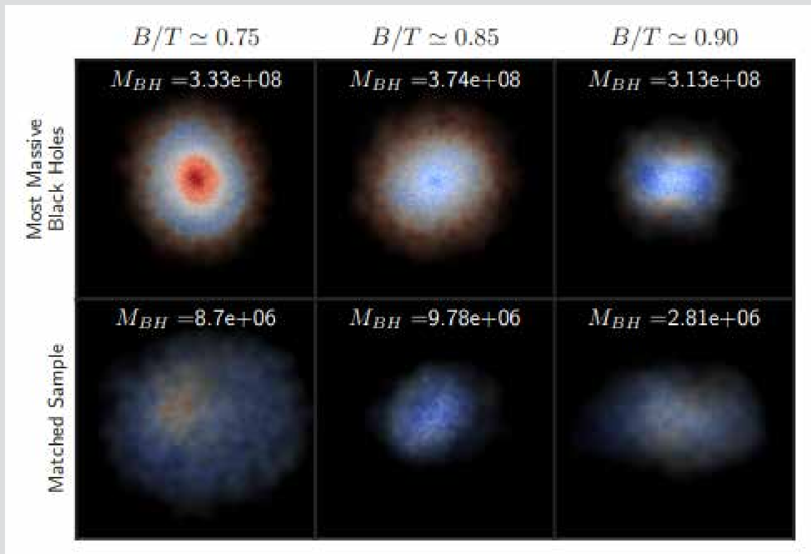


Figure 11 from Marshall et al (2019) (no. 128): The stellar mass distribution of three BlueTides galaxies from the most massive black hole sample, alongside a matched sample of galaxies with a similar stellar mass and bulgeto-total ratio, but low black hole masses. Each galaxy is viewed face-on, with a field-of-view of 3 × 3 kpc. The colour depicts the age of the stellar population, from bluest (≤ 20 Myr) to reddest (≥ 220 Myr), with a linear scale.

eclipsing binary spanning the fully convective boundary", Monthly Notices of the Royal Astronomical Society, 491, 4902.

137. Murray, S., Greig, B., Mesinger, A., Muñoz, J., Qin, Y., Park, J., Watkinson, C. (2020) "21cmFAST v3: A Python-integrated C code for generating 3D realizations of the cosmic 21cm signal.", The Journal of Open Source Software, 5, 2582.

138. Murugeshan, C., Kilborn, V., Jarrett, T., Wong, O. I., Obreschkow, D., Glazebrook, K., Cluver, M. E., Fluke, C. J. (2020) "The influence of angular momentum and environment on the H I gas of late-type galaxies", Monthly Notices of the Royal Astronomical Society, 496, 2516.

139. Nanayakkara, T., Brinchmann, J., Glazebrook, K., Bouwens, R., Kewley, L., Tran, K.-V., Cowley, M., Fisher, D., Kacprzak, G. G., Labbe, I., Straatman, C. (2020) "Reconstructing the Observed Ionizing Photon Production Efficiency at z ~ 2 Using Stellar Population Models", The Astrophysical Journal, 889, 180.

140. Nasirudin, A., Iliev, I. T., Ahn, K. (2020) "Modelling the stochasticity of high-redshift halo bias", Monthly Notices of the Royal Astronomical Society, 494, 3294.

141. Nasirudin, A., Murray, S. G., Trott, C. M., Greig, B., Joseph, R. C., Power, C. (2020) "The Impact of Realistic Foreground and Instrument Models on 21 cm Epoch of Reionisation Experiments", The Astrophysical Journal, 893, 118.

142. Nicholls, D. C., Kewley, L. J., Sutherland, R. S. (2020) "Estimating Electron Temperatures in Ionized Nebulae: The Direct Method and its Limitations", Publications of the Astronomical Society of the Pacific, 132, 033001.

143. Nielsen, N. M., Kacprzak, G. G., Pointon, S. K., Murphy, M. T., Churchill, C. W., Davé, R. (2020) "The CGM at Cosmic Noon with KCWI: Outflows from a Star-forming Galaxy at z = 2.071", The Astrophysical Journal, 904, 164.

144. Nunhokee, C. D., Parsons, A. R., Kern, N. S., Nikolic, B., Pober, J. C., Bernardi, G., Carilli, C. L., Abdurashidova, Z., Aguirre, J. E., Alexander, P., Ali, Z. S., Balfour, Y., Beardsley, A. P., Billings, T. S., Bowman, J. D., Bradley, R. F., Burba, J., Cheng, C., DeBoer, D. R., Dexter, M., de Lera Acedo, E., Dillon, J. S., Ewall-Wice, A., Fagnoni, N., Fritz, R., Furlanetto, S. R., Gale-Sides, K., Glendenning, B., Gorthi, D., Greig, B., Grobbelaar, J., Halday, Z., Hazelton, B. J., Hewitt, J. N., Jacobs, D. C., Julius, A., Kerrigan, J., Kittiwisit, P., Kohn, S. A., Kolopanis, M., Lanman, A., L Plante, P., Lekalake, T., Liu, A., MacMahon, D., Malan, L., Malgas, C., Maree, M., Martinot, Z. E., Matsetela, E., and 17 colleagues (2020) "Measuring HERA's Primary Beam in Situ: Methodology and First Results", The Astrophysical Journal, 897, 5.

145. Obreschkow, D., Elahi, P. J., Lagos, C. del P., Poulton, R. J. J., Ludlow, A. D. (2020) "Characterizing the structure of halo merger trees using a single parameter: the tree entropy", Monthly Notices of the Royal Astronomical Society, 493, 4551.

146. Oh, S., Colless, M., Barsanti, S., Casura, S., Cortese, L., van de Sande, J., Owers, M. S., Scott, N., D'Eugenio, F., Bland-Hawthorn, J., Brough, S., Bryant, J. J., Croom, S. M., Foster, C., Groves, B., Lawrence, J. S., Richards, S. N., Sweet, S. M. (2020) "The SAMI Galaxy Survey: decomposed stellar kinematics of galaxy bulges and disks", Monthly Notices of the Royal Astronomical Society, 495, 4638.

147. Pan, H., Obreschkow, D., Howlett, C., Lagos, C. del P., Elahi, P. J., Baugh, C., Gonzalez-Perez, V. (2020) "Multiwavelength consensus of large-scale linear bias", Monthly Notices of the Royal Astronomical Society, 493, 747.

148. Park, J., Gillet, N., Mesinger, A., Greig, B. (2020) "Properties of reionisation-era galaxies from JWST luminosity functions and 21-cm interferometry", Monthly Notices of the Royal Astronomical Society, 491, 3891.

