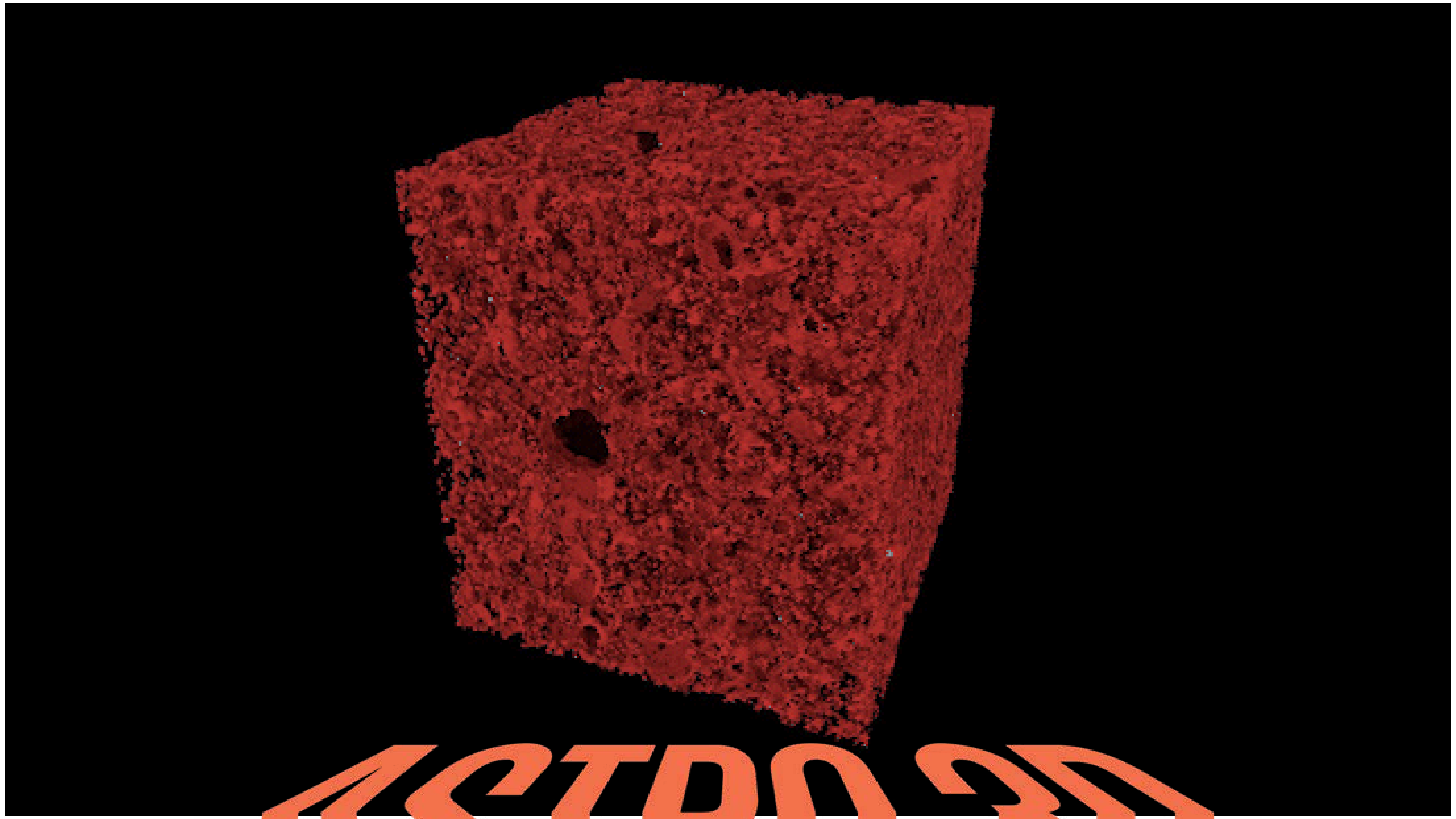

ASTRO 3D

ANNUAL REPORT 2021

AUSTRALIAN RESEARCH COUNCIL CENTRE OF EXCELLENCE FOR ALL SKY ASTROPHYSICS IN 3 DIMENSIONS

Australian Government
Australian Research Council

OUR COLLABORATORS

OUR COLLABORATING UNIVERSITIES

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

OUR PARTNER INSTITUTIONS

ASTRON Netherlands Institute for Radio Astronomy
California Institute of Technology
Chinese Academy of Sciences
CSIRO
NCI Australia
University of Hertfordshire
University of Oxford
University of Toronto
University of Washington

OWNERSHIP OF INTELLECTUAL PROPERTY RIGHTS

ACKNOWLEDGEMENT

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

EDITORIAL BOARD

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GOVERNANCE

CENTRE DIRECTOR
Prof. Lisa Kewley (ANU)

CENTRE DEPUTY DIRECTOR
Prof. Stuart Wyithe (Melbourne)

CHIEF OPERATING OFFICER
Ms Ingrid McCarthy (ANU)

COLLABORATION LEADER
Prof. Joss Bland-Hawthorn (Sydney)

COMMITTEE LEADS
EDI - A/Prof Kim-Vy Tran, (UNSW)
Junior ECRs - Dr Katie Grasha (ANU)
Snr ECRS - Dr Jack Line (Curtin)
Students - PhD Student Yifei Jin (ANU)
Sustainability - Dr Andy Casey (Monash)
Black Lives Matter - Dr Nichole Barry (Curtin)

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.

NODE LEADERS AT EACH COLLABORATING UNIVERSITY
A/Prof. Barbara Catinella (UWA), Prof. Scott Croom (Sydney), Prof. Matthew Colless (ANU), A/Prof Amanda Karakas (Monash), Dr Richard McDermid (Macquarie), Prof. Emma Ryan-Weber (Swinburne), A/Prof. Kim-vy Tran (UNSW), and Prof. Cathryn Trott (Curtin).

NATIONAL 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. With COVID restrictions still in place, an Advisory Board meeting wasn't held in 2021, instead the Board provided input into the mid-term review.

ADVISORY BOARD CHAIR
Professor Tim de Zeeuw, Professor of Theoretical Astronomy at Leiden University and former Director General of the European Southern Observatory.

2021 ADVISORY BOARD MEMBERS
Dr Linda Tacconi, Scientist, Max Planck Institute for Extra-terrestrial 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.

OUR STRATEGIC GOALS

TRANSFORM

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.

BUILD

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.

INSPIRE

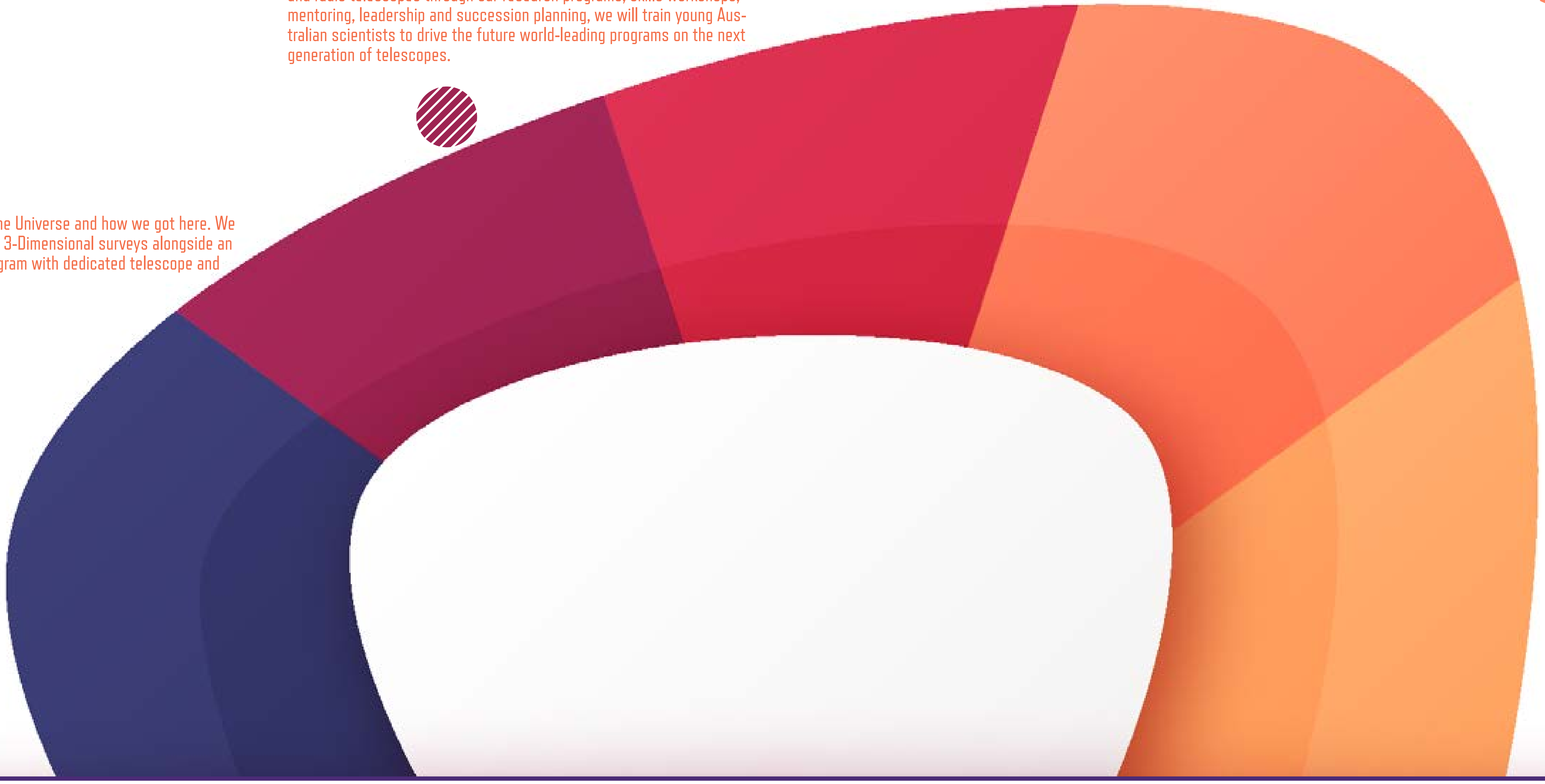
Inspire, train and mentor the next generation of diverse Australian scientific leaders. We will inspire students to study science, technology, engineering and mathematics (STEM) through new teacher education programs and our ambitious nation-wide public outreach campaigns.

NEXT GENERATION

Provide young Australian scientists with transferable skills for the modern workforce by training 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.

CULTURE

Create an innovation culture to facilitate the transfer and commercialisation of astronomical technology to other disciplines by identifying fresh ideas and aiding the commercialisation of new astronomical technology through our Intellectual Property and Innovation Committee, comprised of experts in commercialisation.



QUICK LOOK 2021

OUR PEOPLE

- 20 Chief Investigators
- 10 Partner Investigators
- 58 Associate Investigators
- 48 Affiliates
- 7 Research Fellows
- 30 Postdoctoral Researchers
- 68 PhD Students
- 9 Masters Students
- 10 Honours Students
- 4 Education and Outreach Affiliates
- 19 Masters and Honours Students
- 15 Professional Staff
- 60 Alumni

OUR RESEARCH

- 269 Publications in Peer Reviewed Journals
- 10 National Press Releases
- 67 Invited Talks
- 129 Contributed Talks
- 15 Government and Industry Briefings
- 73 School Talks
- 56 Public Outreach Talks
- 57 Colloquia
- 16 Poster Presentations
- 866 Radio, Press or TV Interviews

ONLINE PRESENCE

- Facebook page likes 552
- Facebook followers 591
- Twitter followers 1261
- YouTube Subscribers 411

WHY ASTRO '3D'?

ABOUT ASTRO 3D

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:

California Institute of Technology, USA (Caltech)

Chinese Academy of Sciences (CAS)

Commonwealth Scientific and Industrial Research Organisation (CSIRO)

National Computational Infrastructure (NCI)

Netherlands Institute for Radio Astronomy (ASTRON)

University of Hertfordshire, UK

University of Washington, USA (UW)

University of Toronto, Canada

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.

WHY ASTRO 3D?

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.

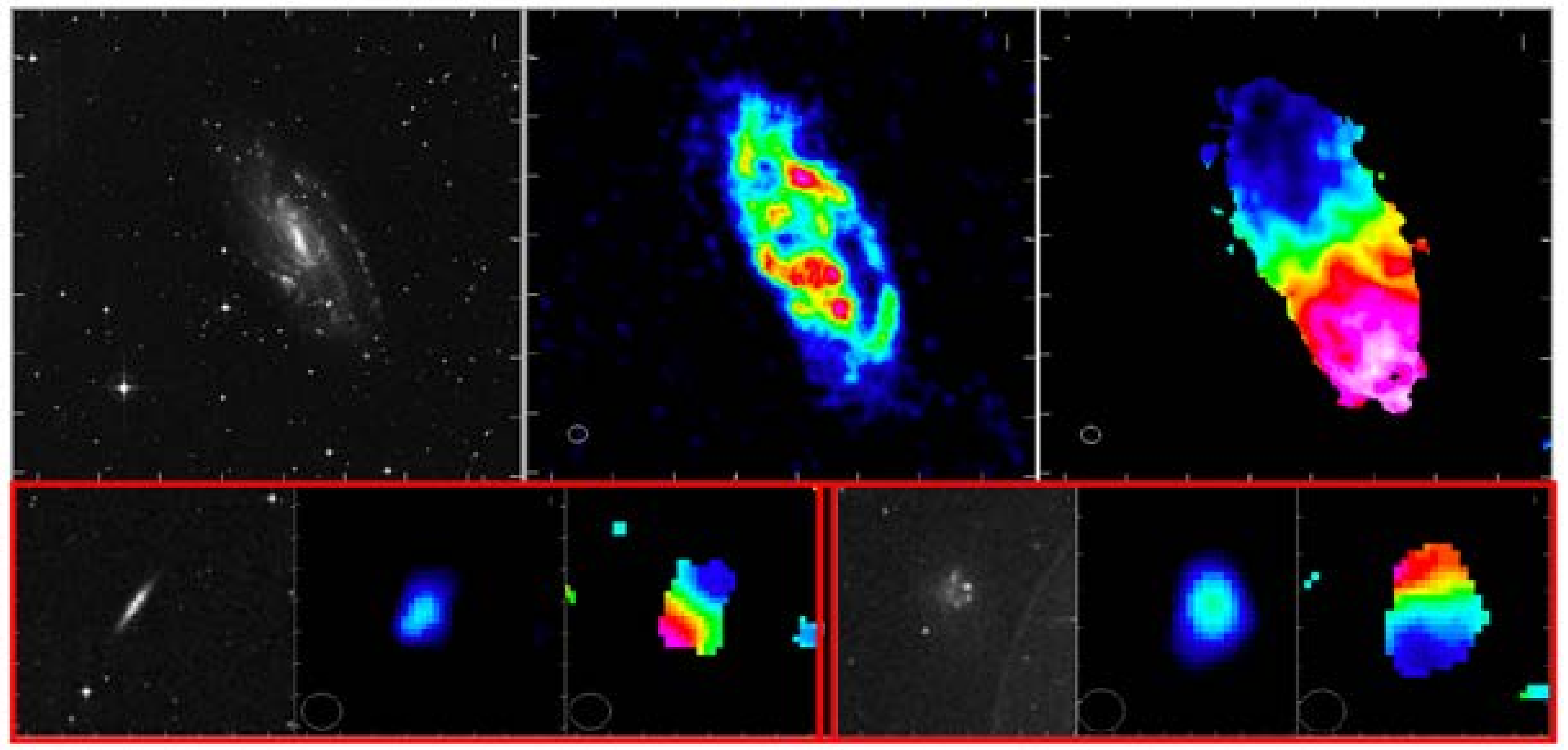


Image above shows the HI (neutral hydrogen gas) in one ASKAP beam (out of 36) after combining seven nights of ASKAP data. They discovered two gas-rich dwarf galaxies in the vicinity of a nearby spiral galaxy (IC 5201). The collage shows IC 5201 on the top row - the optical image (left), the HI distribution (middle) and the HI velocity field - whicih shows how fast the gas is moving (right). The bottom row shows the same thing for the two dwarf galaxies. Image credit: Dane Kleiner (CSIRO - CASS).

DIRECTOR'S WELCOME AND REPORT

ASTRO 3D aims to understand our origins. Our Centre has three goals: (1) to understand the origin of the ionizing radiation in the universe, (2) to understand how matter accumulated into galaxies in the universe, and (3) to understand how the chemical elements formed and proliferated in the stars and galaxies across cosmic time. Our surveys and projects cover the full history of the universe from right after the Big Bang to the present day universe and our own Milky Way.

In 2021, ASTRO 3D continued to make major strides in scientific discovery, education/outreach, and diversity. COVID-19 produced challenges to our education and outreach programs, but our ongoing regular communications and effective on-line collaborations and meetings allowed the Centre science to continue unabated.

Our surveys and projects are in full swing, with 269 publications in refereed journals and 10 press releases. We're increasing our collaborations across all Surveys and Projects, as well as developing new data catalogs, analysis tools and theoretical predictions to help us obtain a 3D picture of how the gas, the first stars and galaxies formed and evolved across 13.7 billion years of cosmic time.

In 2021, we successfully passed our mid-term review and we formally welcomed our new Nodes Macquarie University, Monash University, and the University of New South Wales. Monash further strengthens our galactic archaeology and stellar modelling efforts. Macquarie University significantly strengthens the Centre in the critical areas of Data Intensive Astronomy and Hector technical development and science. UNSW continues to provide leadership and expertise for the Galaxy Evolution program, as well as leadership of the ASTRO 3D Equity, Diversity and Inclusion committee. It has been wonderful to see the new collaborations building with the new Nodes, as they are welcomed into the Centre.

Our surveys and projects continued to make world-first discoveries and reach major milestones. Using the Murchison Widefield Array, ASTRO 3D researchers produced the deepest detection limits in the epoch of X-ray heating. Our Genesis theoretical simulations team has worked directly with observers to produce mock data cubes of galaxies and to make predictions for the first galaxies in the universe. By combining theoretical simulations with deep 3D data of distant galaxies from the world's largest telescopes, ASTRO 3D researchers discovered that galaxies with large, puffy disks continue their star formation for longer than regular galaxies, advancing our understanding of how galaxies evolve. In a world first, our team measured the chemical content of massive outflows of gas from distant galaxies, showing that how galaxies pollute their environment with chemical elements.

PROFESSOR LISA KEWLEY

ASTRO 3D DIRECTOR

Lisa Kewley is a Professor and Australian Research Council Laureate Fellow at the Australian National University. She obtained her PhD in 2002 from the Australian National University on the connection between star formation and supermassive black holes in galaxies. She was a Harvard-Smithsonian Center for Astrophysics Fellow and a NASA Hubble Fellow.

Her awards include the 2006 American Astronomical Society Annie Jump Cannon Award, the 2008 American Astronomical Society Newton Lacy Pierce Prize, and the 2020 US National Academy of Science James Craig Watson Medal.

In 2014, Kewley was elected Fellow of the Australian Academy of Science "for her fundamental advances in understanding of the history of the Universe, particularly star and galaxy formation", and in 2015, Kewley was awarded an ARC Laureate Fellowship,

Australia's top fellowship to support excellence in research.

The SAMI survey completed its target of 3000 data cubes of nearby galaxies using the Anglo Australian Telescope. This is the largest 3D galaxy survey with spectral resolution that can identify shocked gas from massive galactic-scale superwinds in galaxies, and is now public world-wide. ASTRO 3D researchers have used this dataset to understand how galaxies spin, grow, cluster and die. Our Data Intensive Astronomy and Genesis teams havee produced new cutting-edge 3D data visualisation tools to help observers view and analyse their data.

ASTRO 3D is conducting a world-leading survey of stars in the Milky Way to track the chemical and mass accretion history of the Milky Way through galactic archaeology. In 2021, we showed that a star in the Milky Way with unusual chemical elements was formed from a remnant of a magneto-rotational hypernova, an incredibly energetic explosion, the first of its kind to be detected. Also in 2021, our GALAH and SAMI teams combined forces to understand the merger history of our Milky Way. Astronomers previously thought that the Milky Way had a violent past, with the thin and thick disks of the Milky Way produced through violent collisions. Our teams showed that Milky Way's thin and thick discs are likely the 'default' peaceful path of galaxy formation and evolution for spiral galaxies.

In 2022, we are excited to begin commissioning the Hector instrument on the Anglo Australian Telescope. Hector will provide unprecedented resolution and uses innovative robotic positioner technology. ASTRO 3D researchers will use Hector to conduct a generation 3D survey of 10,000 galaxies.

Some of our education outreach programs were largely on hold due to COVID-19, but our Virtual Reality program development continued, with the first demonstration of the program available to ASTRO 3D members at our joint virtual and in-person retreat in December 2021. We are excited to ramp up our education and outreach activities in 2022.

The year 2021 was a year for diversity milestones, with ASTRO 3D being awarded a Bronze Pleiades Award from the Astronomical Society of Australia. We achieved 46% women in the Centre, a major achievement in astrophysics. We are on-track to reaching 50% women in early 2022. Our Centre will be focusing on increasing representation of Aboriginal and Torres Strait Islander people in astronomy for the final years of the Centre. We held Indigenous Awareness training workshops at our Annual Retreat on the east coast and the west coast. Both workshops were highly valued by our members, with high levels of attendance and positive responses on post-workshop surveys. In 2021, our Black Lives Matter Committee formed as a sister committee to our Equity Diversity and Inclusion committee, and we will be forming an Indigenous Advisory Committee in 2022 to help us deliver programs that meet the needs of Aboriginal and Torres Strait Islander students.

Our COO Ingrid McCarthy, our management team, and our administrative and education/outreach staff continued effective, efficient, and highly professional work in the Centre. 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.

I am delighted to share this Annual Report with you, now fully virtual with an exciting new and sustainable format.

Above: MWA Diapole and wildflowers
Image Credit: MWA Collaboration and Curtin University
Right: ASTRO 3D purple duck
Image credit: Cristy Roberts

ADVISORY BOARD CHAIR REPORT

The past year saw a continuation of the restrictions imposed by the COVID-19 pandemic, but the ASTRO 3D partnership continued to thrive and deliver marvellous new science results and actively integrated the new nodes at Macquarie, Monash, and UNSW into the web of connected activities.

Australian partnership in ESO's programme thrived with successful observing proposals for the VLT, progress on instrumentation development, and gaining access to all of ESO's technology development programme, including activities for the Extremely Large Telescope.

The ARC-mandated mid-term review by an external committee was passed with flying colours. The IAB provided advice on the Strategic Plan 2021-2024, and was also interviewed by the review committee. The outcome of the review confirmed that ASTRO 3D is a superb ARC Centre of Excellence, which carries out a world-class research programme, provides excellent training for young researchers, blazes a luminous trail in the increase of equity, diversity and inclusion, and has developed an excellent education and outreach programme. Specifics of this year's remarkable progress is described in this Annual Report.

There are now encouraging signs that in-person meetings will become possible soon, and the IAB looks forward to interact with the ASTRO 3D team in 3D in the course of 2022.

Tim de Zeeuw

IAB Chair

PROFESSOR TIM DE ZEEUW

PROFESSOR OF THEORETICAL ASTRONOMY

Tim de Zeeuw is Professor of Theoretical Astronomy at Leiden Observatory and was Director General at ESO 2007 - 2017. Tim obtained his PhD at Leiden University and worked at the Institute for Advanced Study, Princeton, and at the California Institute of Technology.

Tim's research concentrates on the formation, structure and dynamics of galaxies, including our own, the Milky Way.

In Leiden, he led a group active in the construction of state-of-the-art dynamical models for galaxies, and their comparison to high-quality photometric and spectroscopic observations, with the aim of establishing the properties of dark matter halos around

galaxies, probing the supermassive nuclear black holes, measuring the kinematics and dynamics of the different stellar populations, and ultimately understanding the process of galaxy formation.

TESTIMONIAL

ASTRO 3D has many strengths as a Centre of Excellence – from its world leading research and highly productive international collaborations, leading to new discoveries and advancements in scientific understanding, to nationally recognised education outreach programs and the development and mentoring of new generations of researchers and research leaders.

Its successes are underpinned by a vibrant organisational culture, which has developed from strong and inclusive leadership with a commitment to good governance, mentoring and skills development, open communication and respect for diverse perspectives. At times of crisis, such as that presented by the global COVID19 pandemic, this workplace culture has helped the organisation to continue attracting top new talent from across the nation and around the world, and to evolve and thrive as a leading global centre of expertise. That it is so well positioned is a testament to Director Kewley and leaders throughout the Centre, who have worked tirelessly to pursue and enable opportunities, remove barriers, bring people together and build strong and dynamic connections across disciplines, cultures and borders.

The achievements from 2021 are impressive. ASTRO 3D is not only recognized as an international leader in astrophysical research, but one whose expertise is making a vital contribution to planning for future use of the Square Kilometre Array and Giant Magellan Telescope. Its commitment to educational outreach has seen it create and deliver new astrophysics education programs that excite and inspire hundreds of teachers and young Australians every year. Its people command high levels of respect and recognition in their fields, and in turn invest in mentoring and developing the next generation of researchers and industry professionals.

ASTRO 3D's collaboration with other organisations is extensive and has grown steadily to now include 18 national and international partnerships, enabling the Centre's influence and profile to extend well beyond its immediate field.

In order to thrive, research institutions must attract, develop and retain the best talent from a diverse pool of researchers. The recent announcement that a full 50% of Centre researchers and staff are female (as compared to just 38% back in 2018) is an outstanding achievement to celebrate. Few other science agencies have managed to achieve this outcome. As the Centre enters its 6th year, new targets to further increase the diversity and engagement of the workforce will help set the benchmark still higher.

I congratulate ASTRO 3D on all it has achieved to date and look forward to the year ahead.

Dr Bobby Cerini

General Manager of Science and Learning, Questacon

DR BOBBY CERINI

DEPUTY DIRECTOR AND GENERAL MANAGER

Dr Bobby Cerini is Deputy Director and General Manager of Science and Learning at Questacon.

Bobby represents the Department of Industry, Science, Energy and Resources on a variety of STEM program boards across Australia, and in key national and international stakeholder networks including the Asia Pacific network of science centres and museums (ASPAC) and the Public Communication and Science and Technology network (PCST).

WELCOME TO OUR NEW NODES

NEW COLLABORATING UNIVERSITY PARTNERS

In mid-2019, ASTRO 3D invited submissions in an open call from the Australian astronomical community for new collaborating universities (Nodes). In our call, we highlighted the Centre's needs, including support for theoretical expertise for our Galactic archaeology program, leadership and personnel for our galaxy evolution program, and scientific support and instrument development support for the Hector instrument. We also emphasised the need for support for our Telescopes in Schools program.