149. Pointon, S. K., Kacprzak, G. G., Nielsen, N. M., Murphy, M. T., Muzahid, S., Churchill, C. W., Charlton, J. C. (2020) "Low-mass Group Environments Have No Substantial Impact on the Circumgalactic Medium Metallicity", The Astronomical Journal, 159, 216.

150. Poulton, R. J. J., Power, C., Robotham, A. S. G., Elahi, P. J. (2020) "Extracting galaxy merger time-scales - I. Tracking haloes with WHEREWOLF and spinning orbits with ORBWEAVER", Monthly Notices of the Royal Astronomical Society, 491, 3820.

151. Power, C., Elahi, P. J., Welker, C., Knebe, A., Pearce, F. R., Yepes, G., Davé, R., Kay, S. T., McCarthy, I. G., Puchwein, E., Borgani, S., Cunnama, D., Cui, W., Schaye, J. (2020) "NIFTY galaxy cluster simulations - VI. The dynamical imprint of substructure on gaseous cluster outskirts", Monthly Notices of the Royal Astronomical Society, 491, 3923.

152. Qin, Y., Mesinger, A., Park, J., Greig, B., Muñoz, J. B. (2020) "A tale of two sites - I. Inferring the properties of minihalo-hosted galaxies from current observations", Monthly Notices of the Royal Astronomical Society, 495, 123.

153. Qin, Y., Poulin, V., Mesinger, A., Greig, B., Murray, S., Park, J. (2020) "Reionisation inference from the CMB optical depth and E-mode polarization power spectra", Monthly Notices of the Royal Astronomical Society, 499, 550.

154. Rains, A. D., Ireland, M. J., White, T. R., Casagrande, L., Karovicova, I. (2020) "Precision angular diameters for 16 southern stars with VLTI/PIONIER", Monthly Notices of the Royal Astronomical Society, 493, 2377.

155. Rawlings, A., Foster, C., van de Sande, J., Taranu, D. S., Croom, S. M., Bland-Hawthorn, J., Brough, S., Bryant, J. J., Colless, M., Lagos, C. del P., Konstantopoulos, I. S., Lawrence, J. S., López-Sánchez, Á. R., Lorente, N. P. F., Medling, A. M., Oh, S., Owers, M. S., Richards, S. N., Scott, N., Sweet, S. M., Yi, S. K. (2020) "The SAMI Galaxy Survey: rules of behaviour for spin-ellipticity radial tracks in galaxies", Monthly Notices of the Royal Astronomical Society, 491, 324.

156. Reggiani, H., Schlaufman, K. C., Casey, A. R., Ji, A. P. (2020) "The Most Metal-poor Stars in the Inner Bulge", The Astronomical Journal, 160, 173.

157. Ren, K., Trenti, M., Di Matteo, T. (2020) "Stochastic Processes as the Origin of the Double Power-law Shape of the Quasar Luminosity Function", The Astrophysical Journal, 894, 124.

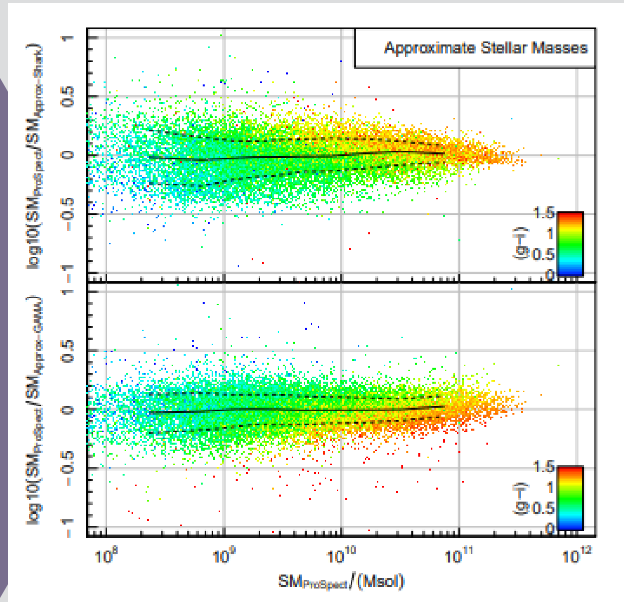
158. Reynolds, T. N., Westmeier, T., Staveley-Smith, L. (2020) "H I deficiencies and asymmetries in HIPASS galaxies", Monthly Notices of the Royal Astronomical Society, 499, 3233.

159. Reynolds, T. N., Westmeier, T., Staveley-Smith, L., Chauhan, G., Lagos, C. D. P. (2020) "H I asymmetries in LVHIS, VIVA, and HALOGAS galaxies", Monthly Notices of the Royal Astronomical Society, 493, 5089.

160. Ridden-Harper, R., Tucker, B. E., Gully-Santiago, M., Barentsen, G., Rest, A., Garnavich, P., Shaya, E. (2020) "K2: Background Survey - the search for undiscovered transients in Kepler/K2 data", Monthly Notices of the Royal Astronomical Society, 498, 33.

161. Riechers, D. A., Hodge, J. A., Pavesi, R., Daddi, E., Decarli, R., Ivison, R. J., Sharon, C. E., Smail, I., Walter, F., Aravena, M., Capak, P. L., Carilli, C. L., Cox, P., Cunha, E. da ., Dannerbauer, H., Dickinson, M., Neri, R., Wagg, J. (2020) "COLDz: A High Space Density of Massive Dusty Starburst Galaxies ~1 Billion Years after the Big Bang", The Astrophysical Journal, 895, 81.

Figure 35 from Rowbotham et al (2020) (no. 162): In this Figure we compare the Shark-derived (top) and GAMA-derived (bottom) Ks & g − i approximate stellar masses against their fully fitted GAMA ProSpect counterparts. In general they agree fairly well in the quality of the prediction throughout the stellar mass range that GAMA is sensitive to. These approximations should be used with caution below $10^8 M_\odot$. There are g − i gradients present for both approximate methods but in opposite direction, where Shark calibrations tend to be too massive for bluer colours and GAMA calibrations tend to be too massive for redder colours.



162. Robotham, A. S. G., Bellstedt, S., Lagos, C. del P., Thorne, J. E., Davies, L. J., Driver, S. P., Bravo, M. (2020) "ProSpect: generating spectral energy distributions with complex star formation and metallicity histories", Monthly Notices of the Royal Astronomical Society, 495, 905.

163. Roederer, I. U., Lawler, J. E., Holmbeck, E. M., Beers, T. C., Ezzeddine, R., Frebel, A., Hansen, T. T., Ivans, I. I., Karakas, A. I., Placco, V. M., Sakari, C. M. (2020) "Detection of Pb II in the Ultraviolet Spectra of Three Metal-poor Stars", The Astrophysical Journal, 902, L24.

164. Rosen, A. L., Krumholz, M. R. (2020) "The Role of Outflows, Radiation Pressure, and Magnetic Fields in Massive Star Formation", The Astronomical Journal, 160, 78.

165. Roy, A., Sutherland, R. S., Krumholz, M. R., Heger, A., Dopita, M. A. (2020) "Helium and nitrogen enrichment in massive main-sequence stars: mechanisms and implications for the origin of WNL stars", Monthly Notices of the Royal Astronomical Society, 494, 3861.

166. Rybizki, J., Demleitner, M., Bailer-Jones, C., Tio, P. D., Cantat-Gaudin, T., Fouesneau, M., Chen, Y., Andrae, R., Girardi, L., Sharma, S. (2020) "A Gaia Early DR3 Mock Stellar Catalog: Galactic Prior and Selection Function", Publications of the Astronomical Society of the Pacific, 132, 074501.

167. Sadler, E. M., Moss, V. A., Allison, J. R., Mahony, E. K., Whiting, M. T., Johnston, H. M., Ellison, S. L., Lagos, C. del P., Koribalski, B. S. (2020) "A successful search for intervening 21 cm H I absorption in galaxies at 0.4 < z <1.0 with the Australian square kilometre array pathfinder (ASKAP)", Monthly Notices of the Royal Astronomical Society, 499, 4293.

168. Salim, D. M., Alatalo, K., Federrath, C., Groves, B., Kewley, L. J. (2020) "Spinning Bar and a Star-formation Inefficient Repertoire: Turbulence in Hickson Compact Group NGC 7674", The Astrophysical Journal, 893, 26.

169. Sano, H., Plucinsky, P. P., Bamba, A., Sharda, P., Filipović, M. D., Law, C. J., Alsaberi, R. Z. E., Yamane, Y., Tokuda, K., Acero, F., Sasaki, M., Vink, J., Inoue, T., Inutsuka, S., Shimoda, J., Tsuge, K., Fujii, K., Voisin, F., Maxted, N., Rowell, G., Onishi, T., Kawamura, A., Mizuno, N., Yamamoto, H., Tachihara, K., Fukui, Y. (2020) "ALMA CO Observations of Gamma-Ray Supernova Remnant N132D in the Large Magellanic Cloud: Possible Evidence for Shocked Molecular Clouds Illuminated by Cosmic-Ray Protons", The Astrophysical Journal, 902, 53.

170. Santistevan, I. B., Wetzel, A., El-Badry, K., Bland-Hawthorn, J., Boylan-Kolchin, M., Bailin, J., Faucher-Giguère, C.-A., Benincasa, S. (2020) "The formation times and building blocks of Milky Way-mass galaxies in the FIRE simulations", Monthly Notices of the Royal Astronomical Society, 497, 747.

171. Santos, S., Sobral, D., Matthee, J., Calhau, J., da Cunha, E., Ribeiro, B., Paulino-Afonso, A., Arrabal Haro, P., Butterworth, J. (2020) "The evolution of rest-frame UV properties, Ly α EWs, and the SFR-stellar mass relation at z ˜ 2-6 for SC4K LAEs", Monthly Notices of the Royal Astronomical Society, 493, 141.

172. Santucci, G., Brough, S., Scott, N., Montes, M., Owers, M. S., van Sande, J., Bland-Hawthorn, J., Bryant, J. J., Croom, S. M., Ferreras, I., Lawrence, J. S., López-Sánchez, Á. R., Richards, S. N. (2020) "The SAMI Galaxy Survey: Stellar Population Gradients of Central Galaxies", The Astrophysical Journal, 896, 75.

173. Satpathy, S., An, Z., Croft, R. A. C., Di Matteo, T., Tenneti, A., Feng, Y., Heitmann, K., Rossi, G. (2020) "On the possibility of baryon acoustic oscillation measurements at redshift z > 7.6 with the Roman space telescope", Monthly Notices of the Royal Astronomical Society, 498, 4955.

174. Scott, N., Eftekhari, F. S., Peletier, R. F., Bryant, J. J., Bland-Hawthorn, J., Capaccioli, M., Croom, S. M., Drinkwater, M., Falcón-Barroso, J., Hilker, M., Iodice, E., Lorente, N. F. P., Mieske, S., Spavone, M., van de Ven, G., Venhola, A. (2020) "The SAMI-Fornax Dwarfs Survey I: sample, observations, and the specific stellar angular momentum of dwarf elliptical galaxies", Monthly Notices of the Royal Astronomical Society, 497, 1571.

175. Shabala, S. S., Jurlin, N., Morganti, R., Brienza, M., Hardcastle, M. J., Godfrey, L. E. H., Krause, M. G. H., Turner, R. J. (2020) "The duty cycle of radio galaxies revealed by LOFAR: remnant and restarted radio source populations in the Lockman Hole", Monthly Notices of the Royal Astronomical Society, 496, 1706.

176. Sharda, P., Federrath, C., Krumholz, M. R. (2020) "The importance of magnetic fields for the initial mass function of the first stars", Monthly Notices of the Royal Astronomical Society, 497, 336.

177. Sharda, P., Gaetz, T. J., Kashyap, V. L., Plucinsky, P. P. (2020) "Spatially Resolved Chandra Spectroscopy of the Large Magellanic Cloud Supernova Remnant N132D", The Astrophysical Journal, 894, 145.

178. Sharma, M., Theuns, T. (2020) "The Iκεα model of feedback-regulated galaxy formation", Monthly Notices of the Royal Astronomical Society, 492, 2418.

179. Simpson, J. D., Martell, S. L., Da Costa, G., Horner, J., Wyse, R. F. G., Ting, Y.-S., Asplund, M., Bland-Hawthorn, J., Buder, S., De Silva, G. M., Freeman, K. C., Kos, J., Lewis, G. F., Lind, K., Sharma, S., Zucker, D. B., Zwitter, T., Čotar, K., Cottrell, P. L., Nordlander, T. (2020) "The GALAH Survey: Chemically tagging the Fimbulthul stream to the globular cluster ω Centauri", Monthly Notices of the Royal Astronomical Society, 491, 3374.