The ASTRO 3D Executive Management and Science Management Committees reviewed these submissions for scientific rigour and contribution to the research, personnel and expertise of the Centre. We conducted extensive budget modelling of the impact of the submissions from the new Nodes on the ASTRO 3D Budget, with forward budget models for all possible scenarios included within our Executive and Science Management Committee discussions.

After an open and transparent process, ASTRO 3D added three new collaborating universities: Monash University, Macquarie University, and the University of New South Wales (UNSW). The addition of the new nodes brings in substantial scientific expertise and person-power and $1M in new cash for the Centre to help us achieve our ambitious science goals in the 2nd half of the Centre.

Monash University, headed by Node Leader CI Amanda Karakas, strengthens the Centre in the critical areas of Galactic archaeology and SAMI data science. One of the primary outstanding needs in the Centre is theoretical modelling of stellar evolution. The modelling of stars is highly complex and accurate stellar yields (i.e. the amount of chemical elements produced by these stars) are required in many research areas in ASTRO 3D from theoretical stellar evolution models, as well as simulations of star-forming galaxies which need to model entire populations of star clusters in galaxies. Monash investigator Amanda Karakas' theoretical model yields are now the standard yields used in astrophysics. They are now being used in Monte Carlo models of stars, chemical evolution models of the Milky Way and our neighbouring galaxies (the Magellanic Clouds), chemical evolution models of star clusters, cosmological simulations of galaxy formation, as well as simulations of the gas in galaxies, and models of the most pristine galaxies in the Universe. The Monash Node will use their ARC funding to employ a Postdoctoral Researchers linked to the GALAH project and for travel.

Macquarie University, led by CI Richard McDermid, significantly strengthens the Centre in the crucial areas of Data Intensive Astronomy and Hector instrument development. One of the primary outstanding needs of the Centre has been in building our data intensive astronomy virtual observatory program to maximise world-wide astronomer access to our vast radio, optical, and theoretical datasets. Macquarie University has extensive expertise in this area, due to their experience building the Australian Virtual Observatory. Macquarie University will lead the Data Intensive Astronomy program to incorporate ASTRO 3D surveys and project datasets, including our theoretical 3D ZOOM simulations. Also, this connection provides a vital career transition pathway for ASTRO 3D ECRs into data science fields. CI Richard McDermid is an ARC Future Fellow and Senior Lecturer. His research field is primarily galaxy formation and evolution, in particular using observations of galaxies to measure the properties of their stars, gas, dark matter and black holes. CI Matt Owers is also an ARC Future Fellow and Senior Lecturer. Broadly, Dr Owers' research interests are in the field of galaxy evolution, and how the large-scale environment impacts the properties of galaxies. He is involved in several large Australian surveys, including the Galaxy And Mass Assembly (GAMA) survey, the SAMI Galaxy Survey, as well as planned surveys such as WAVES and Hector. The Macquarie Node will employ three Postdoctoral Researchers in Data Intensive Astronomy and Hector.

The University of New South Wales (Sydney), headed by CI Kim-Vy Tran, provides leadership and expertise for the Galaxy Evolution program and the ASTRO 3D Equity, Diversity and Inclusion Committee. One of the primary outstanding needs of the Centre is the leadership of the ASTRO 3D Galaxy Evolution program, including our core gravitational lensing at high redshift survey called AGELS. These programs were being led by Swinburne University CI Karl Glazebrook, who had to step down from these roles when he received his ARC Laureate Fellowship to work on a different research program. The UNSW contributions to ASTRO 3D provides leadership of the overall Galaxy Evolution program, as well as coordination and support for the AGELS survey. UNSW also provides fundamental coordination and support for the GALAH survey on the Anglo-Australian telescope, including management of the observations and data processing. CI Kim Vy Tran's research program focuses on Galaxy Evolution, specifically in the intermediate redshift Universe ($1 < z < 5$) and as a function of environment. Within ASTRO 3D, she expands on existing and very productive collaborations across several of the Nodes, namely ANU, Swinburne, and the University of Melbourne. Being part of ASTRO 3D has enabled CI Tran to strengthen connections with theorists at UWA (Node) and Harvard (Partner institution) to compare predictions to observations better. Kim Vy Tran will fill a large unmet need in the Centre; she will lead the ASTRO 3D Galaxy Evolution program, including the AGEL survey. The UNSW Node will employ a Galaxy Evolution Postdoctoral Researcher.

We also added a new International Partner organisation in 2021. The University of Hertfordshire and new CI Chiaki Kobayashi bring world-leading expertise in the chemical evolution of galaxies.

MONASH University

MACQUARIE University SYDNEY·AUSTRALIA

UNSW SYDNEY

University of Hertfordshire UH

STUDENT COMMITTEE

"The talk by Carol Beynon gave me a clear pattern on the formation of my stress. I learnt how to cope with my stress and anxiety. I feel I am more confident and braver to embrace the uncertainty in my life!"

Student feedback from Virtual Student Day

The student committee welcomed new members this year including: Caro Derkenne (Macq), Jennifer Hardwick and Manasvee Saraf (UWA), Yifan Mai (UniSyd) and Balu Sreedhar (UniMelb).

The Student Committee organised the virtual Student Day on 31 August 2021 inviting Ms Carol Beynon from ANU Mental Health Centre to talk on stress management, and Mr Glen Sheldon from APR.Intern to talk on internship seeking through APR.Intern. We received great feedback from students on both speakers and topics.

At the end of 2021, we successfully organised marvelous student sessions at the ASTRO 3D Annual Retreat! We invited Dr. Fang Yuan from Geoscience Australia and Dr. Emily Wisnioski from ANU to give talk on career building from the perspectives of both industry and academia.

The Annual Retreat also gave us a chance to meet and discuss initatives the group would like to see implemented in 2022. There was a high demand from the students present to build skills in science communication, networking, career planning and professional coding practices. These skills would help students to be successful next generation scientific leaders and gain transferable skills for a modern workforce. These initatives included:

1. Training on job application for industry (including preparation of job hunting, resume writing, interview skills etc.) from people who are aware of the interview process and have had read through many resumes, e.g., someone from the HR department of a company or a recruiter;
2. Opportunity/awareness of conferences students can speak at, talk about their research, and connect with others;
3. Workshop on science communication, to communicate our results to a broader audience;
4. Workshop on networking and social skills, social confidence;
5. Workshop on project management, time management, goal setting, even project management within the context of a collaboration; and
6. Sufficient funding for international travel, so students can begin attending conferences and promoting their research internationally, as well as building solid international collaborations.

I would like to thank all ASTRO 3D students for their support to the Student Committee. I would also thank the Student Committee members for their continuous contributions to the committee.

Yifei Jin on behalf of the Student Committee.

SENIOR ECR COMMITTEE

2021 was the Senior ECR Committee's second year of operation, and saw a number of personal changes. Outgoing chairs Phil Taylor (ANU) and Michael Hayden (USyd) stepped down (many thanks for your work), and new members Themiya Nanayakkara (Swin) and Jack Line (Curtin) joined existing members Lilian Garratt-Smithson (UWA) and Andrew Battisti (ANU).

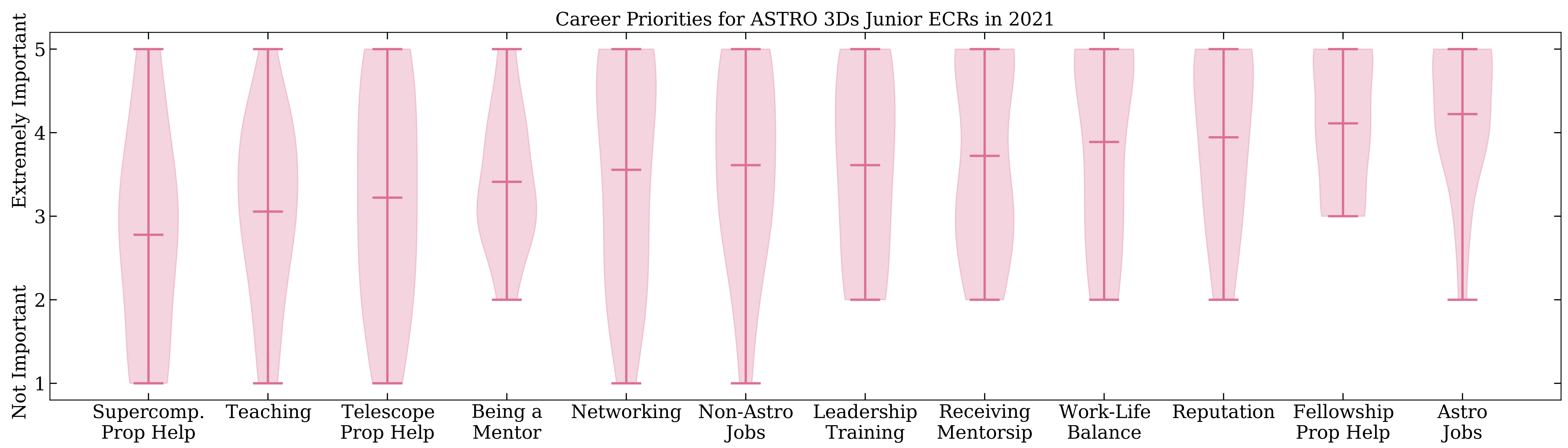
This past year we continued our focus on representing Senior ECR's needs to the Executive team, and providing resources for our peers. We had two main contributions during the year. The first was setting up a program for any ASTRO 3D members to access Coursera training. Coursera offers training courses developed by professional bodies (think IBM and Google) that can not only give you new computational and professional skills, but an accreditation at the end. This training is now negotiated on a node-by-node basis. To access training, simply find a course you want to take, discuss with your line-manager, and fill in the form (which is pinned on the #ASTRO 3D-forms channel of the ASTRO 3D Slack).

Our second contribution was organising a panel discussion based around how to transition from postdoc into junior faculty, which was held just before the science retreat. Huge thanks to our panel of Dr Emily Wisnioski (ANU), Dr Elisabete Lima da Cunha (UWA), A. Prof. Ryan Shannon (Swin), and A. Prof. Cath Trott (Curtin) who gave us candid and invaluable advice. At the end of 2021 we put out a call to try and capture all the knowledge gained during the lockdown period on teaching and working online, to make sure it isn't lost as we emerge from the fog of COVID. This project is ongoing.

Looking forward to 2022, we will hopefully be able to focus on some in-person events, as well as creating resources online that can be used at any time.

Jack Line On behalf of the Senior ECR Committee.

JUNIOR ECR COMMITTEE



This year's activities of the Junior ECR committee can be summarised as supporting our junior ECRs' Career and Work+Life balance.

As in previous years, we created an anonymous questionnaire for our cohort to tell us about their priorities in 2021. The results of this survey are shown in figure to left with violin plots. These plots show violins ranked from on average least important (left) to most important (right) with the shape of the violin indicating the spread of answers. The results indicate that the highest priority for junior researchers is to secure astronomy jobs and fellowships.

Both the ASTRO 3D panel discussion with recent faculty hires in August 2021 and the ASTRO 3D Academic Applications workshop in October 2021 provided great advice on these topics from seasoned fellowship winners and faculty members. Our cohort is also clearly worried about their reputation (3rd highest priority) in a year that has seen continuing restrictions on travelling and in-person collaboration with international researchers. The ASTRO 3D International Seminar Series has proven to be a great way to provide our junior ECRs with international visibility - and the lifting of travel restrictions at the end of 2021 was more than uplifting.

We are looking forward to finally having the newest members of our cohort arriving in Australia from overseas. For all of us, managing our work+life balance was important during this year (and 4th highest priority in the survey). The junior ECR committee therefore organised both an informal cooking and games evening in August 2021 as well as a work+life workshop with Life Coach Chris Edwards in July 2021. The workshop addressed values-based work+life planning, communication, and prioritizing time management skills to set up strategies to juggle personal and career roles and responsibilities.

Finally, the ASTRO 3D ECR leadership training day in April 2021 provided expert guidance on developing doctoral writers, leading positive conversations, and becoming effective supervisors. With the end of lockdowns and international traveling restrictions at the end of 2021, we are looking forward to 2022 and the 2nd half of ASTRO 3D!

Katie Grasha on behalf of the Junior ECR Committee.

Background image: Junior ECRs meeting at Annual Retreat in person and over Zoom. Image credit: Cristy Roberts

THE INTERNATIONAL SEMINARS COMMITTEE

The International Seminars Committee was formed in late-2020 with the aim of aiding students and ECRs in advertising their work in a pandemic-riddled world. Given the lack of travel opportunities that stemmed from the cancellation of in-person conferences, Australian students and ECRs were unable to network as usual, which may have negative ramifications come job season. To mitigate this, the ASTRO 3D ECR Astronomers in Australia Seminar Series was created: a series of 36 online seminars by Australian astronomers that took place from March-July 2021.

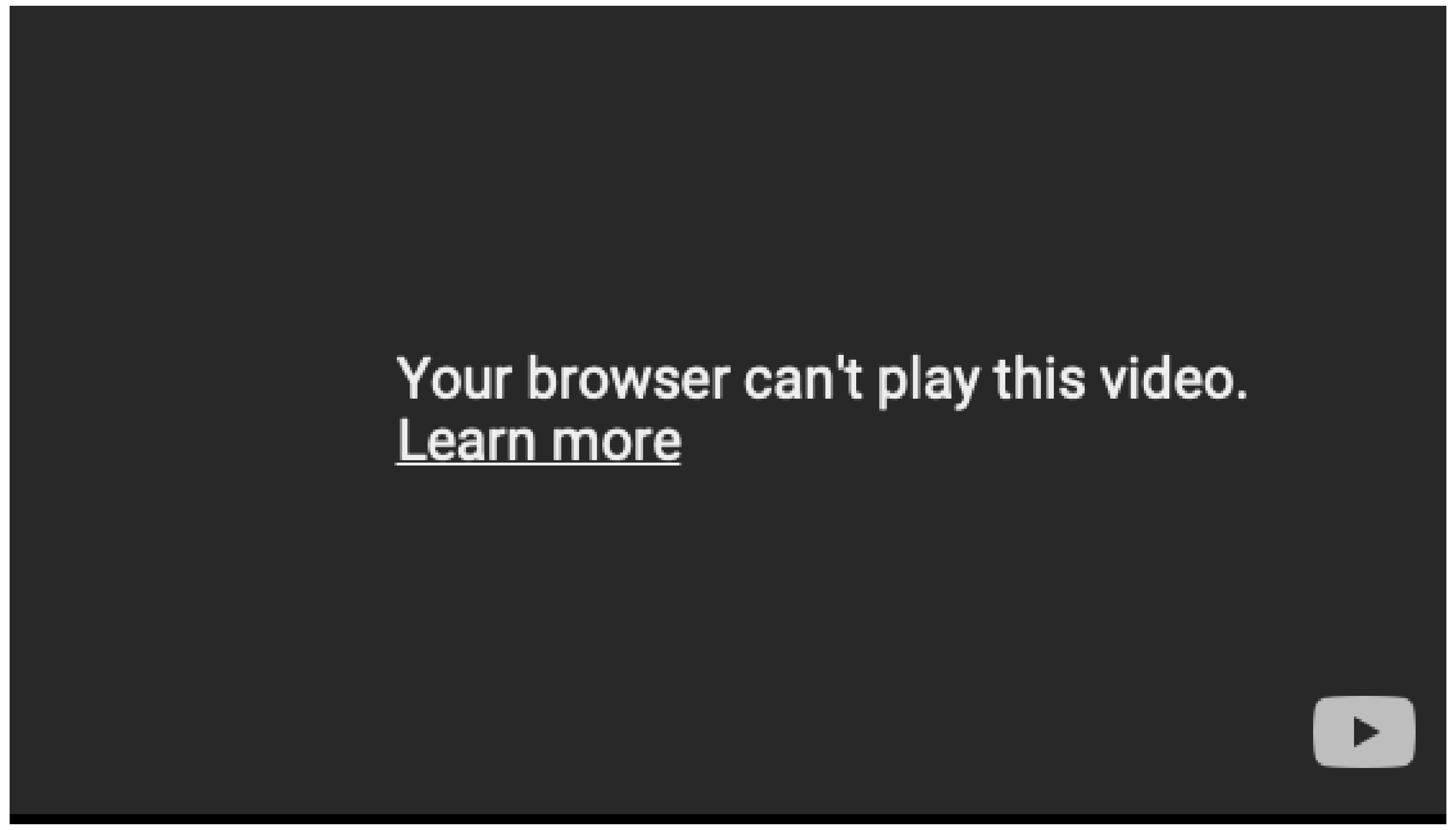
Our committee received many excellent abstract submissions, and selected 36 speakers based on a blind review process. Speakers were located at institutions all across Australia, and were evenly split in gender. The majority of speakers were final year PhD students or postdocs within 3 years of their PhD.

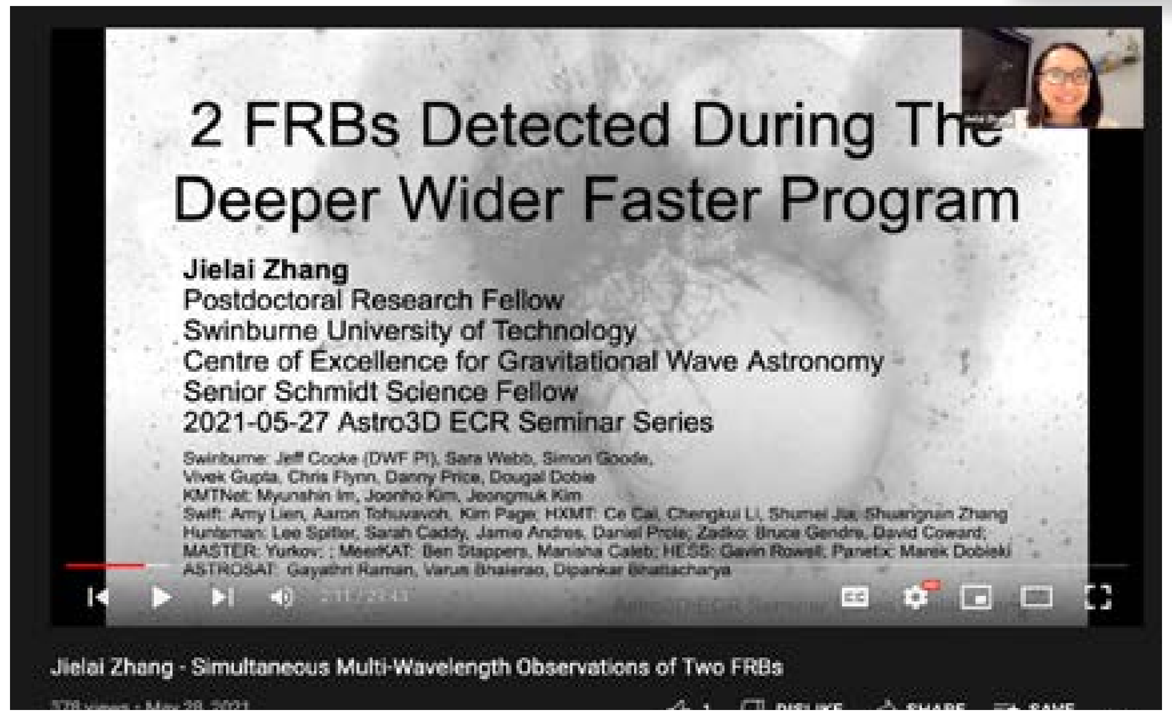
Talks were advertised to our international colleagues via email lists, Twitter, Facebook, and word of mouth. Importantly, the seminars were scheduled at times convenient to those in Europe/Africa, and North and South America. Of course, this meant a few early starts or late nights for our seminar speakers, but ensured higher attendance from an international audience.

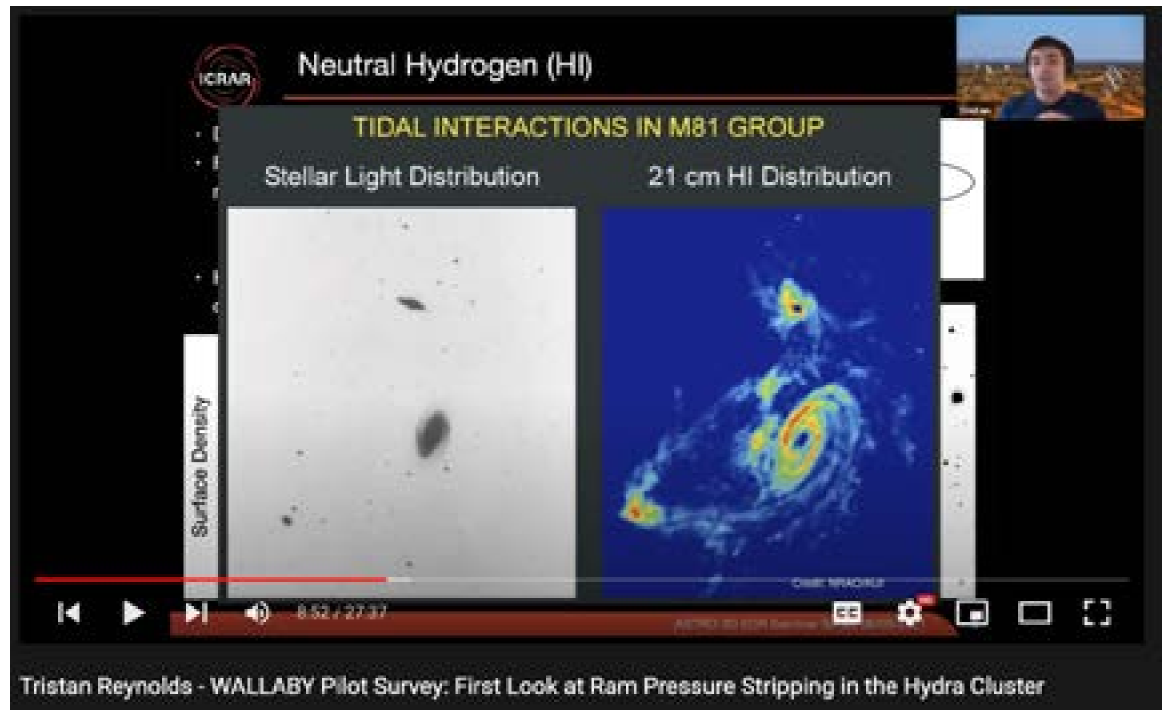
The seminars were a roaring success, covering topics as wide-ranging as galactic archaeology, fast radio bursts, gravitational waves, and ultra-diffuse galaxies. Almost 300 participants from 23 different countries attended which ensured stimulating discussions during question time. As an added benefit, the talks were recorded and placed on ASTRO 3D's YouTube channel where they have already accumulated over 3000 views.

Feedback has been overwhelmingly positive, with speakers and attendees alike pleased to have the opportunity to share in the amazing science being caried out by Australia's junior astronomers. Hopefully come job season, our seminar speakers will be more visible and have a nice talk to attach to their CVs! Many thanks go to the International Seminars Committee team members: Dorota Bayer, Marianne Girard, Anishya Harshan, Yifei Jin, Meridith Joyce, Clare Peter, and Jeffrey Simpson.

Amelia Fraser-McKelvie on behalf of the International Seminars Committee







THE 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 2021, Chair Kim-Vy Tran (UNSW) issued an annual call for expressions of interest. The 2021 EDI Committee of 20 members represents the full spectrum of career stages and ASTRO 3D institutes. The EDI Committee has zoom meetings on the second Wednesday of every month.

The focus for 2021 was assessing our overall progress in meeting the goals set in the original EDI action plan, especially in light of short and long term effects of the pandemic. Our activities were grouped into three main categories: 1) Professional training opportunities; 2) Resource development; and 3) Assessment of EDI strategies. We also organised a Black Lives Matter working group that is now formally a sister committee to EDI and charged with carrying out the BLM action plan developed in 2020.

PROFESSIONAL TRAINING OPPORTUNITIES IN 2021

- We continued our partnership with the OzGrav Centre of Excellence to run the joint EDI Journal Club and included in 2021 a series of professional development webinars. The four webinars were organised by OzGrav and focused on stress and research survival tips for Early Career Researchers.

- In April, Denise Castle and Ingrid McCarthy organised the SBS Cultural Inclusion Training that provided different perspectives from real people through a series of videos. The fully online course is a helpful resource for understanding the changing demographics in Australia. The 90% completion rate for the SBS Training demonstrates the strong commitment by ASTRO 3D members to fostering an inclusive and supportive professional environment.

- In October, Vy Tran organised a workshop to help demystify the process of applying for academic fellowships and faculty jobs for Early Career Researchers (see Highlight on Academic Applications Workshop). With the help of Rebecca Davies, Anishya Harshan, Glenn Kacprzak, Richard McDermid, and Emily Wisnioski, the team held a fully virtual workshop with about 50 participants across all the ASTRO 3D projects and nodes. Feedback was extremely positive with excellent suggestions from participants of ideas for a future workshop.

- For the December Annual Retreat, Ingrid McCarthy organised a Welcome to Country by Aunty Sharyn for attendees at the Fairmont Resort in the Blue Mountains. The program also included an Indigenous Cultural Awareness Training with Dave Widders; an in-person cultural training was also organised for attendees in Western Australia.

EDI RESOURCES IN 2021

- In the first half of 2021, we completed the ASTRO 3D Hiring Guidelines to be used in addition to the ASTRO 3D Recruitment Policy from September 2018 and the hiring policies of the institution. The Hiring Guidelines provide recommendations for three phases: 1) Preparing Hire; 2) Hiring Process; and 3) Post-hiring Assessment. We circulated the Hiring Guidelines for feedback from the ASTRO 3D community and to adopt for future hiring rounds.

- There is growing evidence that COVID and lockdowns have immediate and long term effects on personal well-being and career progression. We have prepared guidelines for hiring committees and applicants to include a statement on “Achievements Relative to Opportunity.” The guidelines recommend that hiring panels invite applicants to include a brief statement on how COVID has impacted their career progression. We also provide example COVID impact statements that can be tailored as needed to include in applications.

- To help foster and support an inclusive and diverse workforce, we need to determine whether our EDI strategies are effective at recruiting people from all groups in our society. The EDI committee developed optional demographic questions that were included in the 2021 ASTRO 3D climate survey and added to the hiring guidelines. We hope that the demographic questions can guide respectful long term assessments within our academic communities.

- The 2020 BLM Action Plan is in the hands of a very energetic team led by Christene Lynch and Nichole Barry, and is now officially a sister committee to the EDI committee. The BLM team is active on multiple fronts including developing posters on Indigenous astronomy and engaging with Indigenous elders for feedback on content. Christene Lynch provided a progress report at the joint EDI journal club in July, and it was great to hear about coordination of efforts across the nodes and especially with Delese Brewster, Duane Hamacher, and Tash Marshall.