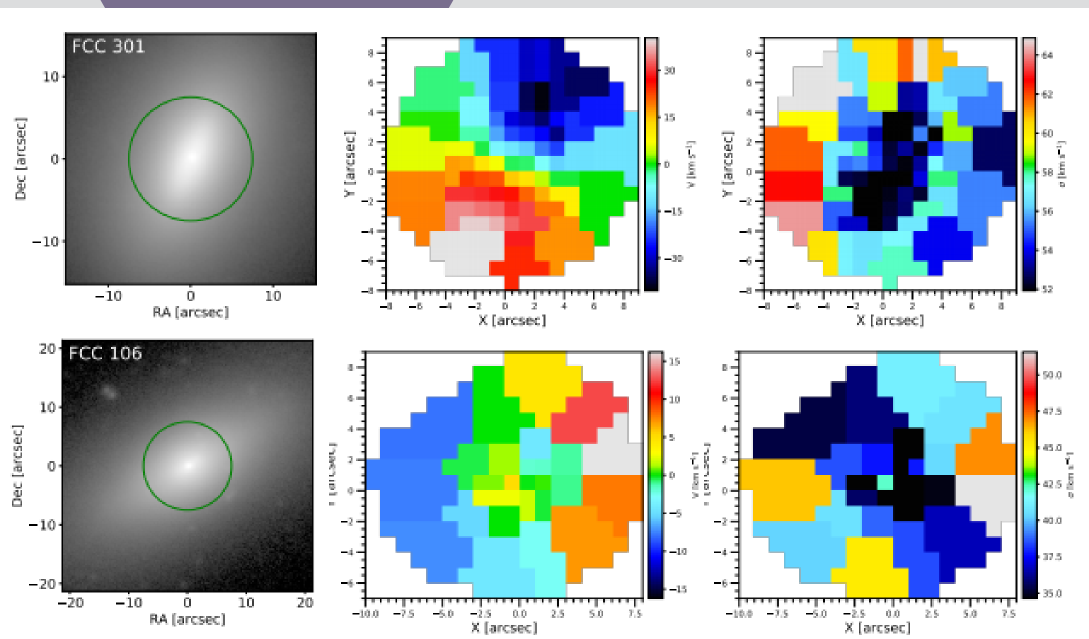
180. Sinha, M., Garrison, L. H. (2020) "CORRFUNC - a suite of blazing fast correlation functions on the CPU", Monthly Notices of the Royal Astronomical Society, 491, 3022.

2020 PUBLICATIONS

181. Sokolowski, M., Jordan, C. H., Sleap, G., Williams, A., Wayth, R. B., Walker, M., Pallot, D., Offringa, A., Hurley-Walker, N., Franzen, T. M. O., Johnston-Hollitt, M., Kaplan, D. L., Kenney, D., Tingay, S. J. (2020) “Calibration database for the Murchison Widefield Array All-Sky Virtual Observatory”, Publications of the Astronomical Society of Australia, 37, e021.

182. Spina, L., Nordlander, T., Casey, A. R., Bedell, M., D’Orazi, V., Meléndez, J., Karakas, A. I., Desidera, S., Baratella, M., Yana Galarza, J. J., Casali, G. (2020) “How Magnetic Activity Alters What We Learn from Stellar Spectra”, The Astrophysical Journal, 895, 52.

Figure from Scott et al (2020) (no. 174): Stellar kinematic maps for two example dE galaxies. Upper row: FCC301, a galaxy exhibiting strong, ordered rotation. Lower row: FCC106, a dispersion dominated system with minimal rotation. Left column: r-band cutout images from FDS, with diameter 4 R_e. Green circle indicates the approximate position of the SAMI IFS field-of-view. Centre column: Voronoi-binned maps of the mean line-of-sight stellar velocity, V. Right column: Voronoi-binned maps of the mean line-of-sight stellar velocity dispersion, σ.



183. Steinhardt, C. L., Jauzac, M., Acebron, A., Atek, H., Capak, P., Davidzon, I., Eckert, D., Harvey, D., Koekemoer, A. M., Lagos, C. D. P., Mahler, G., Montes, M., Niemiec, A., Nonino, M., Oesch, P. A., Richard, J., Rodney, S. A., Schaller, M., Sharon, K., Strolger, L.-G., Allingham, J., Amara, A., Bahé, Y., Bœhm, C., Bose, S., Bouwens, R. J., Bradley, L. D., Brammer, G., Broadhurst, T., Cañas, R., Cen, R., Clément, B., Clowe, D., Coe, D., Connor, T., Darvish, B., Diego, J. M., Ebeling, H., Edge, A. C., Egami, E., Ettori, S., Faisst, A. L., Frye, B., Furtak, L. J., Gómez-Guijarro, C., Remolina González, J. D., Gonzalez, A., Graur, O., Gruen, D., Harvey, D., and 45 colleagues (2020) “The BUFFALO HST Survey”, The Astrophysical Journal Supplement Series, 247, 64.

184. Stevens, A. R. H., Bellstedt, S., Elahi, P. J., Murphy, M. T. (2020) “The imperative to reduce carbon emissions in astronomy”, Nature Astronomy, 4, 843.

185. Stockinger, G., Janka, H.-T., Kresse, D., Melson, T., Ertl, T., Gabler, M., Gessner, A., Wongwathanarat, A., Tolstov, A., Leung, S.-C., Nomoto, K., Heger, A. (2020) “Three-dimensional models of core-collapse supernovae from low-mass progenitors with implications for Crab”, Monthly Notices of the Royal Astronomical Society, 496, 2039.

186. Stockmann, M., Toft, S., Gallazzi, A., Zibetti, S., Conselice, C. J., Margalef-Bentabol, B., Zabl, J., Jørgensen, I., Magdis, G. E., Gómez-Guijarro, C., Valentino, F. M., Brammer, G. B., Ceverino, D., Cortzen, I., Davidzon, I., Demarco, R., Faisst, A., Hirschmann, M., Krogager, J.-K., Lagos, C. D., Man, A. W. S., Mundy, C. J., Peng, Y., Selsing, J., Steinhardt, C. L., Whitaker, K. E. (2020) “X-shooter Spectroscopy and HST Imaging of 15 Massive Quiescent Galaxies at z ~ 2”, The Astrophysical Journal, 888, 4.

187. Sweet, S. M., Glazebrook, K., Obreschkow, D., Fisher, D. B., Burkert, A., Lagos, C. D. P., Espejo Salcedo, J. M. (2020) “Stellar angular momentum distribution linked to galaxy morphology”, Monthly Notices of the Royal Astronomical Society, 494, 5421.

188. Tadaki, K.-. ichi ., Belli, S., Burkert, A., Dekel, A., Förster Schreiber, N. M., Genzel, R., Hayashi, M., Herrera-Camus, R., Kodama, T., Kohno, K., Koyama, Y., Lee, M. M., Lutz, D., Mowla, L., Nelson, E. J., Renzini, A., Suzuki, T. L., Tacconi, L. J., Übler, H., Wisnioski, E., Wuyts, S. (2020) “Structural Evolution in Massive Galaxies at z ~ 2”, The Astrophysical Journal, 901, 74.

189. Tang, H., Scaife, A. M. M., Wong, O. I., Kapińska, A. D., Rudnick, L., Shabala, S. S., Seymour, N., Norris, R. P. (2020) “Radio Galaxy Zoo: new giant radio galaxies in the RGZ DR1 catalogue”, Monthly Notices of the Royal Astronomical Society, 499, 68.