EDI ASSESSMENTS IN 2021

- The EDI committee reviewed the demographics of the ASTRO 3D Early Career Researcher Seminar series and were pleased to see that the double-blind process for selecting talks resulted in a gender representative and diverse cohort of speakers.

- ASTRO 3D was recognised with an ASA Pleiades Award in June with the successful proposal led by Katie Grasha, Marie Partridge, and George Heald. The Pleiades award committee gave the ASTRO 3D proposal high marks in all criteria which bodes well for the next round of Pleiades Awards in 2022.

- In June, Marie Partridge led the assessment of the ASTRO 3D 2019 Diversity & Inclusion Action Plan and confirmed excellent progress. Overall, ASTRO 3D has or is in the process of achieving most of the stated goals. The review also identified planned goals that are not possible, for example having a uniform set of reporting guidelines because of different policies across the ASTRO 3D nodes on confidentiality issues.

- To assess the experiences of ASTRO 3D members when they move onwards in their careers, Denise Castle led the development of an Exit Survey in July 2021. Through a series of optional questions, the 10 minute survey captures individual's perspectives on what being a member of ASTRO 3D is like at the node and Centre-wide levels. The survey is anonymous and responses are reviewed with strict confidentiality by professional staff.

- We end 2021 with the findings from the ASTRO 3D Climate Survey that closed in September. With an impressive completion rate of 59%, we hope to learn how we can better support our community and make positive change within astronomy and beyond.

Kim-Vy Tran On behalf of the EDI Committee.

THE SUSTAINABILITY COMMITTEE

With the chair of the Sustainability Committee on parental leave for much of the last 12 months, we found 2021 to be somewhat challenging, however, some progress has been made!

Dr Phil Taylor (ANU) provided guidelines for reducing household and office rubbish sent to landfill. Composting food waste, being mindful of packaging when making purchases, repairing broken items rather than replacing them, buying secondhand, being a responsible recycler, and recycling as much as you are all suggestions we can take on board, both at home and in workplaces. Many of these practical initiatives are being implemented at ANU, and we hope that many other Nodes will start to implement them in 2022.

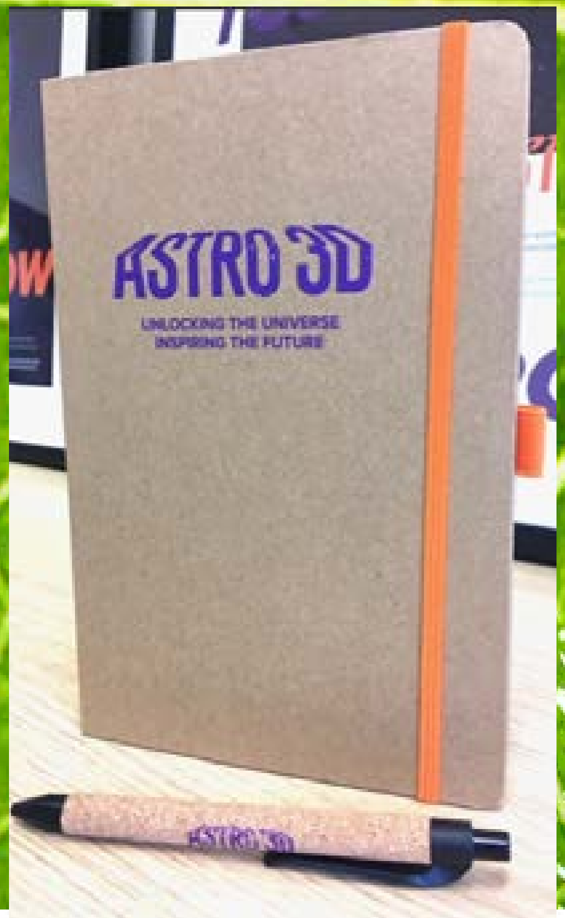
In April, Dr Adam Stevens (UWA) shared an open letter from Astronomers for Planet Earth, that asks for sustainability to become a core practice of all astronomical endeavours. It acknowledges that astronomy research contributes a large carbon footprint, via computation, telescope operations and travel. The letter is still open for you to sign, and as ASTRO 3D, we will continue to endeavour to suggest ways we can help reduce our impact on the planet.

One silver lining of the continuation of COVID restrictions was the move towards hybrid meetings. The Chief Operating Officers of Centre's of Excellence recognise how difficult hybrid events can be – fully virtual or fully in-person are much easier to organise! Hybrid events are difficult to do well. ASTRO 3D utilised Zoom for our fully virtual Science Meeting, however, it was less successful and interactive as a tool for our hybrid Annual Retreat. We will be looking into better tools and software to enable all our events to run as hybrid in the last couple of years of the Centre.

Our Annual Retreat also saw a new award for Championing the Environment, highlighting our commitment to this important issue and the winner was Andy Casey! We look forward to many nominations for this in 2022!

As we move back to in-person events, COO Ingrid McCarthy has drafted Sustainable Event Guidelines, so that our environmental impact in both travel and the event itself can be minimised. The Guidelines will be reviewed by the Committee in early 2022 and be widely circulated.

The Committee will be calling for new members in 2022, and are looking forward to publishing our Guidelines and providing more practical advice on how we can help ASTRO 3D become more sustainable.



SCIENCE MANAGEMENT COMMITTEE ACTIVITY PLAN 2022

GENESIS SIMULATIONS

Develop suite of controlled non-cosmological simulations and cosmological zoom counterparts to study outflows and their signatures that can be probed in IFU surveys.

Write introductory paper on Genesis hydrodynamical simulations with a focus on outflows and observable signatures.

Exploit first data of the MAGPI survey by comparing with simulations.

Provide SAMI/HECTOR teams with simulated IFU-like data from EAGLE.

Release of SimSpin v2.0 for the IFU community, with significant improvements made for the observation of hydrodynamical simulations.

Publish paper on the statistical calibration of Meraxes against multiple observational datasets and redshifts.

Ingestion of Genesis data into SAGE.

Publish paper on the cosmic variance in the 21cm signal using the new model with extended trees.

DATA INTENSIVE ASTRONOMY (DIA)

Report on results of Pawsey PACER programs for ASTRO-3D science projects (DINGO).

Report on results of AusSRC programs for ASTR0 3D science projects (WALLABY, FLASH).

Initial internal release of Hector data products through the Optical Data Centre (ODC) archive interface.

Report on prototype 'archive' interface to Genesis-related numerical/hydro simulation outputs through ODC.

MWA EOR SURVEY

Submit the MWA Real Time System description paper.

Complete Hyperdrive software for Direction Independent and Direction Dependent calibration and for redundant calibration, spectral regularisation.

Develop and implement data quality visualisation with DuG.

Explore the effect of diffuse emission on the EoR end-to-end pipeline.

Apply new ionospheric corrections, and LoBES catalogue to deep integration of data.

Define extended source subtraction threshold for EoR2 processing.

Determine interferometric Effects of Deformed Beams including Depolarisation & Rotation Measure.

FIRST STARS PROJECT

Obtain high-resolution UV spectra from UVES/VLT for the most metal-poor stars known to determine abundances of O and compare with extragalactic sources at high redshift.

Determine the detailed chemical composition of the extremely metal-poor star SMSS J0843--1415 that has exceptionally high [Zn/Fe] and light s-process element abundances to constrain, for the first time, nucleosynthesis in electron--capture supernovae.

Make ESO DDT observations awarded with VLT/UVES.

Calculate updated stellar nucleosynthesis models of metal-poor asymptotic giant branch (AGB) stars.

Calculate new stellar interior models of primordial and extremely metal-poor low and intermediate-mass stars.

Simulate convective-reactive (CR) events using 3D and 1D+ nuclear-hydrodynamics to investigate fast evolutionary phases in primordial stars.

Model the impact of binary stars on the yields of AGB stars.

FIRST GALAXIES PROJECT

Measure the z~8 luminosity function from the SuperBoRG survey.

Contribute to JWST PASSAGE survey: identification of z>8 galaxies from large area slitless spectroscopy.

Adapt BoRG pipeline for applications to NIRCAM parallel data for identification of z>6 sources.

Data-model comparison for absorption and emission spectroscopy in GRB host galaxies with the Eagle simulation.

Analyse spatial correlations between z~2 and z~8 Lyman Break galaxies and connections to contamination in high-z samples.

Analysis of NIRCAM parallel data for identification of z>6 sources.

GALAXY EVOLUTION PROJECT

Publish papers on XQR-30 metal absorber catalogue and on the redshift evolution of CIV cosmic mass density.

Complete DUVET Pilot Paper 1.5 describing outflows vs CO flux and multiphase outflow analysis paper.

Publish DUVET papers on Face-on Galaxies, outflow in NGC1569 and geometry of outflows.

Publish metallicity gradient paper for TYPHOON spirals.

Create TYPHOON HII region catalogue.

Make comparison of observed metallicity gradients with the Illustris simulation.

Complete paper describing cause of low gas fractions in the early Universe in massive proto-cluster galaxies.

Perform AGEL follow-up observations.

ASKAP SURVEYS

Submit ESO and ALMA proposals for FLASH follow-up.

Start the full FLASH survey.

Improve the DINGO phase 1 equatorial data quality and create value-added data products.

Process DINGO pilot phase 2 data.

Complete follow-up paper on HI scaling relations.

Start the full DINGO survey.

Make the public release of WALLABY pilot survey phase 1 value-added data.

Submit the WALLABY data release paper.

Start the full WALLABY survey.

Organise 2022 WALLABY science meeting.

SAMI/HECTOR SURVEY

Submit SAMI paper connecting spin, age and environment.

Publish paper on connecting gas accretion and kinematic misalignment to simulations (based on SAMI).

Develop Hector stellar kinematic pipeline.

Compare stellar kinematic properties of Milky Way Analogues from Hector and SAMI.

GALAH SURVEY

Compare chemodynamics of GALAH with hydrodynamical simulations of spiral galaxies.

Determine the radial and vertical abundance gradients of the Galaxy.

Upgrade the new pipeline of The Cannon and SME to take into account non-spectroscopic information in a Bayesian framework.

Complete novae yields, metal-rich AGB yields, and CNO studies of metal rich stars.

Complete study of impact of binaries with metal-rich stars and core collapse AGB boundary.

Complete the paper on Milky Way surrogate N-body models.

GENESIS THEORETICAL SIMULATIONS

The ASTRO 3D Genesis simulation program focuses on the following 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 (IGM);

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; and

3. Uncovering the history of the local galaxy population, including radio galaxies and 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 the ASTRO 3D and 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), and our own in-house runs targeting individual galaxies (both non-cosmological and cosmological zooms), which address specific problems with an ASTRO 3D focus.

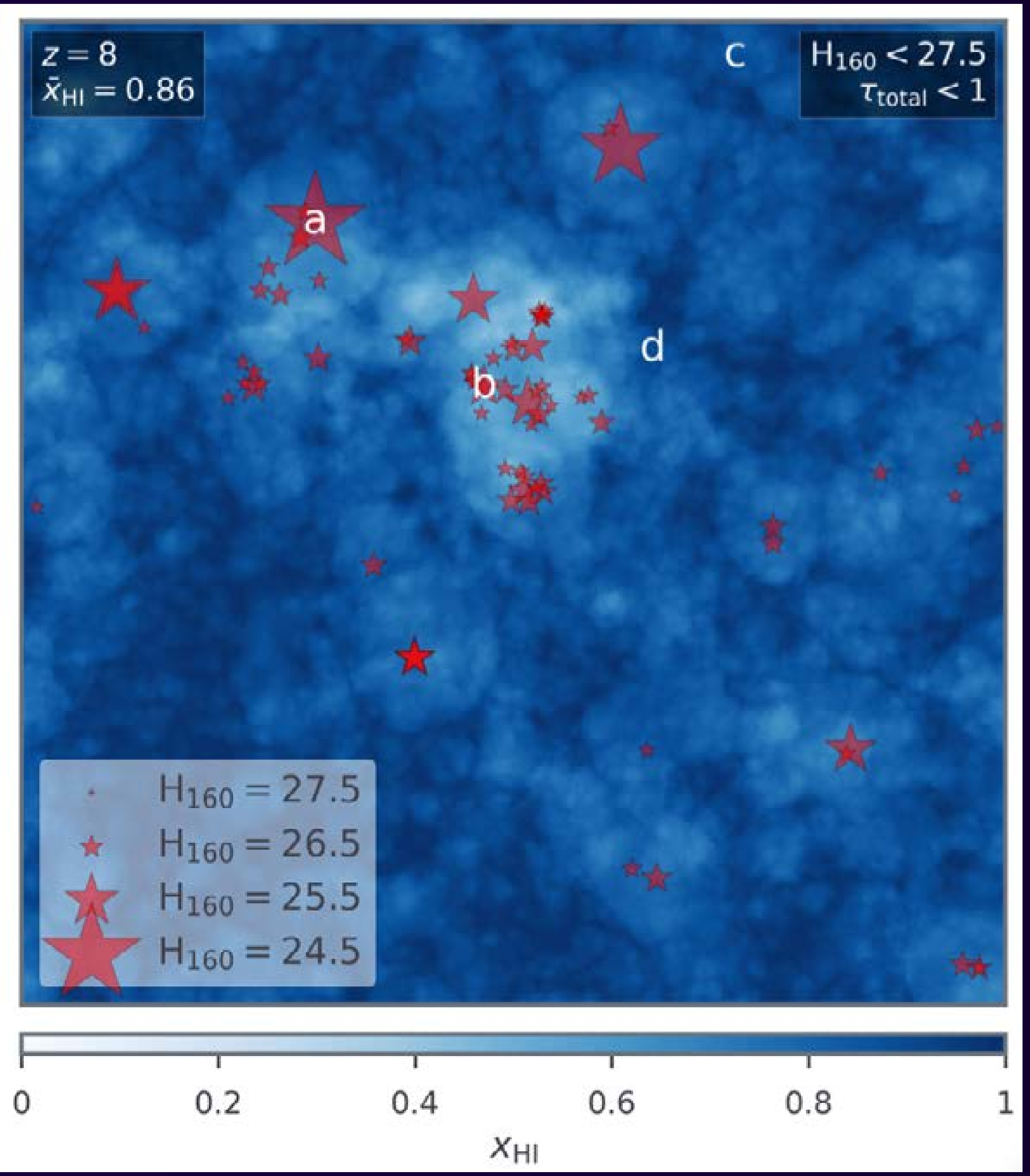


Fig 1: The neutral hydrogen fraction (xHI) of a simulated volume at z=8 (projected with a depth of 100cMpc). Only UV-bright, Lyα transparent galaxies are shown. From Qin et al. 2021.

2021 PROJECT HIGHLIGHTS

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 large, high resolution, volumes. These simulation have the resolution to resolve low-mass dark matter halos that powered the growth of the ionising background during the Epoch of Reionisation (EoR), along with 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 modeling the EoR leverages novel work by ASTRO 3D PhD student, Balu Sreedhar, extending work done by former student, Yisheng Qiu, who 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, Balu has been able to extend the effective mass resolution of our highest resolution Genesis simulation by a factor of 10, with an effective particle number of over 1 trillion particles. This allows us to model the formation of the first star forming haloes at z=20.

ASTRO 3D PDRA Yuxiang Qin has examined Lyα transmission through the inter-galactic medium and the environments of bright galaxies during the EoR using the Meraxes sem-analytic model. Unexpectedly, observations reveal Lyα emission from galaxies at high redshifts, contrary to expectation if the IGM is neutral, suggesting that they are in the vicinity of luminous galaxies that have ionized the local IGM. Using Meraxes, Yuxiang has reproduced the observations, and predicts that the JWST will discover many such Lyα detectable neighbors, offering a novel means to map the morphology of Reionisation. How such galaxies cluster during the EoR is shown in Fig 1.

ASTRO 3D PDRA Kate Harborne has been developing v2.0 of her SimSpin package, which generates integral field spectroscopic datacubes from simulated galaxies, and using it to generate samples of SAMI/HECTOR and MAGPI survey. SimSpin v2.0 can now produce full spectral energy distributions, incorporating the metallicities and ages of stellar populations, as well as gas properties. Kate is working closely with several ASTRO 3D projects, providing the bridge between Genesis data products and the specific project requirements.

ASTRO 3D PhD student Garima Chauhan studies the relationship between neutral atomic hydrogen (HI) mass and host halo virial mass using the SHARK semi-analytical model and the prospects for its accurate recovery in current and forthcoming galaxy surveys. HI stacking can be used to obtain a measurement of the HI mass in a halo, but the shape of the recovered relation has been sensitive to the technique used. By constructing mock HI and optical galaxy catalogs and applying the different techniques that have been used in the literature, Garima demonstrated that a combination of effects influence both the halo mass and HI mass estimates, but that future, deeper, galaxy surveys such as 4MOST WAVES can more accurately recover the intrinsic relation (see Fig 2).

ASTRO 3D PhD student Adam Batten has investigated how Fast Radio Bursts (FRBs) can be used to probe ionized baryons in the intergalactic medium (IGM). Using the EAGLE simulations to provide a mode ionized baryons in the IGM, Adam computed the dispersion measure, which corresponds to the integrated column density of electrons along the line-of-sight, and was able to deduce the mean relationship between dispersion measure and the redshift of a source, accounting for realistic large-scale structure and the effects of under- and over-dense regions along the line of sight. This model is publicly available in the FRUITBAT python package.

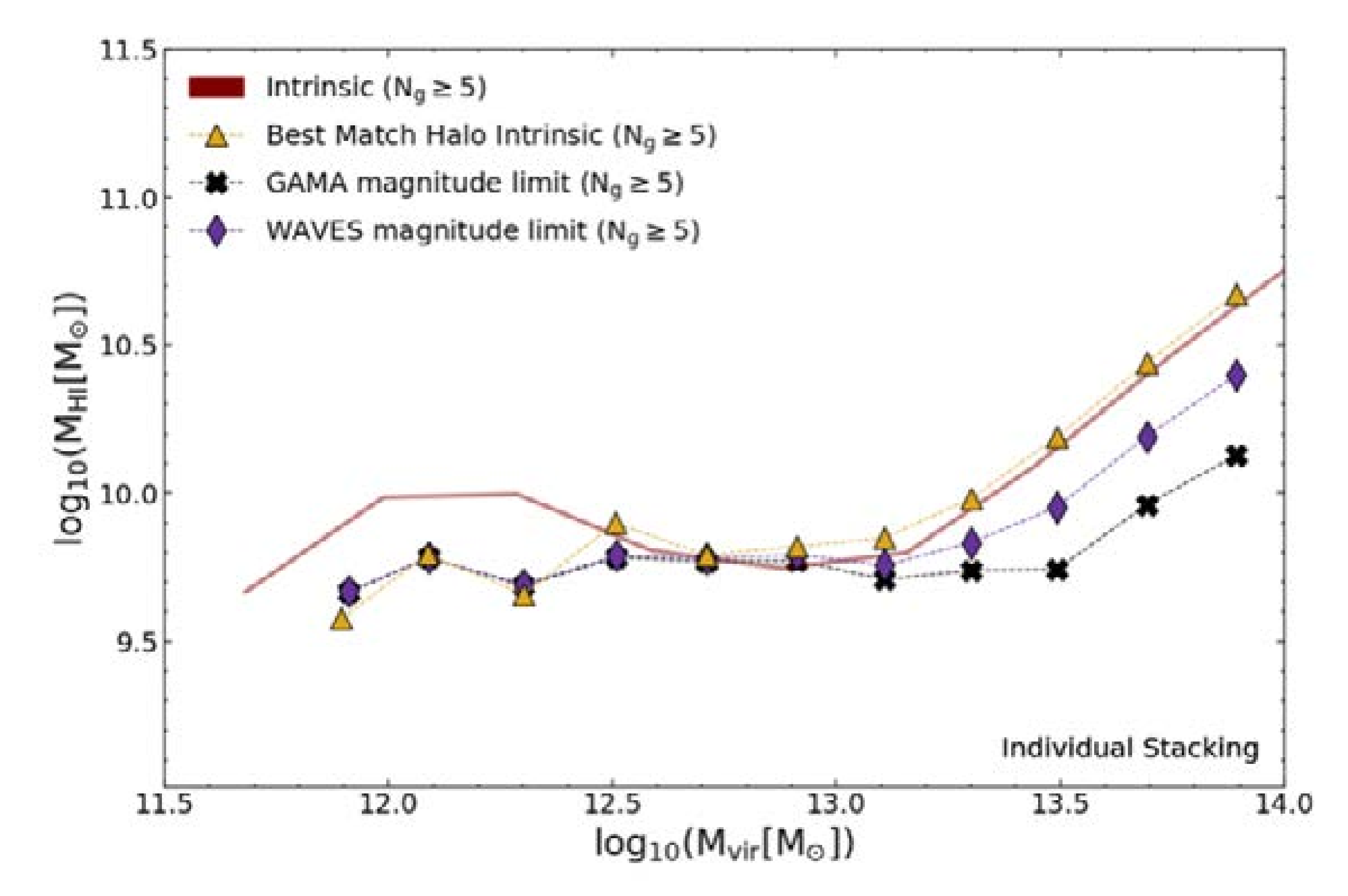


Fig 2: Comparison of the neutral atomic hydrogen mass in galaxies associated with galaxy groups as a function of galaxy group virial mass. The intrinsic relation is given by the red line, while the symbols correspond to relations recovered by the galaxy group finder based on selection criteria adopted by galaxy surveys (e.g. GAMA, 4MOST WAVES). From Chauhan et al. 2021.

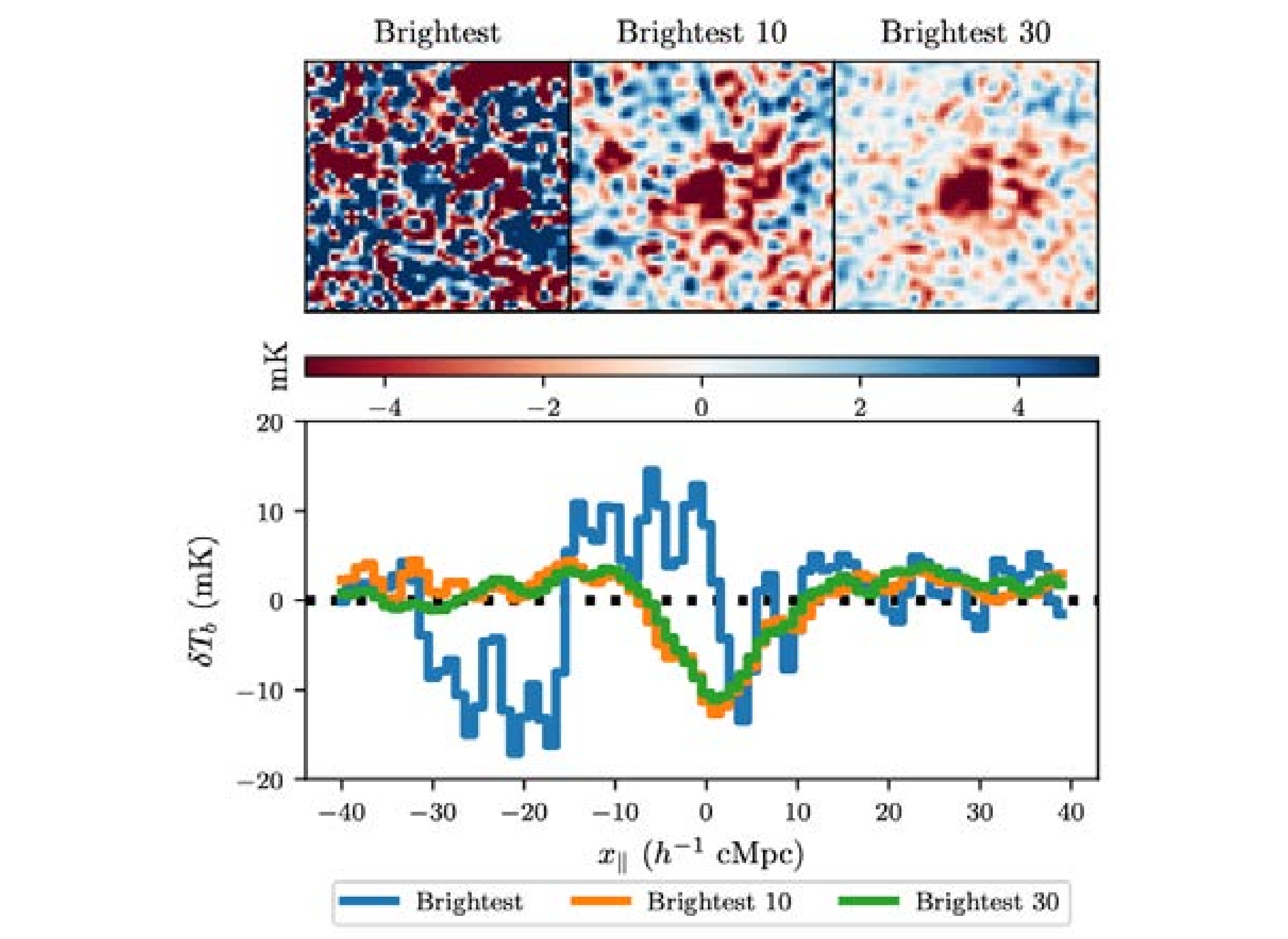


Fig 3: From top left to top right, brightness temperature slices of the single, 10, and 30 brightest simulated galaxies at z=9. The central region becomes clearer as more images are stacked. As more galaxies are stacked, the detected deficit in brightness temperature along the line-of-sight becomes evident, as shown in the bottom panel. From Davies et al. 2021.

ASTRO 3D PhD student James Davies worked with the BLUE TIDES simulation to investigate the feasibility of experiments with the Square Kilometer Array (SKA) to detect ionization by the first stars and galaxies during the EoR. By constructing mock observations, James showed that stacking redshifted 21cm emission images around optically identified bright galaxies could allow HII regions to be detected with the SKA at z=9, during the EoR. As shown in Fig 3, increasing the number of bright galaxies in the stack improves the chances of detecting the ionized region, as is evident from the change in brightness temperature in the proximity of the stacked galaxy.

Finally, congratulations to several of our ASTRO 3D PhD students, who successfully completed their PhDs - including Lucie Bakels, Garima Chauhan, James Davies, and Dian "Pipit" Triani.