190. Taylor, P., Kobayashi, C., Kewley, L. J. (2020) “Oxygen loss from simulated galaxies and the metal flow main sequence: predicting the dependence on mass and environment”, Monthly Notices of the Royal Astronomical Society, 496, 4433.

191. Tepper-García, T., Bland-Hawthorn, J., Li, D. (2020) “The M31/M33 tidal interaction: a hydrodynamic simulation of the extended gas distribution”, Monthly Notices of the Royal Astronomical Society, 493, 5636.

192. Tiley, A. L., Vaughan, S. P., Stott, J. P., Davies, R. L., Prichard, L. J., Bunker, A., Bureau, M., Cappellari, M., Jarvis, M., Robotham, A., Cortese, L., Bellstedt, S., Ansarinejad, B. (2020) “K-CLASH: spatially resolving star-forming galaxies in field and cluster environments at z ~ 0.2-0.6”, Monthly Notices of the Royal Astronomical Society, 496, 649.

193. Tran, K.-V. H., Forrest, B., Alcorn, L. Y., Yuan, T., Nanayakkara, T., Cohn, J., Cowley, M., Glazebrook, K., Gupta, A., Kacprzak, G. G., Kewley, L., Labbé, I., Papovich, C., Spitler, L., Straatman, C. M. S., Tomczak, A. (2020) “MOSEL: Strong [OIII] 5007 Å Emitting Galaxies at (3 < z < 4) from the ZFOURGE Survey”, The Astrophysical Journal, 898, 45.

194. Traven, G., Feltzing, S., Merle, T., Van der Swaelmen, M., Čotar, K., Church, R., Zwitter, T., Ting, Y.-S., Sahlholdt, C., Asplund, M., Bland-Hawthorn, J., De Silva, G., Freeman, K., Martell, S., Sharma, S., Zucker, D., Buder, S., Casey, A., D’Orazi, V., Kos, J., Lewis, G., Lin, J., Lind, K., Simpson, J., Stello, D., Munari, U., Wittenmyer, R. A. (2020) “The GALAH survey: multiple stars and our Galaxy. I. A comprehensive method for deriving properties of FGK binary stars”, Astronomy and Astrophysics, 638, A145.

195. Trayford, J. W., Lagos, C. del P., Robotham, A. S. G., Obreschkow, D. (2020) “Fade to grey: systematic variation of galaxy attenuation curves with galaxy properties in the EAGLE simulations”, Monthly Notices of the Royal Astronomical Society, 491, 3937.

2020 PUBLICATIONS

196. Triani, D. P., Sinha, M., Croton, D. J., Pacifici, C., Dwek, E. (2020) "The origin of dust in galaxies across cosmic time", Monthly Notices of the Royal Astronomical Society, 493, 2490.

197. Troncoso-Iribarren, P., Padilla, N., Santander, C., Lagos, C. D. P., García-Lambas, D., Rodríguez, S., Contreras, S. (2020) "The better half - asymmetric star formation due to ram pressure in the EAGLE simulations", Monthly Notices of the Royal Astronomical Society, 497, 4145.

198. Trott, C. M., Jordan, C. H., Midgley, S., Barry, N., Greig, B., Pindor, B., Cook, J. H., Sleap, G., Tingay, S. J., Ung, D., Hancock, P., Williams, A., Bowman, J., Byrne, R., Chokshi, A., Hazelton, B. J., Hasegawa, K., Jacobs, D., Joseph, R. C., Li, W., Line, J. L. B., Lynch, C., McKinley, B., Mitchell, D. A., Morales, M. F., Ouchi, M., Pober, J. C., Rahimi, M., Takahashi, K., Wayth, R. B., Webster, R. L., Wilensky, M., Wyithe, J. S. B., Yoshiura, S., Zhang, Z., Zheng, Q. (2020) "Deep multiredshift limits on Epoch of Reionisation 21 cm power spectra from four seasons of Murchison Widefield Array observations", Monthly Notices of the Royal Astronomical Society, 493, 4711.

199. Turner, R. J., Drouart, G., Seymour, N., Shabala, S. S. (2020) "RAiSERed: radio continuum redshifts for lobed active galactic nuclei", Monthly Notices of the Royal Astronomical Society, 499, 3660.

200. Turner, R. J., Shabala, S. S. (2020) "RAiSE X: searching for radio galaxies in X-ray surveys", Monthly Notices of the Royal Astronomical Society, 493, 5181.

201. van der Velden, E. (2020) "CMasher: Scientific colormaps for making accessible, informative and 'cmashing' plots", The Journal of Open Source Software, 5, 2004.

202. Varidel, M. R., Croom, S. M., Lewis, G. F., Fisher, D. B., Glazebrook, K., Catinella, B., Cortese, L., Krumholz, M. R., Bland-Hawthorn, J., Bryant, J. J., Groves, B., Brough, S., Federrath, C., Lawrence, J. S., Lorente, N. P., Owers, M. S., Richards, S. N., López-Sánchez, Á. R., Sweet, S. M., van de Sande, J., Vaughan, S. P. (2020) "The SAMI galaxy survey: gas velocity dispersions in low-z star-forming galaxies and the drivers of turbulence", Monthly Notices of the Royal Astronomical Society, 495, 2265.

203. Vaughan, S. P., Tiley, A. L., Davies, R. L., Prichard, L. J., Croom, S. M., Bureau, M., Stott, J. P., Bunker, A., Cappellari, M., Ansarinejad, B., Jarvis, M. J. (2020) "K-CLASH: Strangulation and ram pressure stripping in galaxy cluster members at 0.3 < z < 0.6", Monthly Notices of the Royal Astronomical Society, 496, 3841.

204. Wan, Z., Lewis, G. F., Li, T. S., Simpson, J. D., Martell, S. L., Zucker, D. B., Mould, J. R., Erkal, D., Pace, A. B., Mackey, D., Ji, A. P., Koposov, S. E., Kuehn, K., Shipp, N., Balbinot, E., Bland-Hawthorn, J., Casey, A. R., Da Costa, G. S., Kafle, P., Sharma, S., De Silva, G. M. (2020) "The tidal remnant of an unusually metal-poor globular cluster", Nature, 583, 768.

205. Wang, J., Catinella, B., Saintonge, A., Pan, Z., Serra, P., Shao, L. (2020) "xGASS: H I Fueling of Star Formation in Disk-dominated Galaxies", The Astrophysical Journal, 890, 63.

206. Watts, A. B., Catinella, B., Cortese, L., Power, C. (2020) "xGASS: Robust quantification of asymmetries in global H I spectra and their relationship to environmental processes", Monthly Notices of the Royal Astronomical Society, 492, 3672.

207. Watts, A. B., Power, C., Catinella, B., Cortese, L., Stevens, A. R. H. (2020) "Global H I asymmetries in IllustrisTNG: a diversity of physical processes disturb the cold gas in galaxies", Monthly Notices of the Royal Astronomical Society, 499, 5205.

208. Welker, C., Bland-Hawthorn, J., Van de Sande, J., Lagos, C., Elahi, P., Obreschkow, D., Bryant, J., Pichon, C., Cortese, L., Richards, S. N., Croom, S. M., Goodwin, M., Lawrence, J. S., Sweet, S., Lopez-Sanchez, A., Medling, A., Owers, M. S., Dubois, Y., Devriendt, J. (2020) "The SAMI Galaxy Survey: first detection of a transition in spin orientation with respect to cosmic filaments in the stellar kinematics of galaxies", Monthly Notices of the Royal Astronomical Society, 491, 2864.

209. Wheeler, A., Ness, M., Buder, S., Bland-Hawthorn, J., Silva, G. D., Hayden, M., Kos, J., Lewis, G. F., Martell, S., Sharma, S., Simpson, J. D., Zucker, D. B., Zwitter, T. (2020) "Abundances in the Milky Way across Five Nucleosynthetic Channels from 4 Million LAMOST Stars", The Astrophysical Journal, 898, 58.

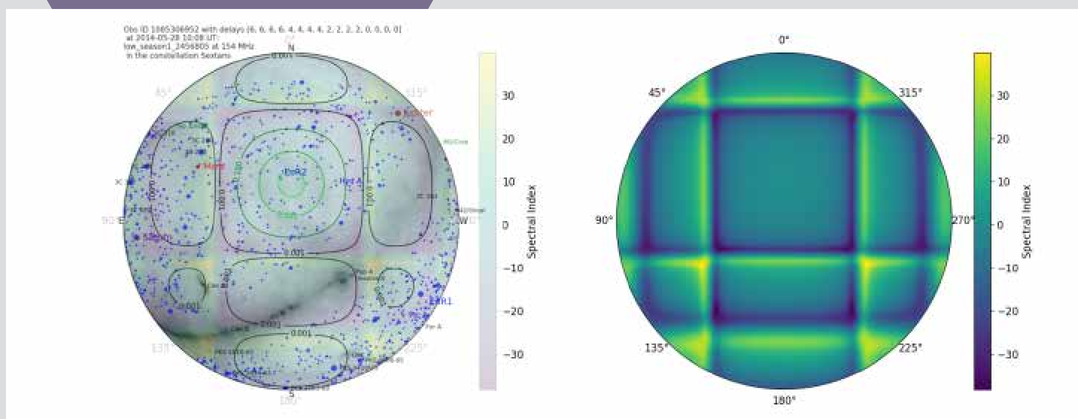
210. Whitler, L. R., Mason, C. A., Ren, K., Dijkstra, M., Mesinger, A., Pentericci, L., Trenti, M., Treu, T. (2020) "The impact of scatter in the galaxy UV luminosity to halo mass relation on Ly α visibility during the epoch of reionisation", Monthly Notices of the Royal Astronomical Society, 495, 3602.

211. Whitmore, B. C., Chandar, R., Lee, J., Ubeda, L., Adamo, A., Aloisi, A., Calzetti, D., Cignoni, M., Cook, D., Dale, D., Elmegreen, B. G., Gouliermis, D., Grebel, E. K., Grasha, K., Johnson, K. E., Kim, H., Sacchi, E., Smith, L. J., Tosi, M., Wofford, A. (2020) "LEGUS and Hα-LEGUS Observations of Star Clusters in NGC 4449: Improved Ages and the Fraction of Light in Clusters as a Function of Age", The Astrophysical Journal, 889, 154.

212. Wilensky, M. J., Barry, N., Morales, M. F., Hazelton, B. J., Byrne, R. (2020) "Quantifying excess power from radio frequency interference in Epoch of Reionisation measurements", Monthly Notices of the Royal Astronomical Society, 498, 265.

213. Wilman, D. J., Fossati, M., Mendel, J. T., Saglia, R., Wisnioski, E., Wuyts, S., Förster Schreiber, N., Beifiori, A., Bender, R., Belli, S., Übler, H., Lang, P., Chan, J. C. C., Davies, R. L., Nelson, E. J., Genzel, R., Tacconi, L. J., Galametz, A., Davies, R. I., Lutz, D., Price, S., Burkert, A., Tadaki, K.-. ichi ., Herrera-Camus, R., Brammer,

Figure 28 from Trott (2020) (no. 198): Sky response of the telescope for the zenith pointing of the EoR2 low-band (left) and the instrumental spectral index for the same pointing (right). Large instrumental indices imprint spectral structure that can be difficult to remove accurately. The Galactic Plane and extended radio galaxies lie close to spectrally-steep regions of the primary beam.



2020 PUBLICATIONS

G., Momcheva, I., van Dokkum, P. (2020) "The Regulation of Galaxy Growth along the Size-Mass Relation by Star Formation, as Traced by Hα in KMOS3D Galaxies at 0.7 < z < 2.7", The Astrophysical Journal, 892, 1.

214. Wittenmyer, R. A., Clark, J. T., Sharma, S., Stello, D., Horner, J., Kane, S. R., Stevens, C. P., Wright, D. J., Spina, L., Čotar, K., Asplund, M., Bland-Hawthorn, J., Buder, S., Casey, A. R., De Silva, G. M., D'Orazi, V., Freeman, K., Kos, J., Lewis, G., Lin, J., Lind, K., Martell, S. L., Simpson, J. D., Zucker, D. B., Zwitter, T. (2020) "K2-HERMES II. Planet-candidate properties from K2 Campaigns 1-13", Monthly Notices of the Royal Astronomical Society, 496, 851.

215. Wofford, A., Ramírez, V., Lee, J. C., Thilker, D. A., Della Bruna, L., Adamo, A., Van Dyk, S. D., Herrero, A., Kim, H., Aloisi, A., Calzetti, D., Chandar, R., Dale, D. A., de Mink, S. E., Gallagher, J. S., Gouliermis, D. A., Grasha, K., Grebel, E. K., Sacchi, E., Smith, L. J., Úbeda, L., Walterbos, R. A. M., Hannon, S., Messa, M. (2020) "Candidate LBV stars in galaxy NGC 7793 found via HST photometry + MUSE spectroscopy", Monthly Notices of the Royal Astronomical Society, 493, 2410.

216. Woods, T. E., Heger, A., Haemmerlé, L. (2020) "On monolithic supermassive stars", Monthly Notices of the Royal Astronomical Society, 494, 2236.

217. Wright, R. J., Lagos, C. del P., Power, C., Mitchell, P. D. (2020) "The impact of stellar and AGN feedback on halo-scale baryonic and dark matter accretion in the EAGLE simulations", Monthly Notices of the Royal Astronomical Society, 498, 1668.