GENESIS

DR DIAN (PIPIT) TRIANI

Postdoctoral Researcher
Australian National University
Genesis
Galaxy Evolution

ABOUT ME

I am interested in the physics of galaxies. Many processes occurred in galaxies across cosmic time, from gas infall, gas cooling, star formation and the inflow/outflow. We get information about these processes from the light we receive from them. The process of producing light in galaxies also amazes me. We need to consider the stellar age, metallicity, surrounding dust and nebular properties. My research is either modelling the physics in galaxy evolution or the physics involved in galaxy emission. I have developed a new semi-analytical model that incorporates detailed dust treatment, essential for gas cooling, star formation and galaxy spectra across UV to infrared. This model will run on Genesis N-body simulations, giving us a very high resolution of the dust properties. I have also developed a tool to generate UV to IR broadband spectra based on the dust properties from the model. Now I am working on modelling emission-line properties, which will provide a description of the molecular region around the stars in galaxies and help us tie the simulation with the observations.

WHY ASTRONOMY?

I grew up in Lombok, a small island in Indonesia where you can clearly see the pristine night sky. I often go to the beach to watch the stars and Milky Way, especially if the electricity is out (which is scheduled, happens 1-2 nights a week). I guess that's how I got curious about the heavenly bodies and started reading books and watching shows about Astronomy. When I finished high school, I got a scholarship to study Astronomy at the University, and that's what really brought me to be an astronomer.

WHAT I LOVE ABOUT ASTRONOMY

The intelligent way people infer what happened in the Universe from the very limited information that we got (and how people designed the observations to get data). Also, the travels and conferences where I can connect with like-minded people while chilling in beautiful locations.

WHAT I DON'T LOVE

The main challenge for me is the need to do international job hunting and constantly moving. We always need to start over a life when starting out a position, my partner needs to find a job, we need to make new friends, and we have to adapt to the new city.

IF I WASN'T AN ASTRONOMER, I WOULD BE...

Working in a gym full-time as a fitness or dance instructors (or maybe opening my own place). I love dancing and am currently teaching Zumba as a hobby. I want to help people get healthy and have fun while doing it.

A HIGHLIGHT IN 2021

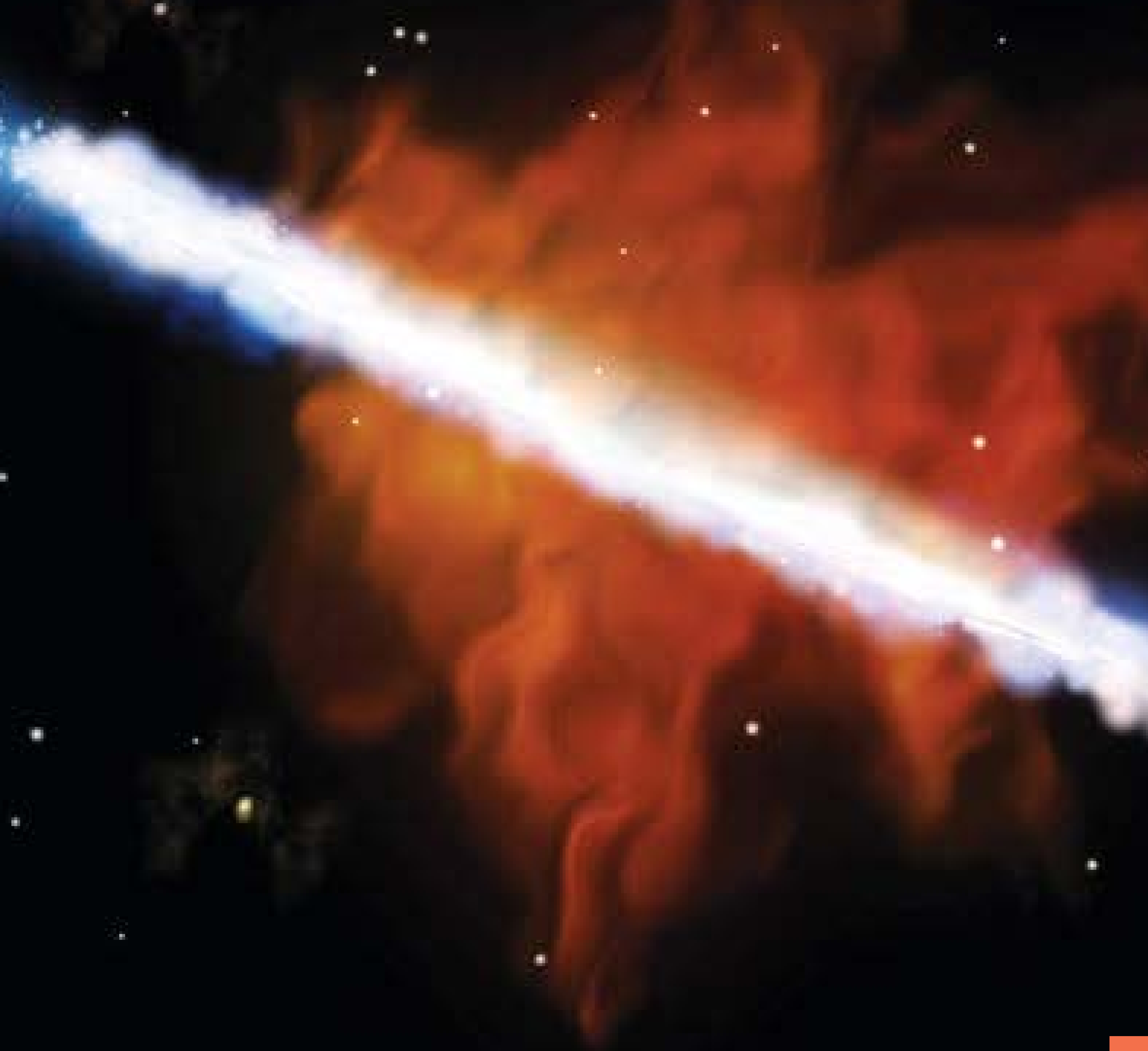
I got an ASTRO 3D postdoctoral position, finished up my PhD thesis, passed my Viva (becoming a Dr!) and moved to Canberra for my postdoc.

I SURVIVED COVID IN 2021 BY...

Lots of dancing, sometimes I offered a free online Zumba class and danced with my participants. I also take long walks and meditation regularly. Online shopping and ordering bubble tea also help when it gets tough. Doing these boosted the motivation I needed when writing my thesis. I also tried to cut myself slack whenever I got demotivated during the lockdown.

GALAXIES PUMP OUT CONTAMINATED EXHAUSTS

RESEARCH REVEALS HOW STAR-MAKING POLLUTES THE COSMOS



Galaxies pollute the environment they exist in, researchers have found.

A team of astronomers led by Alex Cameron and Deanne Fisher from the ARC Centre of Excellence for All Sky Astrophysics in 3 Dimensions (ASTRO 3D) used a new imaging system on at the WM Keck Observatory in Hawaii to confirm that what flows into a galaxy is a lot cleaner than what flows out. The research is published today in The Astrophysical Journal.

“Enormous clouds of gas are pulled into galaxies and used in the process of making stars,” said co-lead author Deanne Fisher, associate professor at the Centre for Astrophysics and Supercomputing at Swinburne University in Australia. “On its way in it is made of hydrogen and helium. By using a new piece of equipment called the Keck Cosmic Web Imager, we were able to confirm that stars made from this fresh gas eventually drive a huge amount of material back out of the system, mainly through supernovae."

“But this stuff is no longer nice and clean – it contains lots of other elements, including oxygen, carbon, and iron.”

The process of atoms flooding into galaxies – known as ‘accretion’ – and their eventual expulsion – known as ‘outflows’ – is an important mechanism governing the growth, mass and size of galaxies.

Until now, however, the composition of the inward and outward flows could only be guessed at. This research is the first time the full cycle has been confirmed in a galaxy other than the Milky Way.

To make their findings, the researchers focused on a galaxy called Mrk 1486, which lies about 500 million light years from the Sun and is going through a period of very rapid star formation.

“We found there is a very clear structure to how the gases enter and exit,” explained Dr Alex Cameron, who has recently moved from University of Melbourne in Australia to the UK’s University of Oxford.

“Imagine the galaxy is a spinning frisbee. The gas enters relatively unpolluted from the cosmos outside, around the perimeter, and then condenses to form new stars. When those stars later explode, they push out other gas – now containing these other elements – through the top and bottom.”

The elements – comprising more than half the Periodic Table – are forged deep inside the cores of the stars through nuclear fusion. When the stars collapse or go nova the results are catapulted into the Universe – where they form part of the matrix from which newer stars, planets, asteroids and, in at least one instance, life emerges.

Mrk 1486 was the perfect candidate for observation because it lies “edge-on” to Earth, meaning that the outflowing gas could be easily viewed, and its composition measured. Most galaxies sit at awkward angles for this type of research.

“This work is important for astronomers because for the first time we’ve been able to put limits on the forces that strongly influence how galaxies make stars,” added Professor Fisher.

“It takes us one step closer to understanding how and why galaxies look the way they do – and how long they will last.”

Other scientists contributing to the work are based at the University of Texas at Austin, the University of Maryland at College Park, and the University of California at San Diego – all in the US – plus the Universidad de Concepcion in Chile.

Animation and stills available at www.scienceinpublic.com.au

Galaxies pump out contaminated exhausts,
Credit: James Josephides, Swinburne Astronomical Productions.

JAMES JOSEPHIDES - SWINBURNE ASTRONOMY PRODUCTIONS

DATA INTENSIVE ASTRONOMY - DIA

The Data Intensive Astronomy (DIA) program 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.

2021 PROJECT HIGHLIGHTS

In 2021 the DIA team at Swinburne released the new Vis3D data visualisation tool in TAO. Vis3D is launched from the catalogue page of an already built mock galaxy catalogue and allows the user to interactively explore their data in three dimensions within the browser. Filters can be applied to cut the data on any (and multiple) galactic or halo properties to focus on the science of most interest. Various views into the data can be saved, and each can be downloaded locally for further analysis. Vis3D also makes visually striking images for talks, papers, and outreach.

As also reported under ASKAP HI surveys, the SoFiA source-finder development team, led by AI Tobias Webster, published their SoFiA2 paper, which describes the performance of a new, parallelised version of their freely available code. A number of international teams used SoFiA in the latest SKAO Science Data Challenge. SoFiA was the top-ranked 'blind' source-finder, and came in at third overall as judged by a set of metrics related to completeness, reliability and parameterisation accuracy.

Macquarie University joining ASTRO 3D as a node in 2021 brought the Data Central team directly into the Data Intensive Astronomy efforts of ASTRO 3D. In addition to enhancing the Centre's cross-project collaborations (see later), Data Central plays a key role in integrating international data archives with ASTRO 3D data sets. In particular, the new Data Central "Data Aggregation Service" now connects data held in the ESO archive with data in the Data Central system, using Virtual Observatory interoperability standards. Users can now search for objects and the system will query the ESO Table Access Protocol (TAP) service and download and reduce associated images and return them to the user with Data Central (and other) catalogues overlaid, thus enhancing the searchability and usability of ESO and ASTRO 3D data sets.

2021 PERSONNAL HIGHLIGHTS

Congratulations to ASTRO 3D postdoc Manodeep Sinha (Swinburne) who was successfully promoted. Manodeep's EMCR membership of the National Committee for Astronomy entered its second year, where he was able to make contributions and submissions on subjects related to career development for Research Software Engineers and best practice for software publication and citation.

Thanks to Vitaliy Ogarko who departed for a new position in Geoscience. Vitaliy made fine contributions to the improvement in functionality and performance of ASKAP calibration algorithms and, during his time at ASTRO 3D, also contributed to a number of cross-disciplinary studies relating to sub-surface imaging!

Two new hires will shortly be made at Macquarie to support ASTRO 3D surveys.

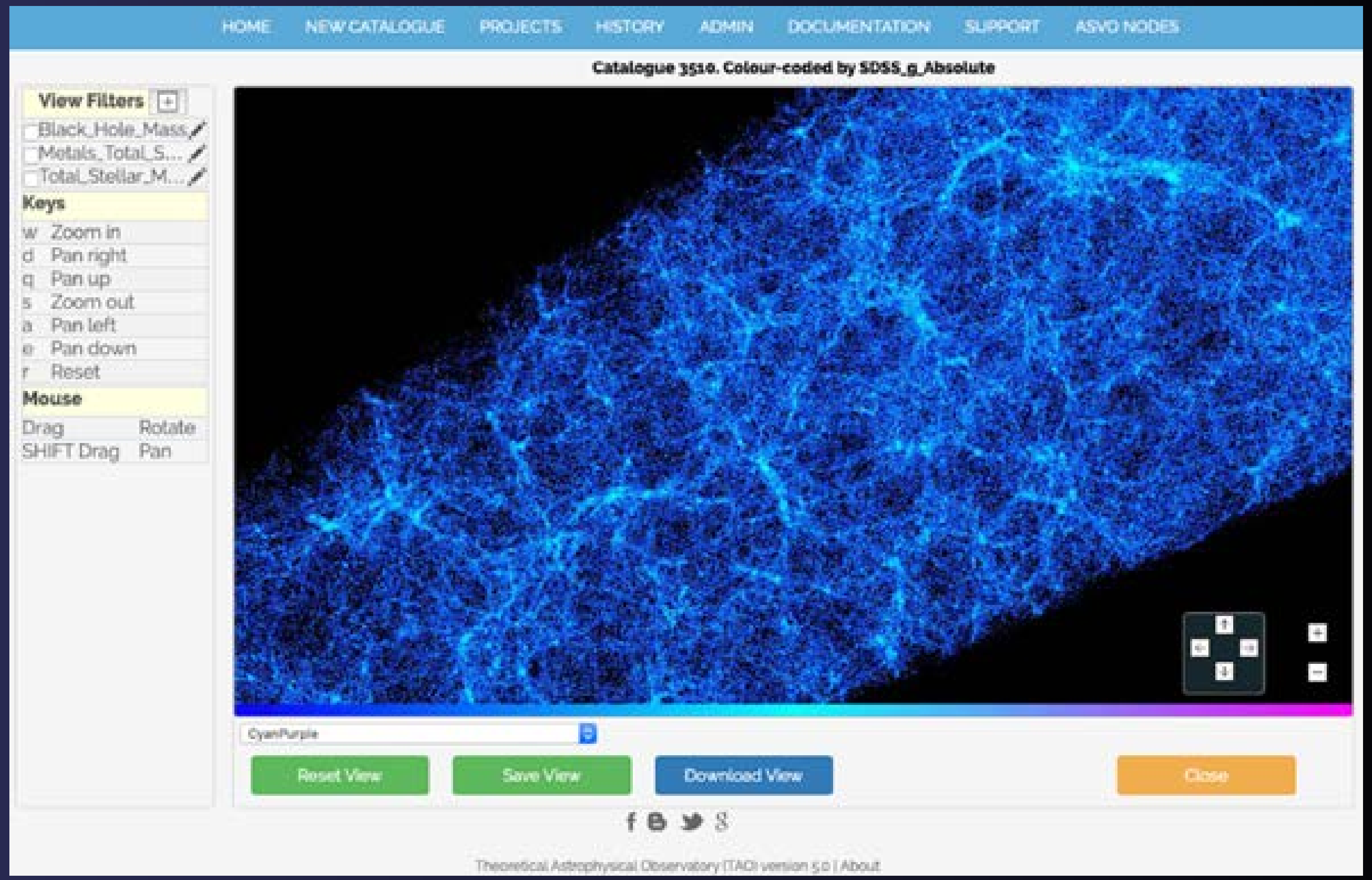


Figure 4: the new Vis3D tool of the Theoretical Astrophysical Observatory (TAO) allows users to interactively explore mock galaxy catalogue data.

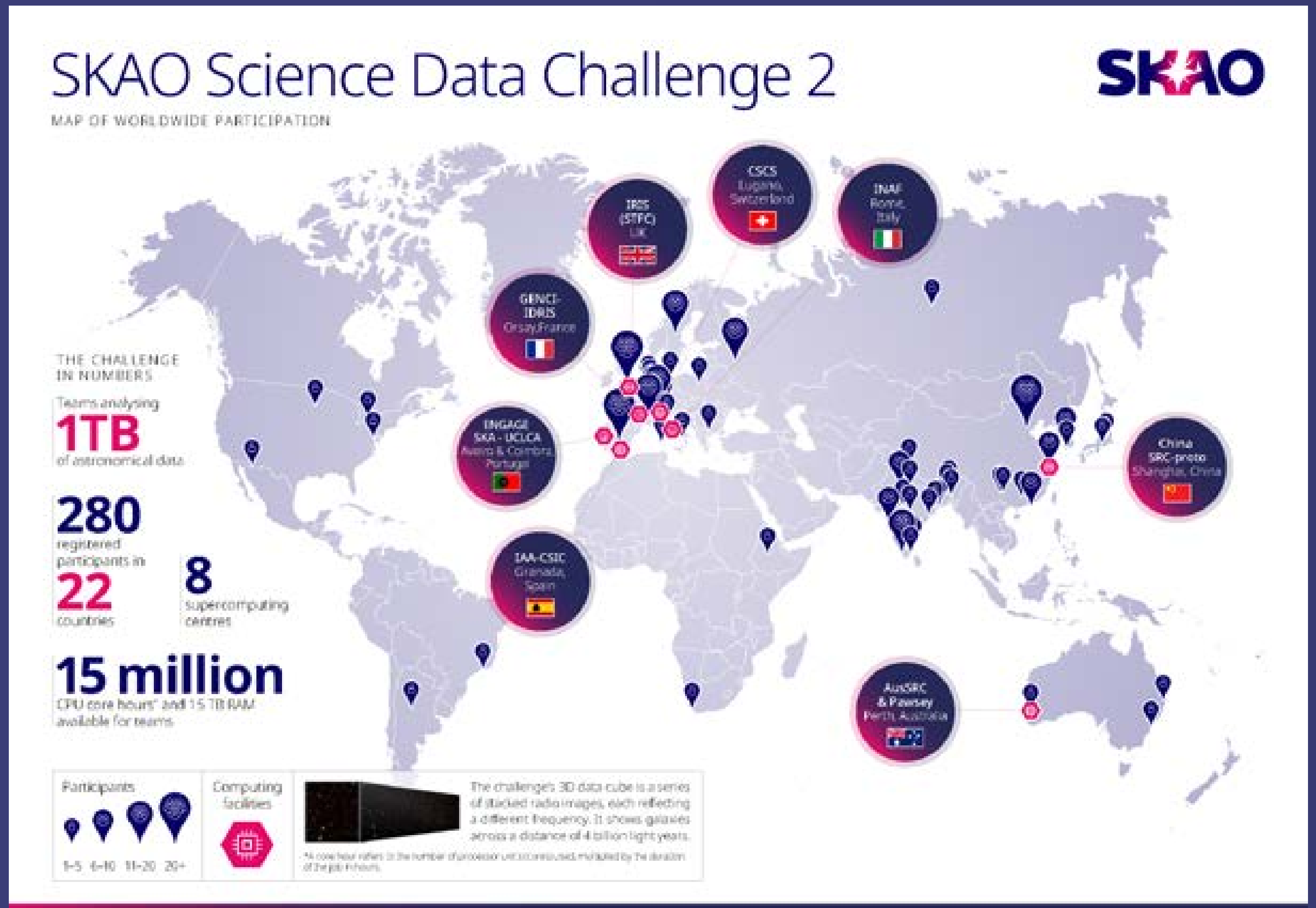


Figure 5: the worldwide distribution of software teams and computing facilities involved in the recent SKAO spectral-line data challenge (credit: SKAO).

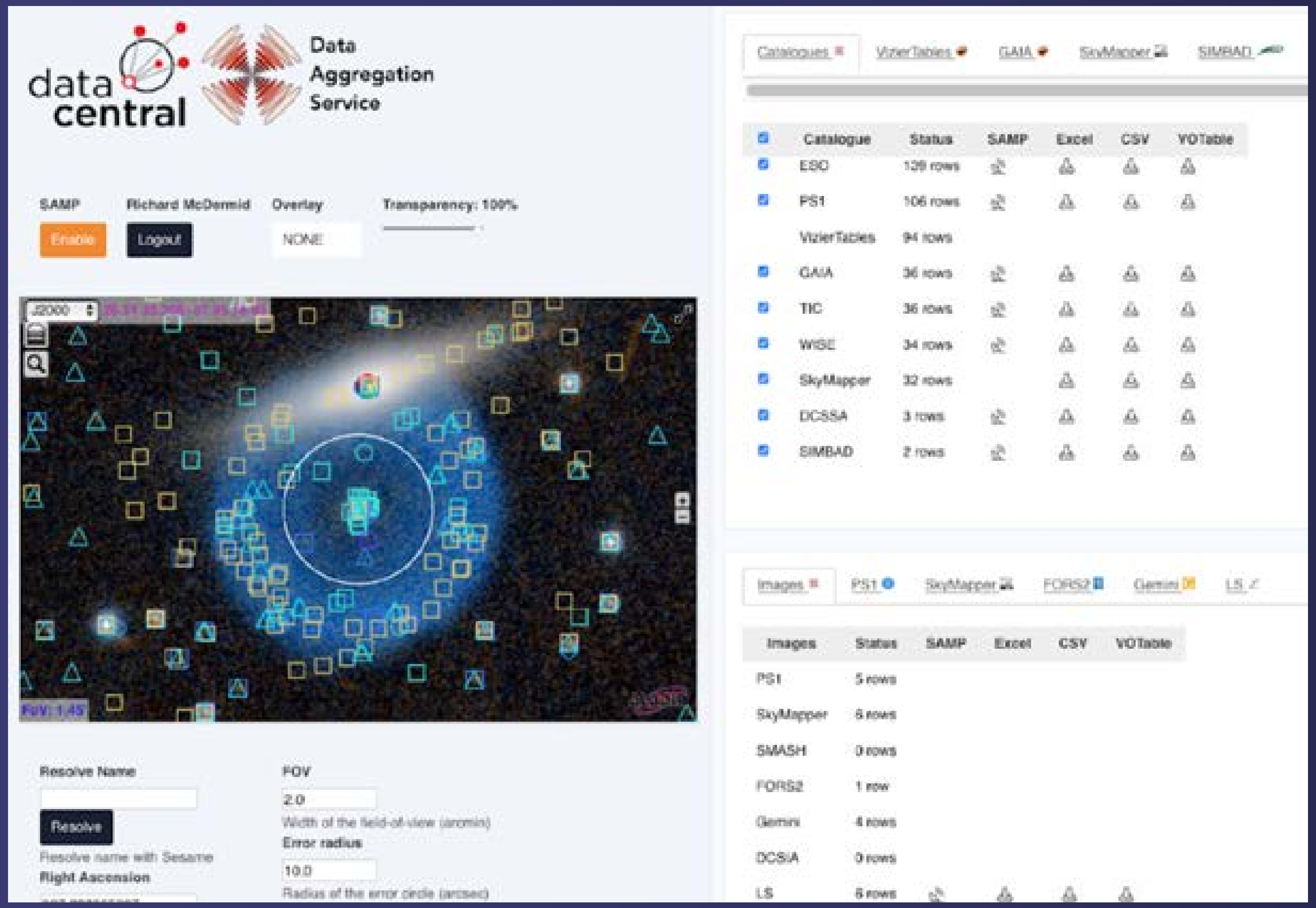


Figure 6: An example query using the Data Central "Data Aggregation Service", seamlessly merging multiple archival data sets from Data Central (e.g. SkyMapper imaging), ESO, and others.

CROSS-PROJECT COLLABORATIONS

The Optical Data Centre (ODC) is an NCRIS-funded project that brings together the data services of Data Central and SkyMapper. It is jointly operated by Macquarie, ANU and NCI, and supports access to data from SAMI (and in the near future, Hector), GALAH and MAGPI for ASTRO 3D astronomers. The ODC uses VO protocols to provide easy access to spectral and multi-wavelength data (e.g. using the Data Aggregation described above). The next phase is to expand on these services, giving convenient access to multiple ASTRO 3D surveys via one interface. This will also include a pilot for access to theory data for the MAGPI survey.

The Data Intensive Astronomy team also continues to engage with national supercomputing providers, Pawsey and NCI, commercial providers such as DUG, cloud computing providers, partner organisation CSIRO, and the newly formed AusSRC consortium to ensure the delivery of adequate resources to ASTRO 3D simulators and the radio astronomy teams - ASKAP HI survey and MWA-EOR.

DR MANODEEP SINHA

Postdoctoral Researcher
Swinburne
Date Intensive Astrronomy

ABOUT ME

My goal is to understand *which* galaxies live in *what* dark matter halos - *the galaxy-halo connection*. I generate synthetic galaxies by applying empirical methods to cosmological N-body simulations' dark matter halo assembly histories. Since we have vast galaxy surveys with *real* galaxies, I can compare how closely the synthetic galaxies resemble the real Universe. To get a statistically robust understanding of the galaxy-halo connection, repeating this comparison with a Bayesian method allows us to constrain the key parameters that control the galaxy-halo connection - i.e., *which* galaxies live in *what* halos.

Over the past few years, I have become interested in not just the "why" of research but also the "how" and "who". For example, I am interested in "how" we develop and credit "research software" as a critical ingredient in the research process. For the "who", I see that the field of Astronomy needs to be more inclusive - gender equity is a key focus of ASTRO 3D, but there are a host of other social attributes that are missing. How we go about improving equity is a complex topic and needs significant participation from the most privileged researchers in Astronomy to have any hopes of progress.

WHY ASTRONOMY?

When I was in 7th grade, I was fascinated by the book called "Essays about the Universe" by Boris Vorontsov-Vel'yaminov. This book piqued my interest so much that I wanted to pursue a career in Astronomy. However, I knew that getting an undergraduate degree in Physics (or Astronomy) might be risky - I worried that my job prospects would be bad if I did not like Astronomy halfway through my undergraduate degree. I, therefore, decided to get an (Electrical) Engineering degree and then pursue Astronomy both during that degree and afterwards if I continued to like Astronomy. Turns out that I continue to be interested in Astronomy nearly 20 years later.

For my PhD thesis, I had to work with Vorontsov-Vel'yaminov catalogue of interacting galaxies. The name had sounded familiar, but I made the connection years later.

WHAT I LOVE ABOUT ASTRONOMY

I like the pursuit of a complex research problem and finding out (on the rare occasions) *why* something is the way it is. Since I predominantly work with enormous simulated datasets, I enjoy creating high-quality software that lets me explore, analyse and visualise these datasets.

WHAT I DON'T LOVE

Moving internationally, leaving friends and family behind, and adjusting to different cultures and expectations is extremely challenging.

IF I WASN'T AN ASTRONOMER, I WOULD BE...

Realistically, I would have been a statistician, but if I were to construct a fantasy occupation, it would be a train driver on the vast Indian Railways train network (I **love** trains).

A HIGHLIGHT IN 2021

I found out that my first-author software paper ([Corrfunc](https://ui.adsabs.harvard.edu/abs/2020MNRAS.491.3022S/abstract), a software package for computing correlation functions) was the highest-cited paper with a Swinburne (CAS) first-author - that was a pleasant surprise :)

I SURVIVED COVID IN 2021 BY...

COVID has been a blur, somewhat due to the pandemic but additionally, due to changed life circumstances - we became parents in Feb 2020. His name is Nikhil Sinha-Piscionere, and watching him grow up has been an absolute joy! Fatherhood, then, has been my secret to surviving the pandemic and the near-constant lockdowns here in Melbourne.

MURCHISON WIDEFIELD ARRAY EPOCH OF REIONISATION - MWA EOR

The cosmic dawn marks the birth of the first generations of stars in the Universe, only 200 million years after the big bang.

Their birth begins one of the largest cosmic-scale transitions in the history of the Universe - the epoch of reionisation

When the strong ionising light from the remnants of these stellar systems evaporated the fog of neutral hydrogen gas that filled the Universe, it left the transparent and ionised Universe we see today.

We use the radio emission line from the hyperfine transition of neutral hydrogen to trace the evolution of stars in this early period, more than 13 billion years in our past. The radio light is stretched by cosmological expansion to low radio frequencies, where we can study the signal with the Murchison Widefield Array (MWA) telescope, located in the Western Australian outback.

The structure of the hydrogen signal encodes key information about the physical conditions around the first stars and galaxies, and details of the early evolution of the Universe. International experiments have started to provide clues about the signal at these early times, but we have yet to detect the signals that tell us about the spatial structure and answer questions such as when and how the first stars formed, and what role black holes played in shaping the Universe we see today. The MWA Epoch of Reionisation program is taking thousands of hours of observations of the sky to extract this weak and ancient radio signal from all of the noise created from the rest of the Universe, and our own signals on Earth.

2021 PROJECT HIGHLIGHTS

The project has achieved a number of major milestones over the past year.

In the methodology program, these include the publication and implementation of the new Long Baseline Epoch of Reionisation Survey (LoBES) by Dr Christene Lynch, forming the new input sky model for the MWA EoR program. LoBES is being hosted on DataCentral for the international community, and will be used as the sky model catalogue for the Third SKA Data Challenge.
On larger scales, PhD student Mike Kriele produced the first m-mode all-sky images from the EDA2 array, providing us with a basis for modelling the diffuse emission in the sky. From an instrumentation perspective, PhD student Aman Chokshi led work to carefully map the telescope's response to the sky, using precision measurements from the Orbcomm satellite network as it passed over the array. Through this work we can better understand what the sky looks like to the telescope.

Dr Chris Jordan has the first release of the Hyperdrive software operating on the Pawsey Supercomputing Research Centre. This major pipeline development ingests legacy and MWAX data, and performs flexible calibration, and is expected to replace the RTS software over the coming two years. MWA EoR has also received support through the AusSRC program with Mx Dev McElhinney providing pipeline development for MWA and future SKA. Dr Bart Pindor continued to improve the existing RTS pipeline to treat the bandpass behaviour more accurately, and initiated the application of a new technique to use ionospheric information to improve calibration.

PhD student Kariuki Chege has been testing how deeply foreground galaxies should be removed from the dataset, given the information available, prior to using these lessons for improved power spectrum upper limits. New PhD student Jaiden Cook has used modelling of extended radio galaxies and supernova remnants in the EoR2 field to demonstrate that 99% of their signal needs to be removed before the EoR can be detected. This work complements Dr Ben McKinley's deep modelling of the large and bright Centaurus A radio galaxy.

This work also leads into the broader use of realistic simulations to test our data analysis methodology and augment the sky model. Dr Jack Line has been developing and testing the WODEN software to provide the testbed dataset for our experiment.

Scientifically, there were two major power spectrum results publications. Dr Shintaro Yoshiura published the deepest upper limits in the Epoch of X-ray Heating, pushing the MWA observing program to lower frequencies and broadening its scope. Completing PhD student, Mahsa Rahimi, led an analysis of data from the EoR1 field, applying several data analysis improvements to her pipeline to achieve competitive results. In addition to these, CI Assoc Prof Cathryn Trott published a paper constraining the temperature of the hydrogen gas around Lyman-alpha emitting galaxies detected with the Subaru Silverrush survey, in a new use of MWA data.

The MWA commissioned the new MWAX data correlator in November 2021, and MWA EoR was poised to be the first to process the new data. The upgraded correlator allows more flexible observing modes, and paves the way for the new receivers which will significantly improve the signal chain.

One of 256 'tiles' belonging to the Murchison Widefiled Array (MWA) radio telescope. Credit: Pete Wheeler

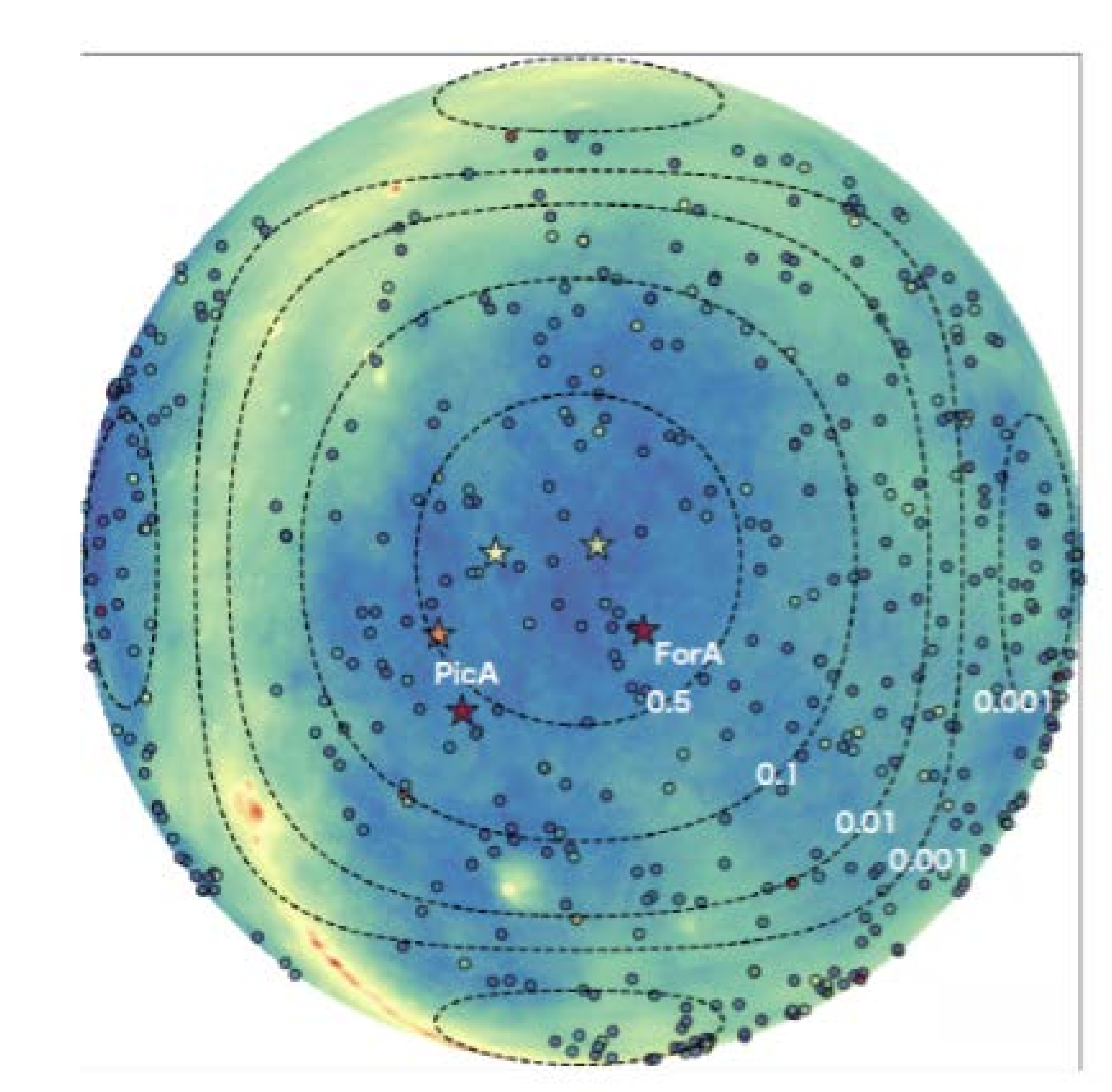


Figure 7: Sky map of the EoR1 observing field, showing dashed contours of the MWA sky response at 80-100 MHz. Yoshiura et al 2021, "A new MWA limit on the 21 cm power spectrum at redshifts 13-17", Monthly Notices of the Royal Astronomical Society, Volume 505, Issue 4, pp.4775-4790

2021 PERSONNEL HIGHLIGHTS

The following awards were received by project members in 2021.

1. CI Prof. Rachel Webster received 2020 Australia Day Honours as an Officer of the Order of Australia for distinguished service to education in the field of astrophysics, astronomical research, and to young women.
2. CI Prof. Cathryn Trott was awarded theNancy Millis Medal for Women in Natural Sciences, Academy of Science.
3. Postdoc Dr. Nichole Barry was awarded the Forrest Research Fellowship. Nichole also received ADACS support for porting of the FHD software to Python.
4. Postdoc Dr. Ben McKinley was elected as the Deputy Principal Scientist for the MWA telescope.

We welcomed new member PhD student Jaiden Cook at Curtin in September. Congratulations to the following students who completed their PhDs this year: Mahsa Rahimi (under review), Ronniy Joseph and Bella Nasirudin.

CROSS-PROJECT COLLABORATIONS

MWA EoR has established new connections with Galaxy Evolution, through Dr Anshu Gupta, who has joined the Curtin node as an ASTRO 3D Fellow. Anshu's EoR analogs work at z=2-4, and identification of Lyman-alpha emitters in MUSE fields at z=6, overlaps with the 21cm work being undertaken with the MWA.

We continue to work closely with the Genesis team, including MWA data model interpretation work with Dr Brad Greig and Dr Yuxiang Qin at the University of Melbourne node, and work with the Genesis simulation boxes with Professor Chris Power at the UWA node. Internationally we continue to work very closely with the University of Washington and Partner PI Miguel Morales.

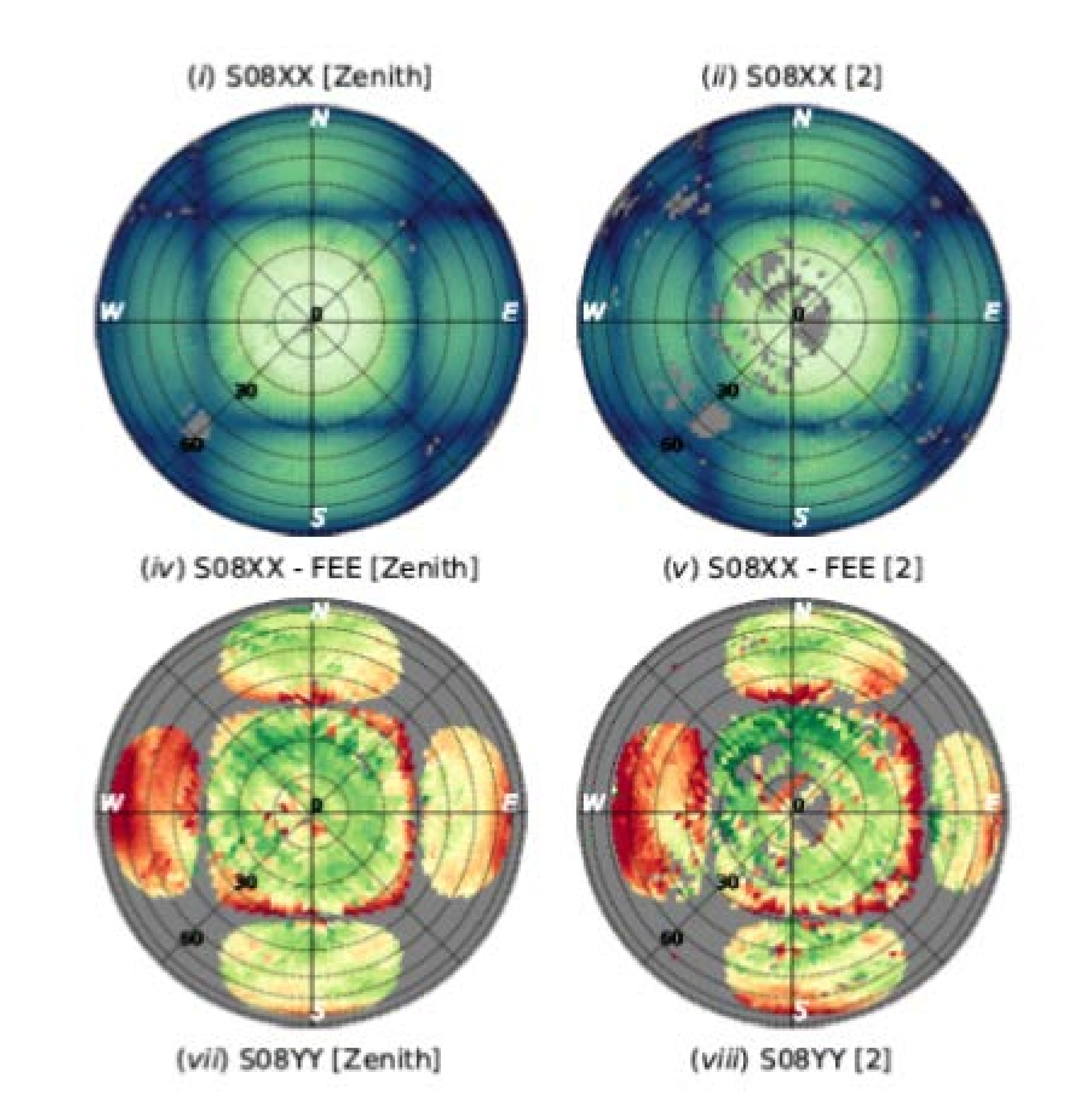


Figure 8: MWA primary beam sky response, mapped via passes over the array of an Orbcomm satellite (top), and difference compared with model (bottom). Chokshi et al 2021, "Dual Polarization Measurements of MWA Beampatterns at 137 MHz", Monthly Notices of the Royal Astronomical Society, Volume 502, Issue 2, pp.1990-2004

MWA EOR

PROFESSOR CATH TROTT

Chief Investigator
Node Leader
Curtin University
MWA EoR Survey Lead

ABOUT ME

I am Node leader at Curtin University, and I am also one of the projct co-leads of the EoR project with the Murchison Widefield Array (EoR MWA). I co-lead the project with Rachel Webster who is based at the University of Melbourne. Together, we collectively oversee about 10 researchers and a similar number of students within this project, The project itself is embedded in an international collaboration where Australia plays a major role and we have many partner organisations.

WHY ASTRONOMY

I grew up in the outer suburbs of Melbourne. In those days, the night sky of Melbourne was quite dark so I could go out at night and see the stars and the magellanic clouds. I didn't have a telescope, I didn't have that opportunity but I did have parents that were really interested in promoting science and our interests. So we'd watch Qantum on the ABC each week. They'd take me to musuems and when I had a bit of an interest in astronomy they really promoted that and motivated me to pursue that as much as I could. I think just being able to go out and see the night sky and look up and wonder was the thing to me that really kept my interest going and engaged me.

WHAT I LOVE ABOUT ASTRONOMY

What I love about Astronomy is getting to spend time thinking about the Universe, and doing it with amazing people who are so talented, passionate and insightful. We are so privileged to get to do this for a job!

WHAT I DON'T LOVE

The hardest thing in Astronomy is timezones. I am not a nighttime person, and evening meetings and conferences are so, so hard when you're exhausted. I never would have made a good optical astronomer, always falling asleep at the ANU 2.3m by 2am!

IF I WASN'T AN ASTRONOMER, I WOULD BE...

An Archaeologist. Growing up I was always really interested in ancient civilisations. I really enjoy reading and exploring new things, so I think archaeology would be something I would try.

A HIGHLIGHT IN 2021

The 2021 ASA Annual Scientific Meeting, run via a hub model, was a real highlight. It felt like we were all together and part of one community again, even though so many people were clearly struggling with different restrictions and lockdowns.

I SURVIVED COVID IN 2021 BY...

Getting outside as much as possible, and enjoying nature, especially on hikes with friends.
Lots of walking, cycling, and breathing the fresh air. We were also lucky enough to have live performances in Perth, so a few trips to the symphony and my daughter's dance competitions also helped!

CLOSING IN ON THE FIRST LIGHT IN THE UNIVERSE

RESEARCH USING NEW ANTENNAS IN THE AUSTRALIAN HINTERLAND HAS REDUCED BACGROUND NOISE AND BROUGHT US CLOSER TO FINDING A 13-BILLION-YEAR-OLD SIGNAL

The early Universe was dark, filled with a hot soup of opaque particles. These condensed to form neutral hydrogen which coalesced to form the first stars in what astronomers call the Epoch of Reionisation (EoR).

“Finding the weak signal of this first light will help us understand how the early stars and galaxies formed,” says Dr Christene Lynch from ASTRO 3D, the ARC Centre of Excellence for All Sky Astrophysics in 3 Dimensions.

Dr Lynch is first author on a paper published in Publications of the Astronomical Society of Australia. She and her colleagues from Curtin University and the International Centre for Radio Astronomy Research have reduced the background noise in their observations allowing them to home in on the elusive signal.

The team worked with new equipment installed on the Murchison Widefield Array (MWA), a radio telescope situated inland and some 800 kilometres north of Perth.

The MWA started operation a decade ago. One of its aims is to find the radio wave signature of that first light, known as the Epoch of Reionisation, or “EoR."

It comprises multiple low-frequency “antenna tiles” which work together to search the sky for the faint remnant of the out-pouring of ionised hydrogen atoms that accompanied first light, which began around 500 million to one billion years after the Big Bang.

Recently the number of antenna tiles was doubled from 128 to 256, significantly extending the land area occupied by the facility – and greatly upping its power.

By combining some of the existing tiles with 56 of the new ones, ARC Centre of Excellence for All Sky Astrophysics in 3 Dimensions scientist Dr Christene Lynch and her team were able to run a new sky experiment, called the Long Baseline Epoch of Reionisation Survey (LoBES), to refine the hunt for the long-sought signal.

“Our challenge is that the Universe is very, very crowded,” Dr Lynch explained.

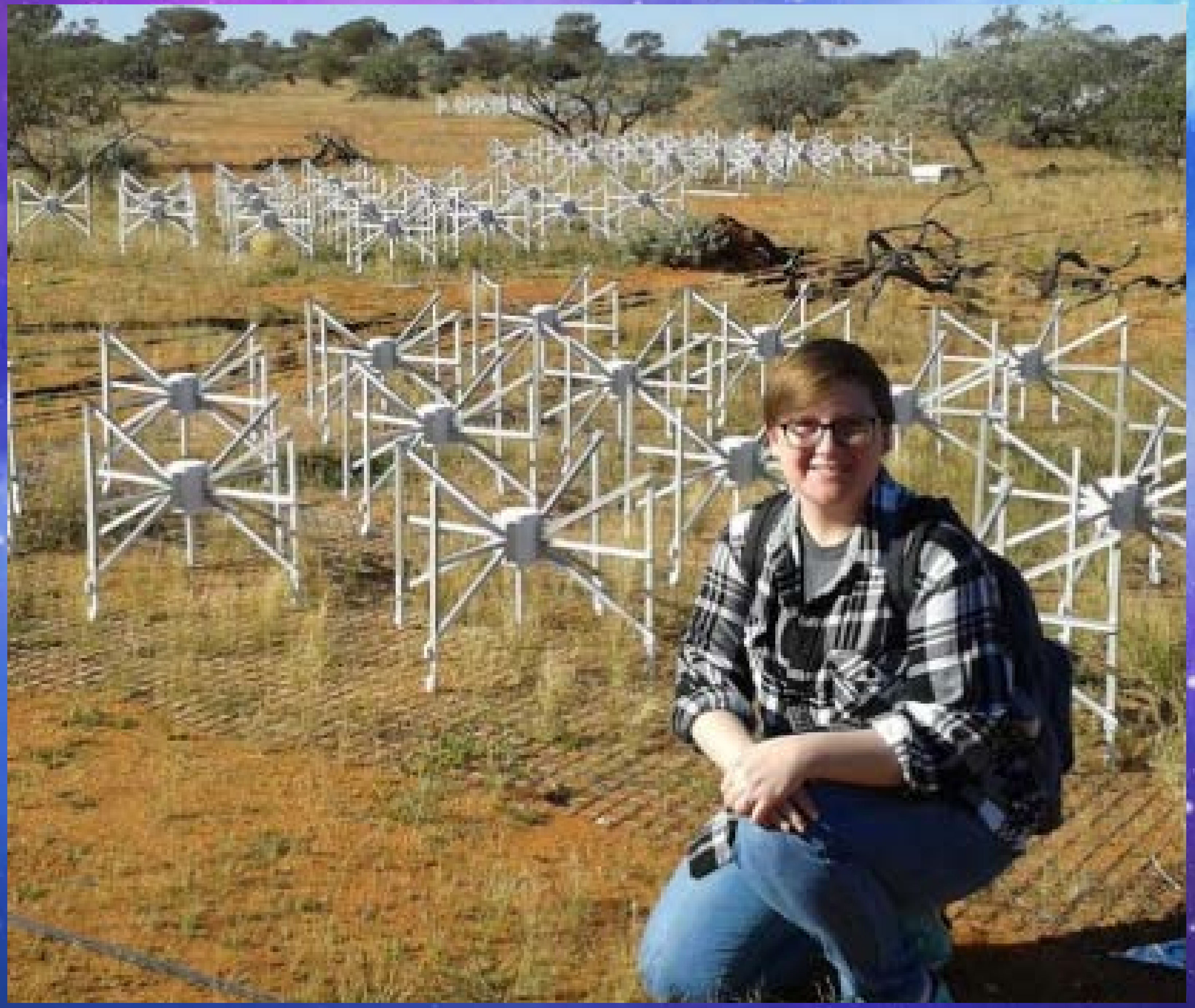


Image: Dr Christene Lynch at the MWA
Credit: Dr Christene Lynch

“There are too many other radio sources that are much brighter than the EoR signal lying between it and us. It is like trying to hear someone whispering from across the room, when between you and that person there are thousands of other people shouting as loudly as possible.

“By using the new tiles and thus expanding the physical area over which the antenna work we were able to reduce a lot of that interference. As more and more of the tiles are added in, we’ll have a much better chance of finding the echo of that first light.”

Dr Lynch worked with colleagues from ASTRO 3D and the Curtin University node of the International Centre for Radio Astronomy Research.

They surveyed more than 80,000 radio signal sources, taking 16 spectral measurements for each. Running the results, they produced real and simulated models in which the noisiest foreground radio signals were reduced by a factor of three.

“The Epoch of Reionisation signal started life as a hydrogen atom radio wavelength of 21 centimetres,” explained Dr Lynch.

“Over the intervening billions of years it has been stretched and grown very, very faint. It’s clear that our new LoBES sky model will significantly improve efforts to properly locate it.”

Co-author Professor Cathryn Trott, an ASTRO 3D Chief Investigator with ICRAR and Curtin, added: “This is our deepest and most detailed view to-date of the radio sky in these EoR fields, and this new catalogue provides us with a cleaner path to locating the EoR signal – a detection that will be a very major achievement for astronomy.”

FIRST STARS

The First Stars team investigates the properties of the first stars through several different avenues.

First, we perform supercomputer simulations that predict how the first stars would have formed. Next, we perform simulations of how those massive stars and their supernovae at the dawn of time enriched the interstellar gas with heavy elements. Finally, we measure the chemical composition of the oldest stars alive today, and compare these results to the theoretical predictions to challenge our understanding of these processes.

The Universe was created in the big bang some 13.8 Billion years ago. The very first stars formed a few hundred million years later and were made up of only hydrogen, helium and lithium. The nature of the first stars, and whether any could have survived to the present day, however, remains one of the hottest topics in modern cosmology and astrophysics.

In particular, to survive to the present-day, a genuine first star must have formed with a mass approximately equal to or less than the mass of the Sun. However, no such stars are known at the present time, which likely indicates that only massive stars formed immediately after the Big Bang: the short lifetimes of massive stars means that none would have survived to the present-day.

Nevertheless, the evolution of these stars was responsible for producing the elements from carbon onwards, and they have strongly influenced how subsequent generations of stars and galaxies formed and evolved. In particular, since different elements are made in different amounts in stars of different mass, we can use the abundances and abundance ratios in extremely metal-poor (and likely very old) stars to learn about the evolution of the chemical elements in our Galaxy.