218. Xiang, M.-S., Rix, H.-W., Ting, Y.-S., Ludwig, H.-G., Coronado, J., Zhang, M., Zhang, H.-W., Buder, S., Tio, P. D. (2020) "Chemically Peculiar A and F Stars with Enhanced s-process and Iron-peak Elements: Stellar Radiative Acceleration at Work", The Astrophysical Journal, 898, 28.

219. Yao, H. F. M., Jarrett, T. H., Cluver, M. E., Marchetti, L., Taylor, E. N., Santos, M. G., Owers, M. S., Lopez-Sanchez, A. R., Gordon, Y. A., Brown, M. J. I., Brough, S., Phillipps, S., Holwerda, B. W., Hopkins, A. M., Wang, L. (2020) "Galaxy and Mass Assembly (GAMA): A WISE Study of the Activity of Emission-line Systems in G23", The Astrophysical Journal, 903, 91.

220. Yuan, T., Elagali, A., Labbé, I., Kacprzak, G. G., Lagos, C. del P., Alcorn, L. Y., Cohn, J. H., Tran, K.-V. H., Glazebrook, K., Groves, B. A., Freeman, K. C., Spitler, L. R., Straatman, C. M. S., Fisher, D. B., Sweet, S. M. (2020) "A giant galaxy in the young Universe with a massive ring", Nature Astronomy, 4, 957.

221. Yuan, Y., Krumholz, M. R., Burkhart, B. (2020) "Understanding biases in measurements of molecular cloud kinematics using line emission", Monthly Notices of the Royal Astronomical Society, 498, 2440.

222. Zhang, S.-B., Hobbs, G., Russell, C. J., Toomey, L., Dai, S., Dempsey, J., Manchester, R. N., Johnston, S., Staveley-Smith, L., Wu, X.-F., Li, D., Yang, Y.-Y., Wang, S.-Q., Qiu, H., Luo, R., Wang, C., Zhang, C., Zhang, L., Mandow, R. (2020) "Parkes Transient Events. I. Database of Single Pulses, Initial Results, and Missing Fast Radio Bursts", The Astrophysical Journal Supplement Series, 249, 14.

223. Zhang, Z., Pober, J. C., Li, W., Hazelton, B. J., Morales, M. F., Trott, C. M., Jordan, C. H., Joseph, R. C., Beardsley, A., Barry, N., Byrne, R., Tingay, S. J., Chokshi, A., Hasegawa, K., Jacobs, D. C., Lanman, A., Line, J. L. B., Lynch, C., McKinley, B., Mitchell, D. A., Murray, S., Pindor, B., Rahimi, M., Takahashi, K., Wayth, R. B., Webster, R. L., Wilensky, M., Yoshiura, S., Zheng, Q. (2020) "The impact of tandem redundant/sky-based calibration in MWA Phase II data analysis", Publications of the Astronomical Society of Australia, 37, e045.

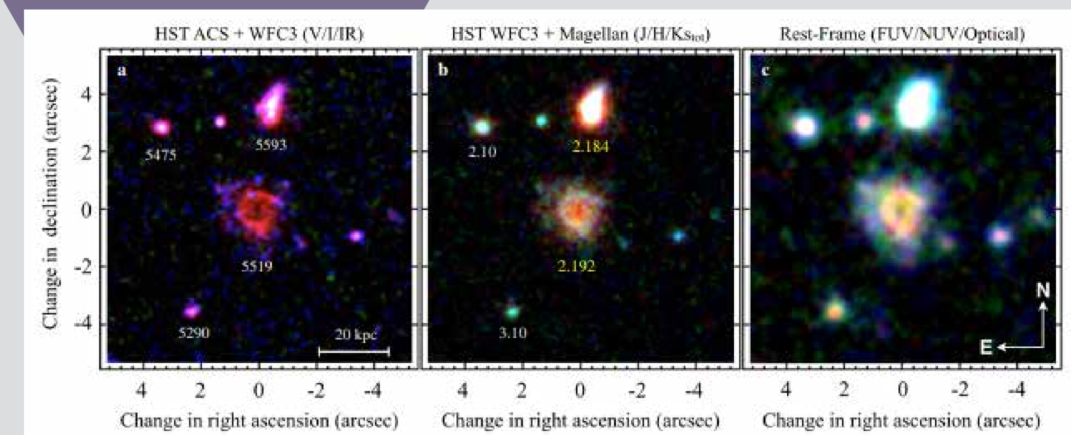
224. Zheng, Z., Li, D., Sadler, E. M., Allison, J. R., Tang, N. (2020) "A pilot search for extragalactic OH absorption with FAST", Monthly Notices of the Royal Astronomical Society, 499, 3085.

225. Zic, A., Murphy, T., Lynch, C., Heald, G., Lenc, E., Kaplan, D. L., Cairns, I. H., Coward, D., Gendre, B., Johnston, H., MacGregor, M., Price, D. C., Wheatland, M. S. (2020) "A Flare-type IV Burst Event from Proxima Centauri and Implications for Space Weather", The Astrophysical Journal, 905, 23.

226. Zinn, J. C., Stello, D., Elsworth, Y., García, R. A., Kallinger, T., Mathur, S., Mosser, B., Bugnet, L., Jones, C., Hon, M., Sharma, S., Schönrich, R., Warfield, J. T., Luger, R., Pinsonneault, M. H., Johnson, J. A., Huber, D., Silva Aguirre, V., Chaplin, W. J., Davies, G. R., Miglio, A. (2020) "The K2 Galactic Archaeology Program Data Release 2: Asteroseismic Results from Campaigns 4, 6, and 7", The Astrophysical Journal Supplement Series, 251, 23.

227. Zovaro, H. R. M., Sharp, R., Nesvadba, N. P. H., Kewley, L., Sutherland, R., Taylor, P., Groves, B., Wagner, A. Y., Mukherjee, D., Bicknell, G. V. (2020) "Unravelling the enigmatic ISM conditions in Minkowski's object", Monthly Notices of the Royal Astronomical Society, 499, 4940.

Figure 1 from Yuan et al (2020) (no. 220): Multi-wavelength views of R5519 and and its neighbouring environment. a, a three-colour image combining HST V-band/ACS F606W (blue), I-band/ACS F814W (green), and IR-band/WFC3 F125W+F140W+F160W (red) images.