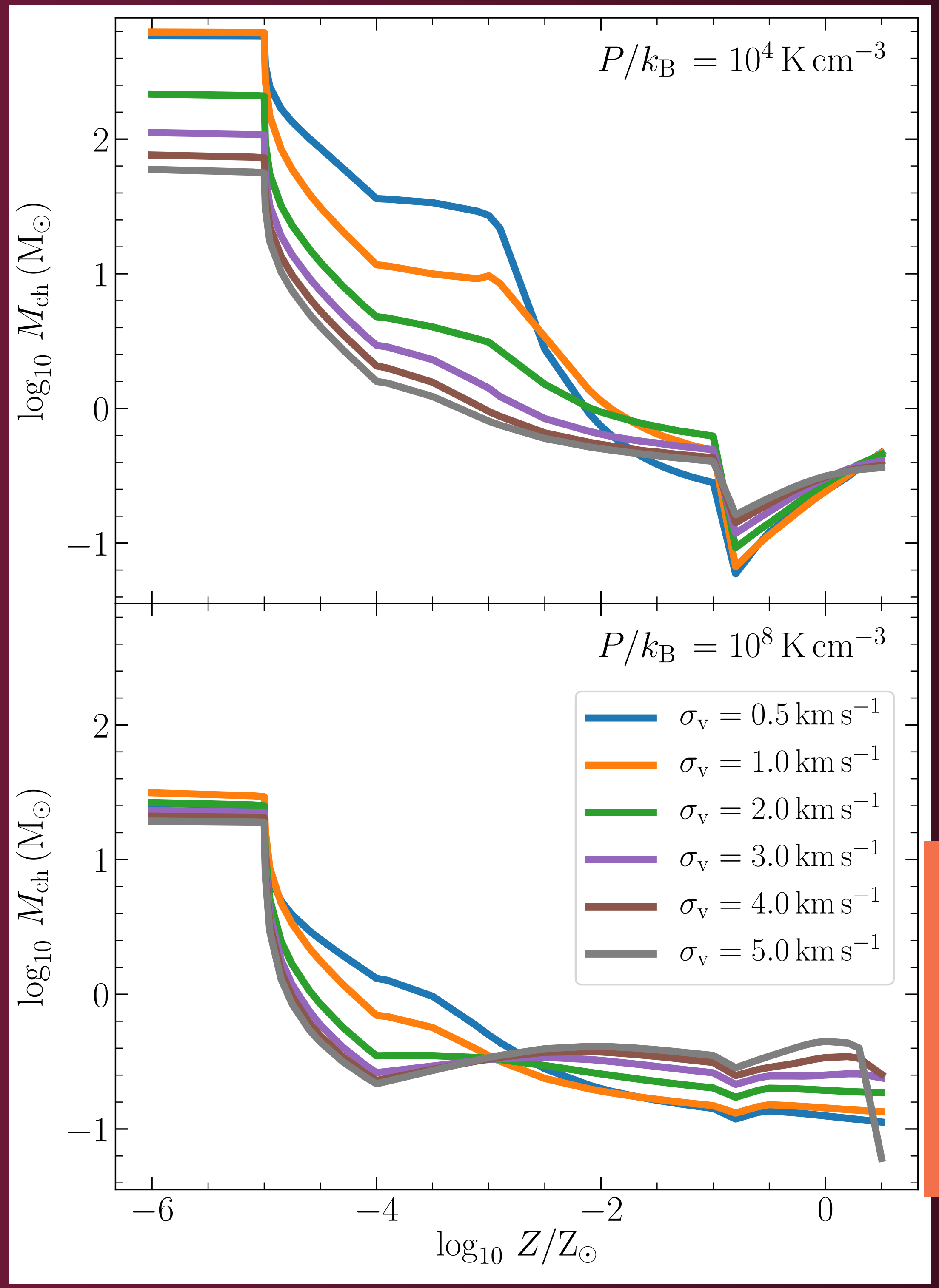


Figure 9: Top panel: Characteristic stellar mass, Mch, as a function of metallicity for a fixed cloud pressure P/kB = 10^4 K cm-3 , typical of the Milky Way, at different effective velocity dispersions Σv as shown in the legend.

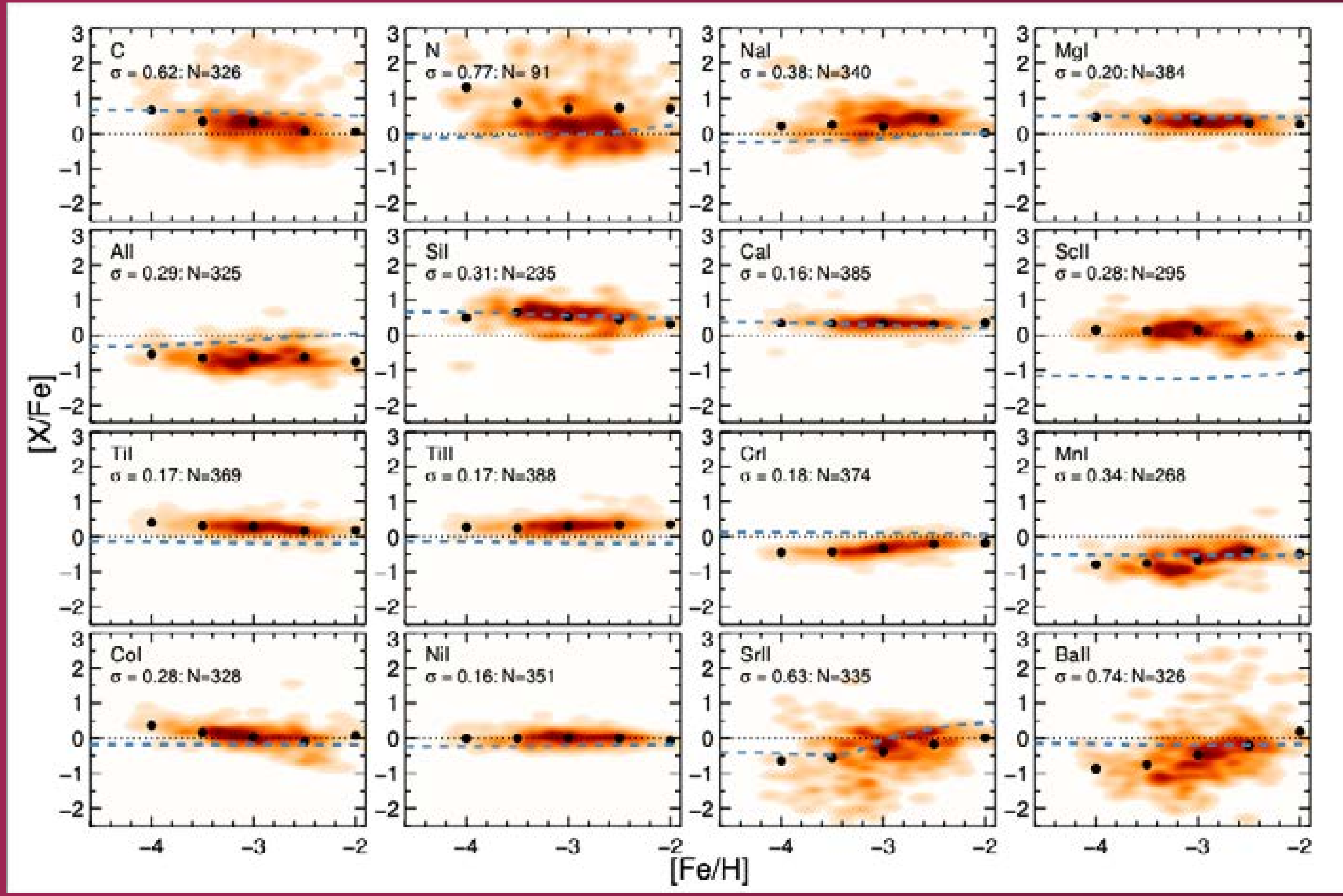
Bottom panel: Same as the top panel but at a high pressure (P/kB = 10^8 K cm-3), typical of starburst environments. Figure from Sharda & Krumholz, 2021, MNRAS, in press, doi:10.1093/mnras/stab/2921.

2021 PROJECT HIGHLIGHTS

The question of the masses of the first stars has been investigated by PhD student Piyush Sharda (ANU) and AI Mark Krumholz (ANU) in a paper accepted by MNRAS. The authors explored the role of metallicity in governing the thermodynamic behavior of gas clouds collapsing and fragmenting under gravity, and the consequences for the characteristic mass of the stars formed in the collapsing clouds. As illustrated in Fig. 9 (upper panel), the calculations show that in low-pressure environments like our own Milky Way galaxy, the characteristic mass transitions from approximately 50 times the solar mass at the lowest metallicities (far left), representing zero metallicity in the distant past, to just 0.3 solar masses at the solar metallicities seen in the present-day interstellar gas. The results are largely independent of the velocity dispersion in the gas clouds and strongly suggest that no genuine first stars are likely to have survived to the present-day in the Milky Way.

The evolution of the chemical elements in the Milky Way has been studied in a recent paper led by AI David Yong (ANU) published in MNRAS that gives detailed chemical abundances for 150 metal-poor stars whose iron abundances range from less than 1/10,000th to 1/125th of the solar iron abundance. The stars studied in the paper originated from the spectroscopic follow-up at the ANU 2.3m telescope of a sample of candidate extremely metal-poor stars selected from SkyMapper Southern Sky Survey photometry. The data facilitate a direct comparison with the predictions of chemical evolution models. This is illustrated in Fig. 10 where the abundances of a number of elements relative to that of iron are plotted against the iron abundance. The agreement between the model predictions and the observations is generally good. The small scatter in the [X/Fe] values for elements such as Mg, Ca, Ti and Ni illustrates that the production of these elements is tightly coupled to that of iron. On the other hand, the substantially larger scatter at fixed [Fe/H] for the light elements C and N, and for the neutron-capture elements Sr and Ba, reveals the requirement for additional nucleosynthetic processes for these elements.

A further important result in the Yong et al. paper is a determination of the metallicity distribution function (MDF). The MDF reveals how the number of metal-poor stars changes with changing iron abundance. As shown in Fig. 11, the MDF decreases rapidly with decreasing iron abundance: for -4 < [Fe/H] < -3, the MDF has a logarithmic slope of -1.5 dex/dex, meaning that for every 30 stars at [Fe/H] = -3, only one is expected at [Fe/H] = -4, testifying to how rare the most metal-poor stars are. An abrupt change in slope of the MDF is visible at [Fe/H] ~ -4 with stars below that metallicity even rarer. The observed MDF provides important input for theories of the formation of low-mass stars at the lowest metallicities, including those in the 'second generation' that were the first to form after the first stars of primordial composition.



The so-called "second cosmological lithium problem" stems from existing claims of the detection of 6Li in metal-poor dwarf stars: standard Big Bang nucleosynthesis is not expected to produce any 6Li. PhD student Ella Wang (ANU) has investigated this problem by analyzing high-resolution, high signal-to-noise ratio spectra for three metal-poor dwarf stars.

The spectra were obtained with the ultra-stable ESPRESSO spectrograph on ESO's Very Large Telescope in Chile. The analysis used the latest 3D non-local thermodynamic equilibrium radiative transfer models and resulted in a consistent non-detection of 6Li in all three stars, with upper limits well below the previous claimed 6Li detections.

The results are in a paper accepted by MNRAS and indicate that the "second cosmological lithium problem" is spurious.

2021 PERSONNEL HIGHLIGHTS

The addition of the new nodes brings new expertise into the First Stars project. In particular, faculty and their post-docs and students at Monash bring considerable expertise in stellar evolution and in the synthesis of the elements. specifically in Asymptotic Giant Branch stars and in supernovae.

Similarly, faculty, post-docs and students at UNSW and Macquarie bring expertise in studying stellar streams in the halo of the Milky Way. Such streams, originating from disrupted dwarf galaxies and globular clusters, play a vital role in understanding the build-up of the stellar halo. The expertise of Partner Investigator Chiaki Kobayashi (Univ. of Hertfordshire) in nucleosynthesis modeling is also an asset to the First Stars research program.

The detailed work by ASTRO 3D post-doc Thomas Nordlander (ANU) on stellar atmospheres, particularly in regard to calculating the effects of 3D and Non-Local Thermodynamic Equilibrium on derived abundances, is beneficial to both the GALAH and First Stars research programs.

Figure 10: The abundances of elements from C to Ba, relative to iron and denoted by [X/Fe], are plotted against iron abundance [Fe/H] for the sample of metal-poor stars discussed in Yong et al. (2021, MNRAS, 507, 4102). The data are in orange and are represented by using generalized histograms of width 0.15 dex for [Fe/H] and 0.30 dex for [X/Fe]. Average values for the data are overplotted as filled circles, and the dashed blue lines are predictions from a Galactic chemical evolution model by Kobayashi, Karakas & Lugaro (2020, ApJ, 900. 179). Figure from Yong et al., 2021, MNRAS, 507, 4102, doi:10.1093/mnras/stab/2001.

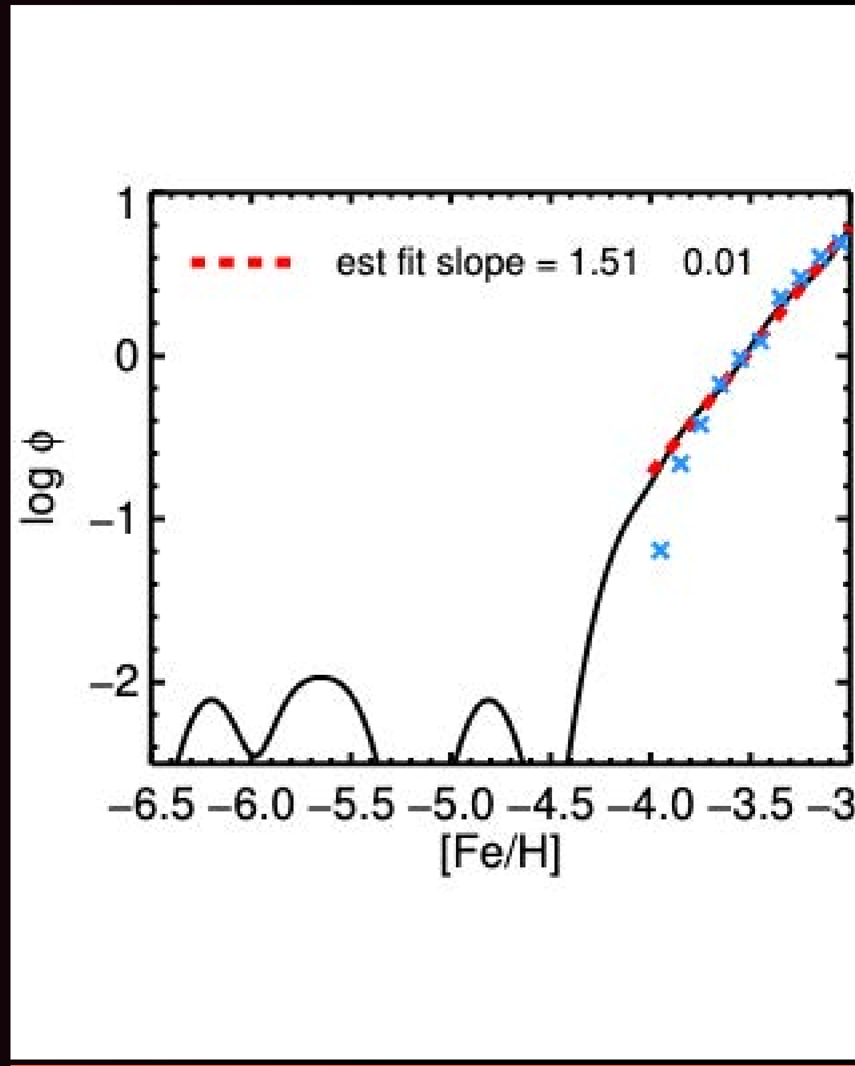


Figure 11: The metallicity distribution function (MDF) for extremely metal-poor stars, denoted by φ, is shown in the form of a generalized histogram (black lines) using a logarithmic scale. The MDF slope for −4 ≤ [Fe/H] ≤−3 is shown as the red dashed line, while shown as blue crosses is the MDF from the independent study of Youakim et al. (2020, MNRAS, 492, 4986) normalized at [Fe/H] = −3.05). The agreement between the two studies is excellent. Figure from Yong et al., 2021, MNRAS, 507, 4102, doi:10.1093/mnras/stab/2001.

DR SIMON CAMPBELL

Affiliate
Monash University
First Stars
GALAH

ABOUT ME

My research focuses on understanding the lives of stars of similar mass to the Sun. To do this I use a variety of methods, from 1D and 3D computer simulations to various types of telescope observations such as spectroscopy and asteroseismology. Stars are central to our understanding of the Universe since they produce almost all the elements in the periodic table, and most of what we know about the Universe has been derived from starlight. I have a particular interest in the oldest stars in the Universe, which was the topic of my PhD, and this is where I contribute to the First Stars Project in ASTRO 3D. My simulations are also used to interpret more modern stars observed in the huge GALAH Survey. The ancient stars I model formed very early in the Universe's history but we can still see some of them today since they live for billions of years. Encoded in their starlight is the history of the early Milky Way, as well as the history of the stars themselves.

WHY ASTRONOMY

As a child being an astrophysicist was never on my radar. I first became interested in astronomy while camping in National Parks in my late teens. There I would see the dark sky, and the staggering number of stars, of varying colours and brightness. I began to wonder what those stars were, so I read up on them and bought a small telescope. Luckily my university had an astronomy course, so I was able to study it formally, and I ended up doing a PhD on stars!

WHAT I LOVE ABOUT ASTRONOMY

Astronomy is a universal interest - everyone can relate to the wonder of the night sky and space. It also seeks to answer some of the biggest questions we have as humans: Where did we come from? Where are we? Are we alone? What is the nature of the Universe? As an astronomy researcher I feel very privileged to be able to contribute to the growing understanding of our Universe.

WHAT I DON'T LOVE

Although astronomy sounds like a 'romantic' career (it can be sometimes!), for example looking through the eyepieces of telescopes at beautiful objects, it actually involves many, many hours wrestling with data and computer codes. This can be frustrating and monotonous at times. The other negative is the lack of job security - there are not many ongoing jobs in the field so most astronomers end up leaving to work in other industries.

IF I WASN'T AN ASTRONOMER, I WOULD BE...

If I wasn't an astronomer I would probably be a climate researcher, since I think we need as many people as possible working on this global problem. Alternatively I might be an investigative documentary maker. Both involve research, so I guess generally if I weren't an astronomer, I would be a researcher of some sort.

A HIGHLIGHT IN 2021

A highlight in 2021 was a study in which we investigated the mystery of the "Super Lithium Rich" giant stars. These are stars that contain around a thousand times the lithium of the Sun, for unknown reasons. The strength of our study was in the way it combined many types of observations of the stars - asteroseismic, spectroscopic, astrometric - as well as detailed stellar models. Through this combination of observations and theory, we found strong evidence to show that the Super Lithium-Rich stars are almost all very young core-helium burning stars, which indicates that possibly all low-mass stars (like the Sun itself) go through a super-lithium-rich phase.

Another 2021 highlight was the culmination of a large international collaborative project on 3D models of stars. 3D models of stars are relatively new, since they require large supercomputers to run. In this study we compared the results of five multidimensional stellar hydrodynamics codes from different international groups. The reason for doing this was to check if different, independent, codes give the same results for a standard stellar-like test problem. The results were very reassuring - all the codes agreed. This has given the international community much more confidence in the new field of multi-dimensional stellar simulations, a field which aims to improve our modelling and understanding of stars, since these huge simulations are very detailed and contain much more physics than traditional 1D simulations.

I SURVIVED COVID IN 2021 BY...

In some ways astronomers were better set up for the COVID-19 pandemic than most, since we were already having some national/international meetings online. Indeed, due to climate change there is a movement in astronomy to do this more, to avoid the carbon emissions from flying so much. That said, telescope facilities were impacted a lot in some cases, so this did slow down research. As a parent with a primary-school-aged child, home learning added an extra load, also reducing productivity. On the bright side I got to see my family a lot more that usual.

NEW TYPE OF MASSIVE EXPLOSION EXPLAINS MYSTERY STAR

'MAGNETO-ROTATIONAL HYPERNOVA' SOON AFTER THE BIG BANG FUELLED HIGH LEVELS OF URANIUM, ZINC IN ANCIENT STELLAR ODDITY

A massive explosion from a previously unknown source – 10 times more energetic than a supernova – could be the answer to a 13-billion-year-old Milky Way mystery.

Astronomers led by David Yong, Gary Da Costa and Chiaki Kobayashi from Australia's ARC Centre of Excellence in All Sky Astrophysics in 3 Dimensions (ASTRO 3D) based at the Australian National University (ANU) have potentially discovered the first evidence of the destruction of a collapsed rapidly spinning star – a phenomenon they describe as a "magneto-rotational hypernova".

The previously unknown type of cataclysm – which occurred barely a billion years after the Big Bang – is the most likely explanation for the presence of unusually high amounts of some elements detected in another extremely ancient and "primitive" Milky Way star. That star, known as SMSS J200322.54-114203.3, contains larger amounts of metal elements, including zinc, uranium, europium and possibly gold, than others of the same age.

Neutron star mergers – the accepted sources of the material needed to forge them – are not enough to explain their presence. The astronomers calculate that only the violent collapse of a very early star – amplified by rapid rotation and the presence of a strong magnetic field – can account for the additional neutrons required.

The research is published today in the journal Nature.

"The star we're looking at has an iron-to-hydrogen ratio about 3000 times lower than the Sun – which means it is a very rare: what we call an extremely metal-poor star," said Dr Yong, who is based at the ANU.

"However, the fact that it contains much larger than expected amounts of some heavier elements means that it is even rarer – a real needle in a haystack."

The first stars in the Universe were made almost entirely of hydrogen and helium. At length, they collapsed and exploded, turning into neutron stars or black holes, producing heavier elements which became incorporated in tiny amounts into the next generation of stars – the oldest still in existence.

Rates and energies of these star deaths have become well known in recent years, so the amount of heavy elements they produce is well calculated. And, for SMSS J200322.54-114203.3, the sums just don't add up.

"The extra amounts of these elements had to come from somewhere," said Associate Professor Chiaki Kobayashi from the University of Hertfordshire, UK.

"We now find the observational evidence for the first time directly indicating that there was a different kind of hypernova producing all stable elements in the periodic table at once — a core-collapse explosion of a fast-spinning strongly-magnetized massive star. It is the only thing that explains the results."

Hypernovae have been known since the late 1990s. However, this is the first time one combining both rapid rotation and strong magnetism has been detected.

"It's an explosive death for the star," said Dr Yong. "We calculate that 13 billion-years ago J200322.54-114203.3 formed out of a chemical soup that contained the remains of this type of hypernova. No one's ever found this phenomenon before."

J200322.54-114203.3 lies 7500 light-years from the Sun, and orbits in the halo of the Milky Way.

Another co-author, Nobel Laureate and ANU Vice-Chancellor Professor Brian Schmidt, added, "The high zinc abundance is definite marker of a hypernova, a very energetic supernova."

Head of the First Stars team in ASTRO 3D, Professor Gary Da Costa from ANU, explained that the star was first identified by a project called the SkyMapper survey of the southern sky.

"The star was first identified as extremely metal-poor using SkyMapper and the ANU 2.3m telescope at Siding Spring Observatory in western NSW," he said. "Detailed observations were then obtained with the European Southern Observatory 8m Very Large Telescope in Chile."

ASTRO 3D director, Professor Lisa Kewley, commented: "This is an extremely important discovery that reveals a new pathway for the formation of heavy elements in the infant Universe."

Other members of the research team are based at the Massachusetts Institute of Technology in the US, Stockholm University in Sweden, the Max Planck Institute for Astrophysics in Germany, Italy's Istituto Nazionale di Astrofisica, and Australia's University of New South Wales.

Caption: The star SMSS J200322.54-114203.3. (centre, with crosshairs) in the south-eastern corner of the constellation Aquila (the Eagle) close to the border with Capricornus and Sagittarius. Credit: Da Costa/SkyMapper

FIRST GALAXIES




The First Galaxies project is focussed 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 leading the development of the first space mission funded by the Australian Space Agency; the SpIRIT satellite, which has the potential to contribute to the discovery of some of the very first stellar nurseries in the Universe and is promoting international cooperation and academia-industry engagement.

2021 PROJECT HIGHLIGHTS

Work continued in 2021 on Hubble Space Telescope data collected as part of the Wide Field Camera 3 Brightest of Reionising Galaxies (BoRG) survey, led by ASTRO 3D CI Michele Trenti, and searched for galaxies within the first 700 million years after the Big Bang. In particular, we focussed on re-analysis of all suitable data in the archive, through the SuperBoRG dataset. SuperBoRG is a compilation of ~0.4 deg^2 archival medium-deep (mF160W ~ 26.5 ABmag) parallel infrared (IR) images taken with the Hubble Space Telescope.

The team selected initial candidates by using the Lyman-break technique and published a revised catalog of sources located more than 13 billion light years from us. First Galaxies postdoctoral research fellow Dr. Nicha Leethochawalit developed a sophisticated code to quantify how complete an Hubble Space Telescope image is, that is, what is the probability of missing the identification of (faint) distant objects in a dataset due to the intrinsic noise present, depending on the selection criteria used.

In simple terms the tool is extremely useful to determine the most efficient way of selecting distant galaxy candidates while limiting the amount of false positives in the sample (a tradeoff between having a pure but small sample or a large but contaminated one).

This will be extremely useful for applications to upcoming James Webb Space Telescope observations, and we made the code publicly available for benefit of astronomers worldwide. On the modeling front, PhD student Keven Ren (UoM) concluded successfully his studies mid year, and published a very interesting model that is capable of capturing the evolution of the quasar luminosity function with minimal parameters, and makes predictions for the quasar population we expect well into the Epoch of Reionisation (redshift z>8) from future space based observatories such as the Nancy Grace Roman Space Telescope.

PhD student Benjamin Metha investigated novel applications of geostatistical techniques to astronomical datasets, showing how mathematical tools generally utilised for Earth observations have a strong potential to be applied to astronomy as well, taking advantage of the increased availability of detailed galaxy maps such as 3D datacubes from integral field spectroscopy.

In October 2021 we welcomed Kristan (Kit) Boyett as First Galaxies postdoctoral research fellow, who joined the University of Melbourne node, working remotely from the University of Oxford, an ASTRO 3D Partner Institution. Dr. Boyett will focus on observations of galaxies in the epoch of Reionisation primarily through James Webb Space Telescope spectroscopic data.

CROSS PROJECT COLLABORATIONS

The team continues to develop the SpIRIT (Space Industry Responsive Intelligent Thermal) nanosatellite, the first and only spacecraft project selected for funding by the Australian Space Agency so far (International Space Investment - Expanding Capability scheme). SpIRIT, which is currently in phase C (final design and fabrication of flight hardware), is an international partnership with the Italian Space Agency which will contribute to 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 that our team will be able to use to study the first billion years after the Big Bang.

DR ALEX JAMES CAMERON

Affiliate
Oxford University
First Galaxies
Galaxy Evolution

ABOUT ME

I study the chemical composition of galaxies and use this to understand the physical processes that have shaped galaxy evolution. I am involved in two projects that do this in different ways.

Recently I have worked with the team at Swinburne on the DUVET survey which has allowed us to directly measure the chemical composition in galactic inflows and outflows of nearby galaxies. These gas flows are known to be critical in shaping galaxy assembly, but have historically been very poorly understood. These measurements from DUVET have greatly improved our understanding on the properties of these gas flows.

I am also a member of the JADES survey along with colleagues at Oxford, across Europe and in the USA and Canada. JADES will make use of the forthcoming James Webb Space Telescope (launching in December 2021) and will make revolutionary new measurements of chemical abundances in galaxies within the first billion years after the Big Bang. This will vastly improve our understanding of how evolutionary processes shaped galaxies in earliest epochs of galaxy assembly.

WHY ASTRONOMY?

I grew up on a farm near Wangaratta, in rural Victoria. The night sky there is perfect for star-gazing, and I fell in love with staring at the night sky from a very young age.

I didn't go straight into astronomy though; my Masters degree was in organic chemistry. From that experience I learned that I enjoyed doing research, but also that I didn't enjoy working in a lab. Instead, inspired by my inner child who grew up staring at the night sky, I reached out to some astronomers about the prospect of switching fields to astronomy.