PERFORMANCE INDICATORS 2020

PERFOMANCE MEASURE		2017 ACTUAL	2018 ACTUAL	2019 ACTUAL	2020 TARGET	2020 ACTUAL
Number of research outputs	Papers in refereed journals	11	110	213	*100*	**227**
	Media releases	1	5	7	*6*	**11**
	Centre Videos	-	-	15	*12*	**64**
	Facebook Page posts	-	-	73	*26*	**71**
	Twitter posts	-	-	228	*52*	**119**
	Exhibition or performance	-	-	3	*1*	**2**
	STEM Education workshops	-	-	6	*6*	**5**
	Website News Updates	-	-	7	*12*	**21**
	VR Program Development	-	-	1	*1*	**1**
Quality of research outputs	% of refereed papers in journals with impact factor > 2.5	100%	100%	100%	*80%*	**100%**
Number of training courses held/offered by the Centre	Professional skills workshop	1	4	2	*1*	**1**
	ECR training day	1	1	2	*1*	**1**
	Writing workshops	2	5	6	*6*	**3**
	Transferrable Skills workshop	-	-	1	*1*	**3**
Number of workshops/ conferences held/ offered by the Centre	International conference	0	2	2	*2*	**2**
	National conference/ workshop	1	2	2	*2*	**2**

Continued

PERFOMANCE MEASURE		2017 ACTUAL	2018 ACTUAL	2019 ACTUAL	2020 TARGET	2020 ACTUAL
Number of *additional* researchers working on Centre research	Postdoctoral researchers	16	14	3	*10*	**8**
	Honours students	2	1	3	*2*	**5**
	Masters by coursework	0	2	3	*2*	**0**
	PhD students	28	13	20	*12*	**15**
Number of presentations/ briefings	Public briefings/ lectures	3	123	230	*40*	**246**
	Government briefings	5	22	29	*4*	**35**
	Industry briefings	0	12	39	*2*	**42**
	Non-government organisation briefings	0	5	6	*6*	**7**
	Briefings to professional organisations & bodies	4	36	6	*4*	**6**
	Professional conferences/ workshops presentations	68	163	123	*40*	**221**
Number of new organisations collaborating with, or involved in, the Centre	New collaborative relationships	5	7	15	*4*	**11**
	New participating organisation	-	-	0	*1*	**3**
Maintain a collaborative and cohesive structure	Cross-node authorship of publications	36%	46%	83%	*85%*	**37%**
	Project team meetings with cross-node collaboration	4	12	6	*6*	**6 cross node teams, meeting at least monthly**
	Centre-wide climate survey	0	1	0	*1*	**0 (to occur early 2021)**

Continued

PERFORMANCE INDICATORS 2020

PERFOMANCE MEASURE		2017 ACTUAL	2018 ACTUAL	2019 ACTUAL	2020 TARGET	2020 ACTUAL
Create a diverse Centre	Females at all levels	38%	39%	40%	*45%*	**42%**
	At least 35% travel funds to females	28%	42%	42%	*45%*	**51%**
	Female visitors	44%	50%	58%	*50%*	**n/a**
	Child care at all Centre-suported conferences	100%	100%	100%	*100%*	**n/a**
Build the expertise for the next-generation telescopes	Students working on optical GMT pathfinder instruments	13%	29%	25%	*20%*	**37%**
	Students working on radio SKA pathfinder instruments	10%	16%	31%	*20%*	**20%**
	Students working on space telescope data	13%	16%	6%	*10%*	**15%**
	Students with data intensive research experience	19%	80%	51%	*30%*	**44%**
Train the next generation of scientists	% satisfaction with Centre-run skills workshops	-	-	87%	*80%*	**87%**
	% of PhD students and ECRs attending skills workshops	-	-	31%	*20%*	**30%**
	% ECRs achieving prestigious fellowships	-	-	28%	*20%*	**27%**
	% PhD students or ECRs achieving high quality jobs in other fields				*20%*	**24%**

CONSOLIDATED FINANCIAL STATEMENT 2020

	2020 ACTUAL ($)
INCOME	**$**
ARC Grant	4,595,388
State Government Grants	0
Other Grants	38,253
University Contributions	1,322,859
Partner Contributions	0
Other Income	337,056
TOTAL INCOME	**6,293,556**
EXPENSES	**$**
Salaries	5,026,420
Travel and Visitor Support	250,980
Equipment	22,620
Workshops and Conferences	50,557
Management and Administration	539,279
Education, Outreach and Communications	131,471
PHD Support	126,034
TOTAL EXPENSES	**6,147,361**
NET SURPLUS (DEFICIT)	**146,194**
Brought Forward Balance	6,163,072*
CARRY FORWARD BALANCE	**6,309,267**

*** Amendment of $19,587 relates to an amount being paid, but not reported in 2018 (Swinburne Node).**

NOTES TO FINANCIAL STATEMENTS

1. ARC CONTRACT & GOVERNANCE

a) During the 2020 financial year ASTRO 3D involved six Australian Universities and a further ten Australian and International partner organisations. Funding was approved by the ARC for seven years, subject to review after four years. The Centre commenced operation on 1 July 2017, a six month delay on the original 1 January commencement. The mid-term review will be conducted in June 2021.

b) In line with strategic objectives, three organisational Nodes have been approved as an addition to the Centre, namely Monash University, University of NSW and Macquarie University. These new node organisations were approved by the Australian Research Council as at January 2021. The new structure of the Centre will now encompass nine Nodes as of 2021.

c) From an operational and financial perspective, the centre operates as a single body, and all funding provided by the ARC is disseminated by the Australian National University as the administering organisation.

d) The Centre's operational and financial affairs are governed under defined policies and procedures.

e) Financial reporting provides institutional expenditure per Node, with the Business Manager for the Centre providing Consolidated Financial Reports for review by the Chief Operating Officer and Director.

2. INCOME

a) Income received from the ARC for 2020 amounted to $4.595m, including an amount relating to indexation of $295k.

b) University Contributions reflects all funds provided at Node level. Other income includes a range of sundry costs including reimbursement of travel costs to ANU Node, invoiced costs associated with various programs including the Indigenous Program, COVID-19 financial support program and STAR Program for Education and Outreach.

3. EXPENDITURE

a) Expenditure for the year was $6.1m against a budget of $7.2m (85%). This variance primarily relates to the impact of COVID at a general level on Centre activities, specifically travel and events such as the Annual Science Workshop and the Centre's Annual Retreat which could not be held and delays in employment related start dates.
b) Development of the Virtual Reality Program is now underway, with the launch of the Program expected in 2021.
c) The carried forward balance is 31% higher than budgeted. This relates the impact that COVID has had on Centre operations and delays associated with it.

4. FINANCIAL MANAGEMENT

a) A financial reforecast was undertaken early 2020, to reflect the impact of COVID on Centre operations.
b) As part of a sustained review of financial management practices, a review of financial reporting was undertaken with agreement to provide quarterly reporting to the Executive Management Committee.
c) Centre-wide financial policies relating to reporting and budgeting were developed and implemented to ensure consistency of financial management across the Centre.