What really convinced me to move into astronomy was that the data analysis skills required are widely applicable across many industries. As a result, I've always felt confident in the knowledge that even if I decide to move away from astronomy, it has provided me with many valuable, transferable skills.

WHAT I LOVE ABOUT ASTRONOMY

I love that in astronomy we get to ask very big questions. I also love the scale that I get to work at: trying to understand galaxies that are thousands of light years across and billions of light years away. From that perspective, I still often experience the child-like excitement that first drew me to astronomy.

WHAT I DON'T ABOUT ASTRONOMY

How much you have to move. This year was my first international move (Melbourne to Oxford), so there was at least an element of adventure to offset how difficult it was to move away from my home. But if I have to move a few more times before getting a permanent job and living a less transient lifestyle, it will only become more difficult each time.

IF I WASN'T AN ASTRONOMER, I WOULD BE...

School teacher. I've always found teaching to be very rewarding. If I ever decide to move away from astronomy research, I think I would try to move back to rural Victoria and teach high school science.

A HIGHLIGHT IN 2021

From an astronomy perspective: The JWST collaboration that I am a part of had its first in person meeting since 2019 in November. It was hosted in Pisa and was a very fun and productive week. I only joined the team a year ago, so it was the first time I was able to meet my new colleagues in person. Online meetings have been very important recently, but nothing quite compares to seeing people in person.

From a personal perspective: My sister got married in March. It fell into one of the lucky windows when weddings were allowed in Victoria so we got to celebrate it with a (mostly) complete guest list. Something I certainly no longer take for granted!

I SURVIVED COVID IN 2021 BY...

I've had a pretty lucky run with COVID restrictions in 2021. I spent the first few months of 2021 in COVID-Free Australia, before moving to Oxford in May, shortly after the UK lockdown had been lifted. So I've managed to avoid any lockdowns in 2021. But I spent most of 2020 writing my thesis in lockdown. The highlight of my weeks was always playing online board games with my other locked-down friends. More than anything else, that's what got me through.

GALAXY EVOLUTION

The Galaxy Evolution team, led by Associate Investigator, Kim-Vy Tran, aims to understand: how chemical elements accumulate in galaxies and their surroundings; how visible and dark matter assembles within galaxies; and how ionising radiation is produced and escapes galaxies over 12 billion years of cosmic time.

This project bridges the First Galaxies program with nearby galaxies observed with SAMI and Hector and complements ASKAP observations of the cool gas in galaxies.

2021 PROJECT HIGHLIGHTS

The Galaxy Evolution team had a truly exciting 2021 with major progress across the multiple surveys and awarded telescope time, most notably with the first cycle of the James Webb Space Telescope. Despite the continuing impact of the pandemic, the GE members maintained a high publication rate, disseminated science outcomes by giving "international" talks (via online platforms), applied successfully for major funding grants, and completed multiple PhDs. GE members also fostered collaborative opportunities across ASTRO 3D projects by running mini-workshops, monthly discussions, and busy weeks.

Highlights of award success in 2021 include Dr. Rebecca Davies (Swinburne) being honoured with a Gruber Foundation Fellowship for promising young astronomers. Dr. Kathryn Grasha (ANU) and Dr. Sarah Sweet (University of Queensland) both won ARC Discovery Early Career Research Awards (DECRA). Dr. Grasha's research will focus on "Stars and galaxies: The chemical abundance breakthrough", and Dr. Sweet on "Understanding diversity: Chemical and kinematic tracers of galaxy evolution". Special congratulations to Dr. Caroline Foster (USyd and Macquarie) who was awarded a Future Fellowship on how "Time takes its toll: understanding why galaxies slow down as they get older".

Figure 12: ASTRO 3D Galaxy Evolution with Lenses (AGEL) Karl Glazebrook led a successful proposal to obtain imaging with the Hubble Space Telescope of gravitational lenses from the AGEL survey. The first target imaged by Hubble in October 2021 has the auspicious nick-name "Happy Face", and an initial reduction by Karl and Colin Jacobs demonstrates the spectacular resolution provided by HST.

The GE project is particularly affected by observing disruptions due to the pandemic, and we are deeply grateful to the observatory staff all over the world that made it possible to continue obtaining critical data-sets. New data on highly competitive facilities including the Very Large Telescope, Keck Observatory, Atacama Large Millimeter Array, and the Hubble Space Telescopes were acquired during 2021, and observations are scheduled through 2022. The high quality multi-wavelength data ensure that the GE team will meet and likely exceed the goals defined in the original ASTRO 3D proposal.

With the thrilling launch of JWST in December 2021, several teams are eagerly awaiting the first observations to be available by mid-2022. GE members contributed to successful JWST proposals that totaled an astounding 927 hours of awarded time, a true testament to the exciting research led by ASTRO 3D members. Further evidence of ASTRO 3D leadership in exploring the Universe using space observations were the successful HST proposals led by Dr. Nikki Nielsen and Prof. Karl Glazebrook (Fig. 12), both at Swinburne.

To further build collaborative opportunities across the ASTRO 3D projects, GE members spear-headed multiple efforts to connect virtually. Events in 2021 include a mini-workshop on the Epoch of Reionisation and First Galaxies organised by Anshu Gupta (Curtin) in June 2021, and Kathryn Grasha (ANU) leading a monthly metallicities discussion connecting theory to observations from the very local Universe to the first galaxies. The MAGPI team held busy weeks focused on the incoming observations taken with MUSE on the VLT.

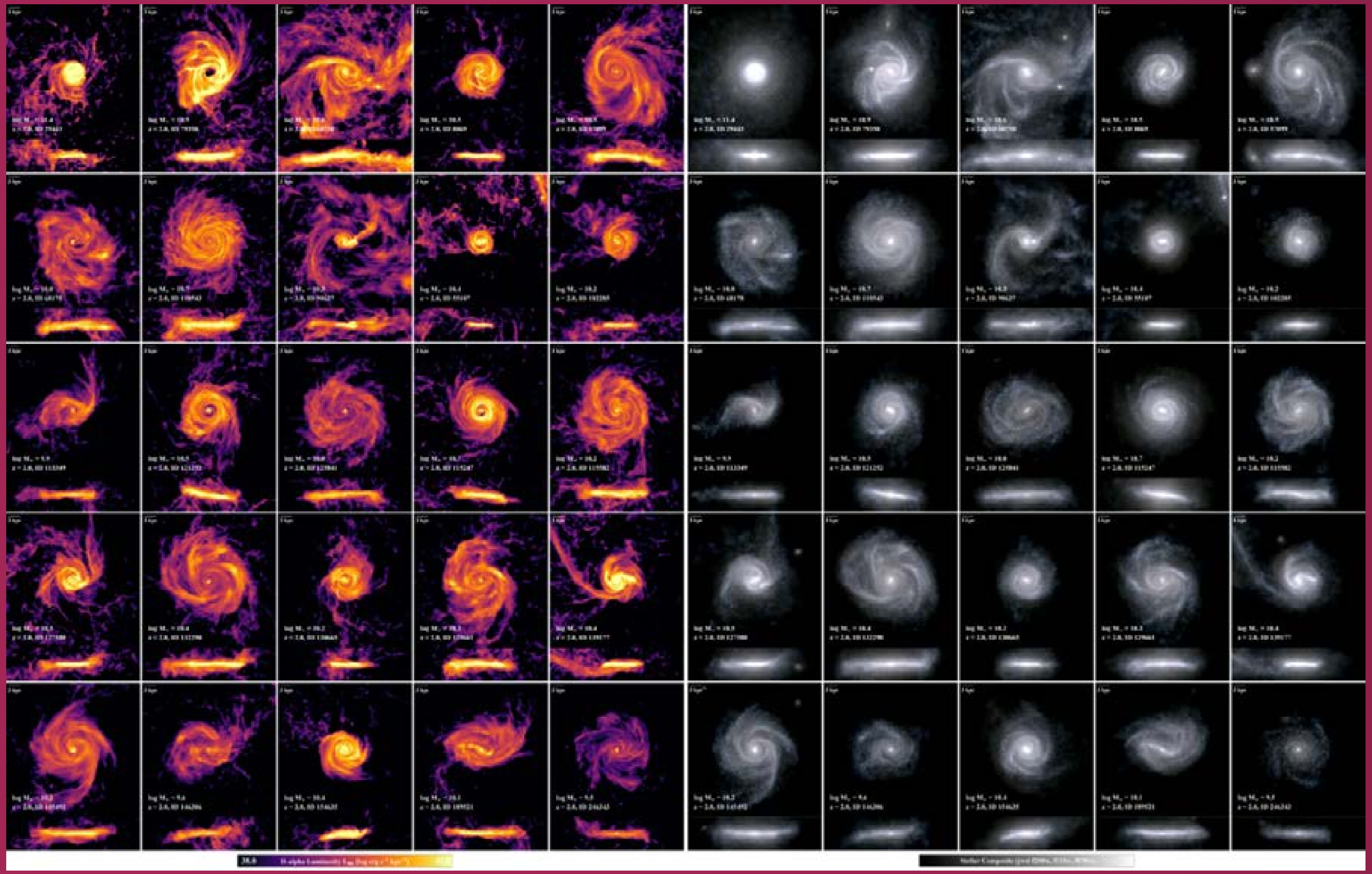


Figure 13: Dr. Anshu Gupta's (UNSW & Curtin) press release on "puffy galaxies make stars longer" at cosmic noon includes beautiful images from the IllustrisTNG cosmological simulations. The images on the left show the light emitted by excited gas in the simulated spiral galaxies, and the images on the right show light emitted by the stars in the same galaxies. These results are from the MOSEL survey that Dr. Gupta leads and illustrate the strong interplay between observers and theorists that helps us gain better understanding of how galaxies evolve.

Looking forward to the second half of the Centre's life, the GE project will focus on making full use of the rich variety of observations and simulations available within ASTRO 3D.

GE members will strengthen existing connections with First Galaxies, ASKAP, and SAMI to study HI gas and the Circum-galactic Medium (CGM). Of particular interest is the ionisation and enrichment history of the multi-phase gas in and around galaxies, and on interpreting observational results using cosmological simulations.

Highlights from the GE surveys include press releases based on results by Alex Cameron (UMelbourne) and Deanne Fisher (Swinburne) on gas flows in nearby galaxies, and by Anshu Gupta (UNSW & Curtin) on puffy galaxies at cosmic noon (Fig. 13).

A list of the main surveys currently led by Galaxy Evolution members to address the three main themes of the GE project of ionisation, chemical evolution (metallicities), and kinematics:

DUVET – Deanne Fisher (Swinburne) et al: ionisation conditions and gas kinematics in nearby disk galaxies

MAGPI – Caroline Foster (USyd), Trevor Mendel (ANU), Claudia Lagos (UWA), Emily Wisnioski (ANU) et al.: metallicities and kinematics of galaxies at z~0.3-0.5

AGEL – Kim-Vy Tran (UNSW), Karl Glazebrook (Swinburne) et al.: metallicities and kinematics of lensing systems (0.3<z<3)

K3-LARS – Emily Wisnioski (ANU) et al.: kinematics and metallicities of galaxies at z~2

MOSEL – Anshu Gupta (UNSW), Kim-Vy Tran (UNSW): kinematics of emission-line galaxies at z~3

XQR-30 – Emma Ryan-Weber (Swinburne) et al.: ionisation conditions of metal absorbers towards z~6 quasars

GALAXY EVOLUT

DR ANSHU GUPTA

ASTRO 3D Fellow
Curtin University
Galaxy Evolution Project
Magpi

ABOUT ME

I work on various aspects of galaxy formation and evolution ranging from the role of environment, chemical enrichment, and mass assembly history of galaxies. Recently I have been co-leading the MOSEL survey where we are studying the physical properties of galaxies that mimic the behaviour of “first galaxies”. These mimic galaxies exist almost 1 billion years after the reionisation of the Universe completed making them easily accessible with current instruments. My plan is to use the Mimic galaxy sample to identify the source of ionising radiation in the early Universe.

My research lies at the intersection of multiple science themes in ASTRO 3D. In particular, the origin of the ionised Universe and the periodic table elements. The nature of my work with the MOSEL survey leads me to actively collaborate with the galaxy evolution, first galaxies, genesis simulations and the epoch of reionisation teams within ASTRO 3D.

WHY ASTRONOMY?

I was interested in science ever since I can remember. At my undergraduate university I tried my hand at a wide variety of disciplines from evolutionary biology, biophysics, optical physics to astronomy. In my fourth year, Dr. Nissim Kanekar came to give a 1-hour lecture on astronomy that went up to three hours because we all kept asking questions. I decided to work with him for my final year summer project. That summer project really cemented my interest in astronomy.

WHAT I LOVE ABOUT ASTRONOMY

The most fun thing about astronomy is that it’s not really a single sub-field of physics like quantum mechanics, optics, nuclear physics. It’s a sub-field where we are studying the laws of nature unfold at the biggest scale, i.e., the entire Universe. Therefore, it requires understanding of basic principles of all sub-fields of physics. The extremely pretty images and observing runs at Hawaii and Chile are definitely an added bonus!

WHAT I DON'T LOVE

As an early career researcher, the hardest bits are usual issues of academia, lack of job uncertainty and the expectation to change cities, countries every couple of years.

IF I WASN'T AN ASTRONOMER, I WOULD BE...

Since I moved to Australia, I have found baking as my alternate passion. I really enjoy how simple ingredients like flour, water and salt get transformed into incredible loaf of sourdough. I also enjoy researching and trying cake recipes. Pre-pandemic, I visited my friend’s house in Germany and made a Black Forest cake for 10 Germans. It was bit daunting task but there was no cake left by the end of the night, so I am pretty sure they all enjoyed it.

A HIGHLIGHT IN 2021

2021 was a year of big changes for me. I got the permanent residency of Australia and moved to Perth to start my ASTRO 3D fellowship at the Curtin University. Science wise, I was successful in securing 22 hours on Xshooter/VLT (nearly $150K in telescope time) to push the MOSEL survey science forward. I also organised the first in person writing retreat on the west coast since the pandemic at Rottnest Island. To be honest, writing with the quokkas on Rottnest was really the biggest highlight of 2021.

I SURVIVED COVID IN 2021 BY...

I haven’t seen my family for two years, so I am still trying to survive COVID and remain positive. For me having my partner join me in Australia last year has been really good.

MILKY WAY NOT UNUSUAL, ASTRONOMERS FIND

DETAILED CROSS-SECTION OF ANOTHER GALAXY REVEALS SURPRISING SIMILARITIES TO OUR HOME

The first detailed cross-section of a galaxy broadly similar to the Milky Way, published today, reveals that our galaxy evolved gradually, instead of being the result of a violent mash-up. The finding throws the origin story of our home into doubt.

The galaxy, dubbed UGC 10738, turns out to have distinct ‘thick’ and ‘thin’ discs similar to those of the Milky Way. This suggests, contrary to previous theories, that such structures are not the result of a rare long-ago collision with a smaller galaxy. They appear to be the product of more peaceful change.

And that is a game-changer. It means that our spiral galaxy home isn’t the product of a freak accident. Instead, it is typical.

The finding was made by a team led by Nicholas Scott and Jesse van de Sande, from Australia’s ARC Centre of Excellence for All Sky Astrophysics in 3 Dimensions (ASTRO 3D) and the University of Sydney.

“Our observations indicate that the Milky Way’s thin and thick discs didn’t come about because of a gigantic mash-up, but a sort-of ‘default’ path of galaxy formation and evolution,” said Dr Scott.

“From these results we think galaxies with the Milky Way’s particular structures and properties could be described as the ‘normal’ ones.”

This conclusion – published in The Astrophysical Journal Letters– has two profound implications.

“It was thought that the Milky Way’s thin and thick discs formed after a rare violent merger, and so probably wouldn’t be found in other spiral galaxies,” said Dr Scott.

“Our research shows that’s probably wrong, and it evolved ‘naturally’ without catastrophic interventions. This means Milky Way-type galaxies are probably very common.

“It also means we can use existing very detailed observations of the Milky Way as tools to better analyse much more distant galaxies which, for obvious reasons, we can’t see as well.”

The research shows that UGC 10738, like the Milky Way, has a thick disc consisting mainly of ancient stars – identified by their low ratio of iron to hydrogen and helium. Its thin disc stars are more recent and contain more metal.

(The Sun is a thin disc star and comprises about 1.5% elements heavier than helium. Thick disc stars have three to 10 times less.)

Although such discs have been previously observed in other galaxies, it was impossible to tell whether they hosted the same type of star distribution – and therefore similar origins.

Scott, van de Sande and colleagues solved this problem by using the European Southern Observatory’s Very Large Telescope in Chile to observe UGC 10738, situated 320 million light years away. The galaxy is angled “edge on”, so looking at it offered effectively a cross-section of its structure.

“Using an instrument called the multi-unit spectroscopic explorer, or MUSE, we were able to assess the metal ratios of the stars in its thick and thin discs,” explained Dr van de Sande.

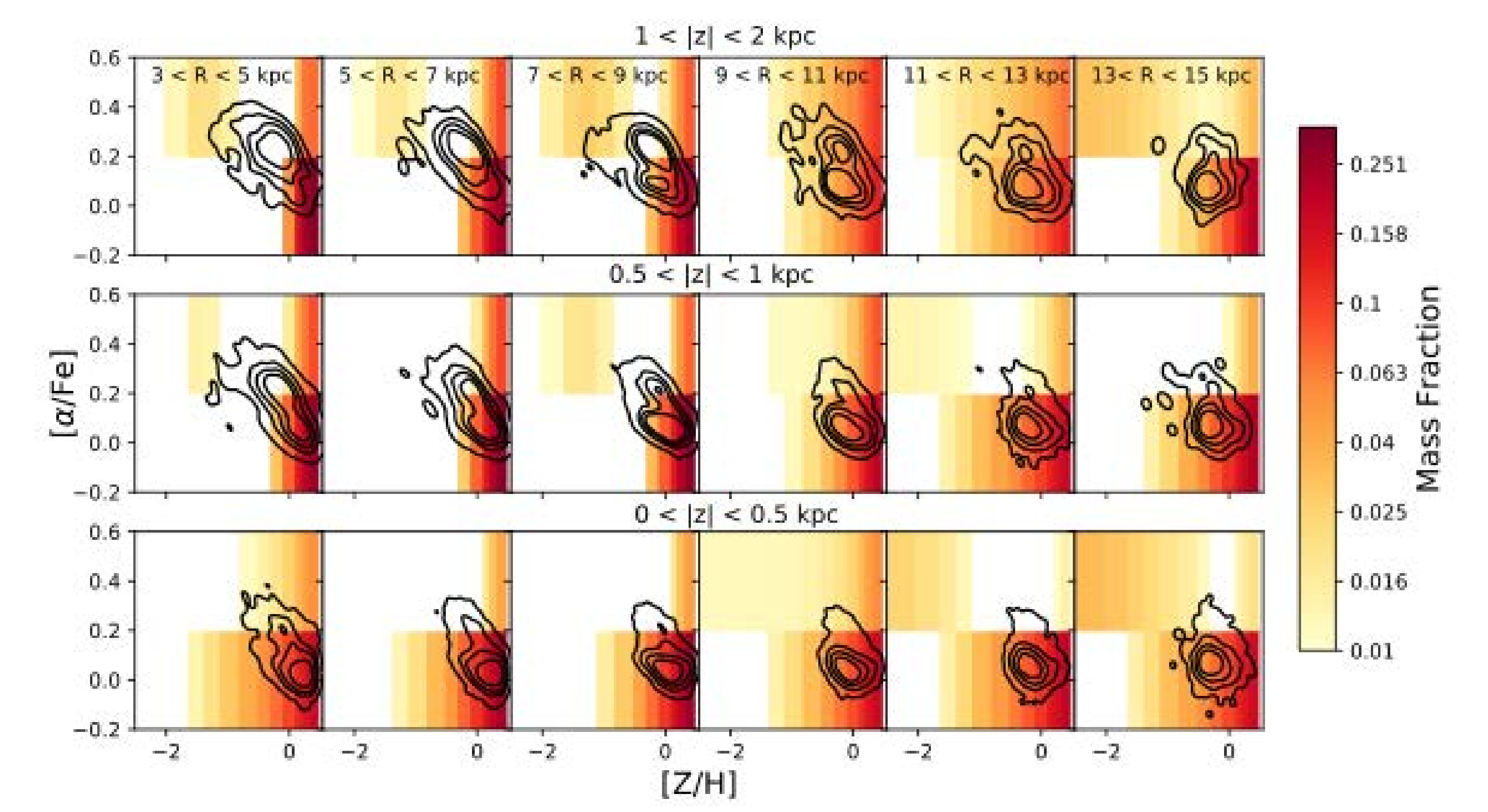
“They were pretty much the same as those in the Milky Way – ancient stars in the thick disc, younger stars in the thin one. We’re looking at some other galaxies to make sure, but that’s pretty strong evidence that the two galaxies evolved in the same way.”

Dr Scott said UGC 10738’s edge-on orientation meant it was simple to see which type of stars were in each disc.

“It’s a bit like telling apart short people from tall people,” he said. “It you try to do it from overhead it’s impossible, but it if you look from the side it’s relatively easy.”

Co-author Professor Ken Freeman from the Australian National University said, “This is an important step forward in understanding how disk galaxies assembled long ago. We know a lot about how the Milky Way formed, but there was always the worry that the Milky Way is not a typical spiral galaxy. Now we can see that the Milky Way’s formation is fairly typical of how other disk galaxies were assembled”.

Other co-authors are based at Macquarie University in Australia and Germany’s Max-Planck-Institut fur Extraterrestrische Physik.



Comparison of the spatially resolved chemistry of UGC 10738 and the Milky Way. Mass fraction of stars as a function of [Z/H] and [α/Fe] (summed over age) in bins of projected radius and scale height. Regions are chosen to match those of Hayden et al. (2015), though we note the scale radii and height of the two galaxies are likely different. Contours enclose 50, 75, 90 and 99 per cent of Milky Way stars from Hayden et al. (2015). We find a high degree of qualitative agreement between the two galaxies, with a low metallicity, alpha-rich component at large scale heights evident in both.

Background Image: Galaxy UGC 10738, seen edge-on through the European Southern Observatory’s Very Large Telescope in Chile, revealing distinct thick and thin discs. Credit: Jesse van de Sande/European Southern Observatory

AT COSMIC NOON, PUFFY GALAXIES MAKE STARS FOR LONGER

GALAXIES WITH EXTENDED DISKS MAINTAIN PRODUCTIVITY, RESEARCH REVEALS

Massive galaxies with extra-large extended "puffy" disks produced stars for longer than their more compact cousins, new modelling reveals.

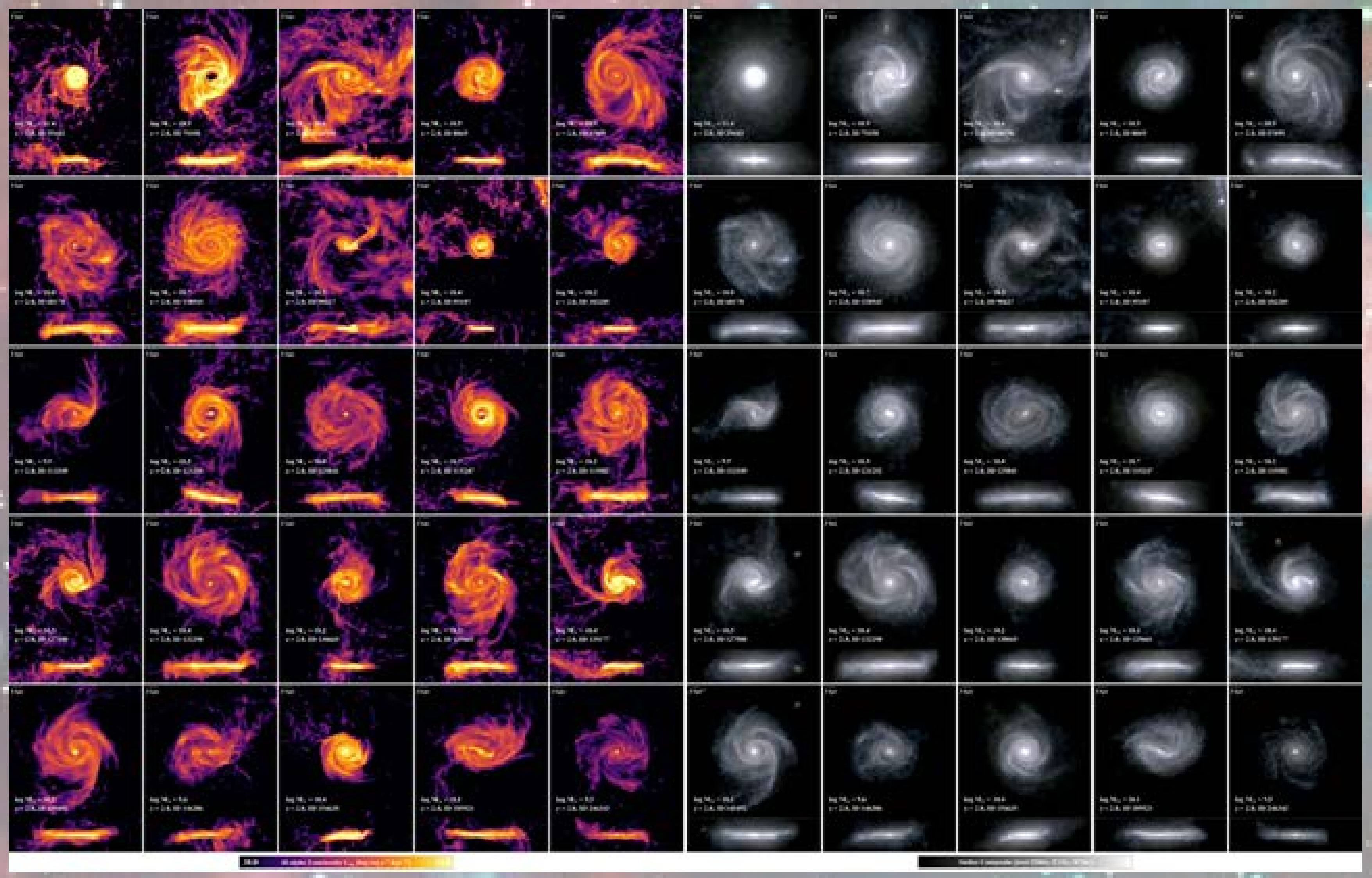
In a paper published in the Astrophysical Journal, researchers led by Dr Anshu Gupta and Associate Professor Kim-Vy Tran from Australia's ARC Centre of Excellence in All Sky Astrophysics in 3 Dimensions (ASTRO 3D), show that the sheer size of a galaxy influences when it stops making new stars.

"There's a period in the life of the Universe known as the 'cosmic noon', which occurred about 10 billion years ago," said Dr Gupta. "That was when star formation in massive galaxies was at its peak. After that, gas in most of these galaxies grew hot – in part because of the black holes in the middle of them – and they stopped forming stars.

"In galaxies that are really, really stretched out, however, we found that things didn't heat up as much and the black holes didn't exert such a great influence, so stars kept getting made over a longer period."

Dr Gupta and Dr Tran, both of whom are based at the University of NSW, Sydney, found that they could predict the end of star formation based on the size of a galaxy's disk – the flat, circular region surrounding its centre, comprising stars, hydrogen gas and dust.

"Where the stars in the disk are widely distributed – you could call it 'puffy' – the gas stays cooler, so continues to coalesce under gravity and form new stars," said Dr Gupta. "In galaxies with more compact disks, the gas heats up quite quickly and is soon too energetic to mash together, so the formation of stars finishes by just after cosmic noon. Puffy disks keep going much longer, say as far as cosmic afternoon tea."



To make their findings, the researchers, with colleagues from Melbourne, Germany, Mexico and the United States, used cosmological galaxy formation simulations from an international collaboration known as the IllustrisTNG project.

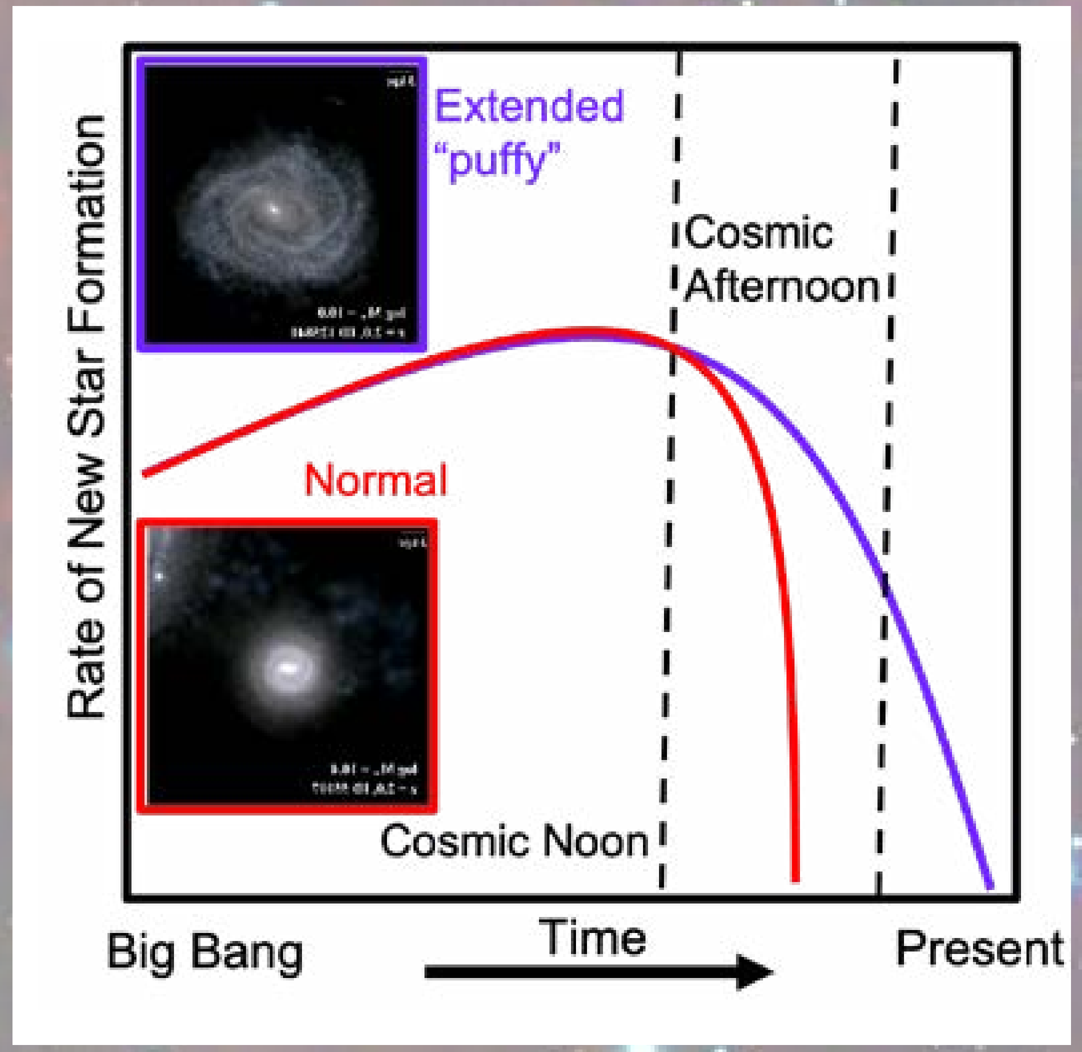
This was integrated with deep observations from an Australian-led project known as the Multi-Object Spectroscopic Emission Line (MOSEL) Survey.

"The IllustrisTNG simulations required millions of hours of supercomputer time," said Dr Tran.

"And the MOSEL survey needs both the WM Keck Observatory in Hawai'i and the Hubble Space Telescope.

"The results mean that for the first time we've been able to establish a relationship between disk size and star-making. So now astronomers will be able to look at any galaxy in the Universe and accurately predict when it will stop making stars – just after lunch, or later in the cosmic afternoon."

The Milky Way, incidentally, is a massive galaxy that is still making stars. That's because it was something of a cosmic late-starter. When cosmic noon arrived it was very small – containing only one-tenth of the star mass it hosts today – and did not attain 'massive' status until much, much later.



As a result, the gas and dust within it has not yet warmed up enough to quench the star-making process.

It is not, however, an extended puffy galaxy, so it will quench, relatively speaking, sooner rather than later.

"Cosmic noon was a long time ago," said Dr Gupta. "I'd say that by now the Universe has reached cosmic evening. It's not night-time yet, but things have definitely slowed down."

As well as UNSW, team members hailed from Swinburne University, the Max-Planck-Institut fur Astronomie, the Universidad Nacional Autonoma de Mexico, and the Flatiron Institute and Columbia University, both in New York.

Image 1: (Above left) An ensemble of twenty-five disk galaxies. The view on the left shows light emitted in the H-alpha line from interstellar gas as a result of ongoing star-formation, while the panels on the right shows the optical light emitted by a mix of young (bluer) and old (redder) stars. Each galaxy can be seen rotated edge-on below its face-on view. Credit: TNG Collaboration

Image 2: (Above right) A graph showing how extended or 'puffy' galaxies continue to make stars longer into the cosmic afternoon than compact ones. Credit: Anshu Gupta

Background Image: The Cat's Paw Nebula in acombination of exposures from the MPG/ESO 2.2-metre telescope Credit: ESO/R. Gendler & R.M. Hannahoe

ASKAP - AUSTRALIAN SQUARE KILOMETRE ARRAY PATHWAY

The Australian SKA Pathfinder (ASKAP) surveys project is investigating the evolution and buildup of neutral hydrogen (HI) in galaxies over the past 7 billion years.

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 three different but interlinked ASKAP surveys; DINGO, FLASH and WALLABY.

The Deep Investigations of Neutral Gas Origins (DINGO) survey (led by AI Martin Meyer) is studying the evolution of galaxies and the gas-rich Universe over the past 4 billion years. This is being achieved through a combination of direct galaxy-by-galaxy analysis in the nearby Universe and statistical stacking studies at higher redshifts. The HI emission line data from DINGO will be combined with extensive multiwavelength data available in the target fields to understand the connections between gas content, stellar populations and star formation history, and the underlying dark matter distribution.

The Widefield ASKAP L-band Legacy All-sky Blind surveY (WALLABY) (led by CI Lister Staveley-Smith) aims to detect 300,000 nearby galaxies (with a mean redshift of about 0.04) across the southern hemisphere. The goals of WALLABY include: measurement of baryonic and dark matter mass profiles of unprecedentedly large galaxy samples; and studying the effect of environment (local galaxy and gas density) on the properties of galaxies in order to better understand galaxy evolution in cosmic voids, filaments, groups and clusters.

The First Large Absorption Survey in HI (FLASH; led by CI Elaine Sadler and AIs James Allison and Elizabeth Mahony) uses measurements of the 21cm HI line seen in absorption against bright background radio sources to study neutral gas in and around distant galaxies. With this technique, FLASH will probe the HI gas content of several hundred individual galaxies and study the evolution of HI over the past 4-8 billion years, where the HI emission line is too faint to be detected in even the deepest ASKAP surveys.

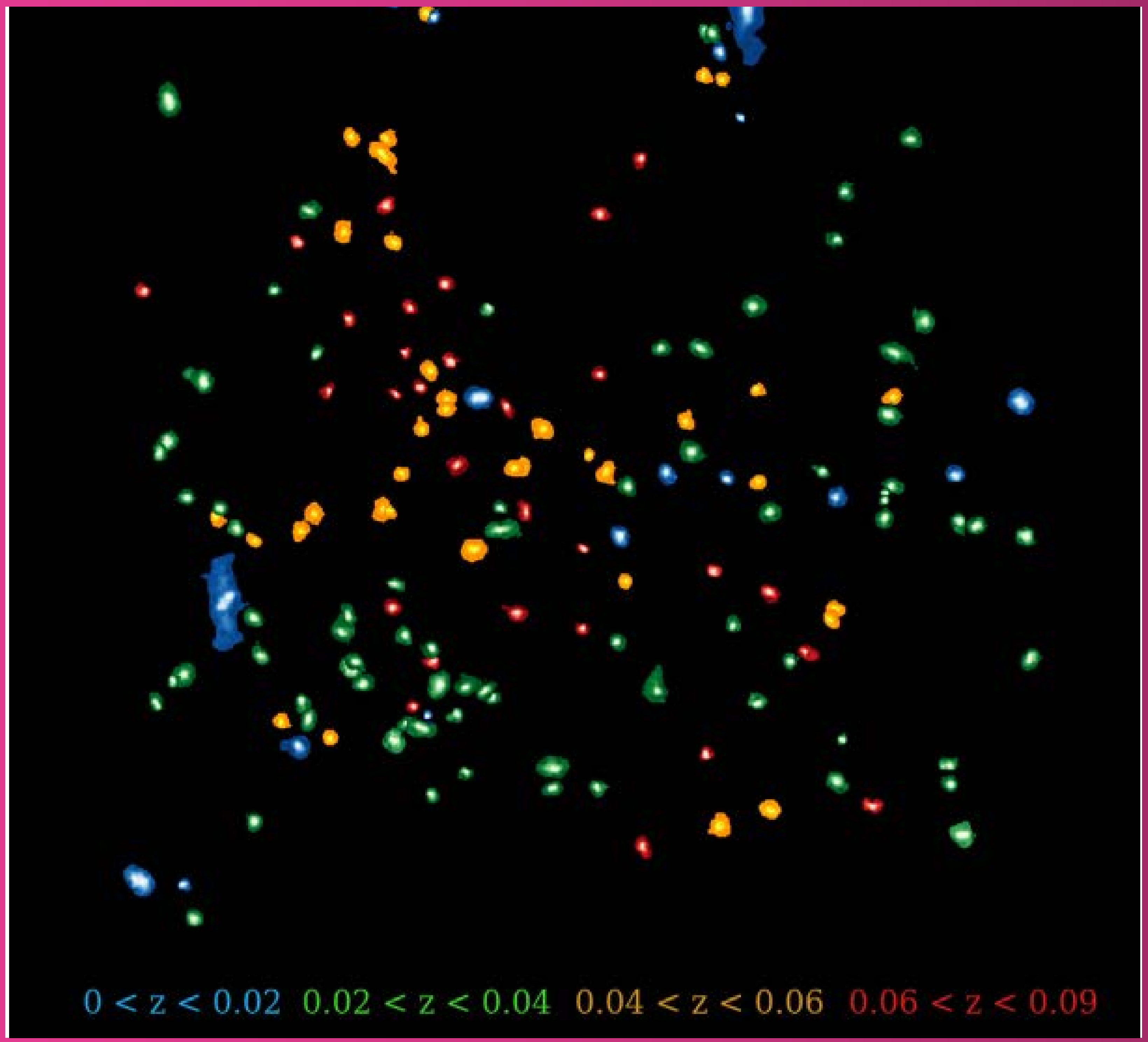


Figure 14: An ASKAP/DINGO HI column density image of the GAMA 23 region, where galaxies have been colour-coded by their redshift and zoomed-in by a factor of two for clarity.

2021 PROJECT HIGHLIGHTS - DINGO

Pilot phase I data from DINGO has been processed and released into the CSIRO ASKAP Science Data Archive (CASDA), with the deepest 53-h integration in the G23 field yielding 168 detections. These data will be further augmented by additional observations from Pilot phase 2, with the first quality gate observations now completed and undergoing assessment. An additional major milestone for the project was the submission of its documentation in November 2021 for the Review of ASKAP Survey Science Projects (RASSP), following which telescope time for the full ASKAP surveys will be allocated.

WALLABY

WALLABY published 5 refereed papers this year with data from Pilot fields. Two were led by ASTRO 3D postdocs Bi-Qing For and Tristan Reynolds, two were led by AIs Chandra Murugeshan and Ivy Wong, and one by PKU/KIAA collaborator Jing Wang. In addition AI Tobias Westmeier published the SoFiA 2 paper describing the parallel and automated source-finding pipeline. The SoFiA team had the distinction of a bronze medal in the SKAO's 2nd Science Data Challenge to find artificial galaxies in simulated SKA data cubes. The SoFiA team were the highest-placed 'blind' source-finding team, in that they didn't make use of the extensive training data set which was made available. All Pilot phase 1 WALLABY data cubes have been made available for public download on CASDA, and the first public data release of value-added data products (moment maps, velocity fields and rotation curves) will occur in 2022. Pilot phase 2 observations are ongoing, and WALLABY looks forward to the allocation of full survey time in 2022 following an international project review process.

FLASH

All the data from the FLASH Pilot Survey have been processed and are now available in the CASDA public data archive. The FLASH team have been working on follow-up studies of the many new HI absorption lines detected in the Pilot Survey, and fig. 16 shows three new detections for which we also have follow-up observations with the MeerKAT telescope. Notable papers from 2021 included the FLASH survey description paper (led by James Allison with contributions from many team members), and a paper led by Elizabeth Mahony presenting a study of a galaxy at redshift z=0.7 where HI was detected in absorption against the lobe of a powerful background radio galaxy. This paper shows that ASKAP can detect 21-cm H I absorption towards extended radio sources as well as the compact sources which have been the traditional targets for HI absorption studies.

2021 PERSONNEL HIGHLIGHTS

PhD student Kristof Rozgonyi completed his thesis on the alternative uv-grid pipeline needed for DINGO deep imaging. This methodology enables the long-term storage and combination of visibility-domain interferometric data, and the mitigation of errors that could otherwise be 'frozen-in' with image-domain combination methods. The pipeline is now being implemented on Pawsey supercomputing infrastructure following a successful PaCER application to support this work (the HiVIS Project).

The WALLABY team was joined by new ASTRO 3D PhD student Manasvee Saraf whose initial PhD project includes a study of the Norma cluster with ASKAP and the Australia Telescope Compact Array. Chandra Murugeshan successfully defended his Swinburne PhD thesis 'The effects of angular momentum and environment on the HI properties of disc galaxies' and has joined partner organisation CSIRO as a postdoc. Chandra has also taken on the role of Deputy WALLABY Project Scientist. ASTRO 3D postdoc Bi-Qing For moved to a new ICRAR-funded position, but fortunately also stays within the WALLABY team. AI Karen Lee-Waddell has transitioned to the new role of AusSRC Director, but remains the WALLABY project scientist.

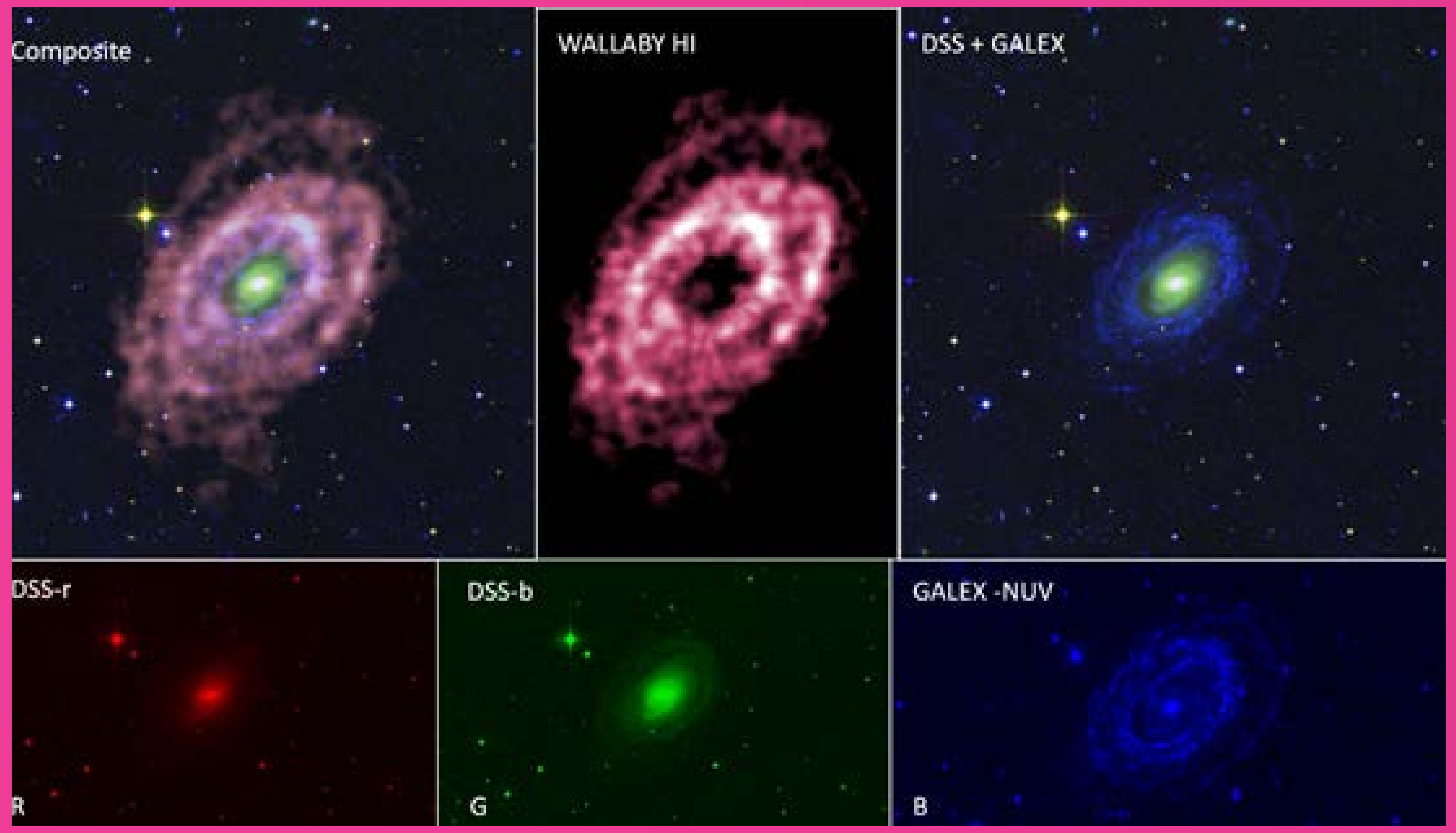
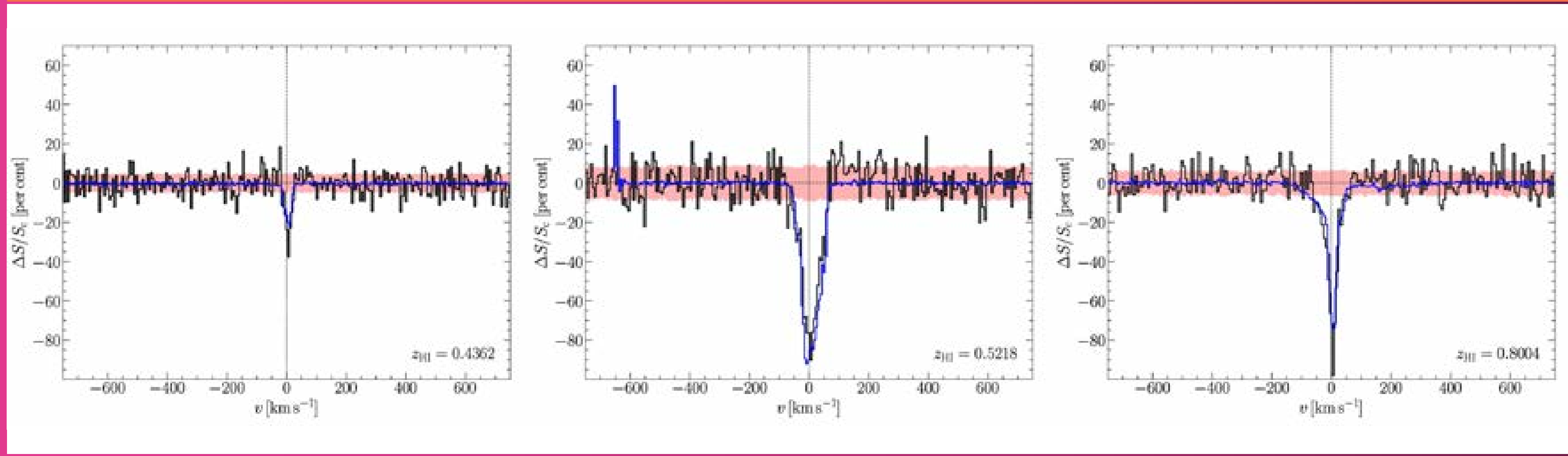


Figure 15: The neutral hydrogen distribution (middle top) in the galaxy NGC 1367 as imaged by ASKAP for the WALLABY survey. Comparisons with optical (DSS) (bottom left and middle) and ultraviolet (GALEX) (bottom right) data, together with a composite image (top left) are shown (For et al. 2021, MNRAS, 507, 2300).

In the FLASH team, 2021 saw some changes to the survey leadership. James Allison (Oxford University), who was a FLASH co-PI from 2018 onwards, stepped down from this role in October when he started a new position working in industry. James will continue as an advisor to the project and a member of the FLASH Executive. Elizabeth Mahony (previously the FLASH Project Scientist) took over as co-PI of FLASH from October 2021, and ASTRO 3D postdoc Hyein Yoon has taken on the FLASH Project Scientist role. In November 2021 we welcomed JNHS Aditya as a new ASTRO 3D postdoc working with the FLASH team. ASTRO 3D student Simon Weng began a PhD project in early 2021 and has been awarded an ESO Studentship to spend 12 months working at the European Southern Observatory headquarters in Germany on a project combining ASKAP, ALMA and MUSE data to study the connection between galaxies and their neutral and ionized gas at intermediate redshift.

Figure 16: HI spectra of three new absorption lines detected in the FLASH Pilot Survey, at lookback times of 4.6 billion years (left), 5.3 billion years (centre) and 6.9 billion years (right). The ASKAP discovery spectra are shown in black, and follow-up observations from the South African MeerKAT telescope are over-plotted in blue. The good agreement between the line profiles measured at the two telescopes provides a useful external validation of the reliability of the ASKAP data (images provided by Elizabeth Mahony).



CROSS PROJECT COLLABORATIONS

DINGO continued to work with other ASKAP surveys and the spectral-line working group to improve outputs of the ASKAPsoft pipeline. As part of the RASSP process, DINGO also engaged with GAMA and SAMI team members to optimise multiwavelength science outcomes in the survey redesign process.

Good representation of WALLABY science was achieved at several collaborative science meetings during the year, including the SKA Science meeting (12-19 March 2021), the ASA meeting (12-16 July 2021), ACAMAR7 (9-11 November 2021), and the annual WALLABY science meeting (12 November 2021).

We held two online 'FLASH Science Roundtable' meetings with team members from around the world in September and October 2021, and FLASH science results were presented at several meetings including the East Asia SKA workshop and an international workshop on CSS and GPS radio sources (both in May 2021), and the ASA meeting in July 2021. We also gave an invited FLASH presentation at a joint meeting of the international SKA radio continuum and HI science working groups in November 2021.

ASKAP

DR CHANDRASHEKAR MURUGESHAN

Affiliate
CSIRO
ASKAP - WALLABY Survey

ABOUT ME

My research is focused on studying the kinematics and dynamics of galaxies. Specifically, I have an interest in measuring the angular momentum in galaxies, which is believed to play an important role in galaxy evolution. In addition, my research also focuses on the various ways in which the neutral hydrogen (HI) gas is accreted and stripped in galaxies. I make use both archival HI data from radio interferometers from around the world, as well as new high-resolution ASKAP observations of the HI gas in galaxies as part of the WALLABY survey to accomplish this.

WHY ASTRONOMY?

My association with astronomy goes back to my childhood days. Growing up back in the 90's India, blackouts were very common in the summers. On such evenings I would often find myself on the terrace with my favourite star gazing book, torch, a pair of binoculars and a pocket radio (for companionship!), and stare at the sky trying to identify the constellations in the book. Those early blackouts were probably the reason why I fell in love with astronomy. By the time I graduated high school, I had decided that I was going to pursue physics and astronomy as a passion and a career.

WHAT I LOVE ABOUT ASTRONOMY

I absolutely love the fact that we can sit at our desks, use our telescopes and peer into the depths of the cosmos to uncover and solve some of the greatest mysteries in the Universe.

WHAT I DON'T LOVE

Learning to be patient! Sometimes it takes years before a result can be finalised or a discovery confirmed.

IF I WASN'T AN ASTRONOMER, I WOULD BE...

The idea of studying the complexity of the human brain and mind has always excited me. So if not an astronomer, I would have liked to perhaps pursue a career in neuroscience.

A HIGHLIGHT IN 2021

While 2021 has definitely been a rough year, it has also been an eventful one for me. I not only successfully graduated with a PhD earlier this year, but also secured a postdoc position at CSIRO to work on new and exciting research relating to ASKAP/WALLABY.

I SURVIVED COVID IN 2021 BY...

Lockdowns and restrictions due to COVID did have an effect on me both mentally and physically, but I have been dealing with such hard times by focusing on the positives and by being thankful. My exercise and meditation routines have helped me stay sharp and not lose focus. Keeping in constant touch with family and friends all along was also really helpful.

SAMI/HECTOR

SAMI and Hector are two integral field spectrographs that 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.

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 ionization diagnostics and many others.

The SAMI Galaxy Survey of over 3000 galaxies is the first integral field sample that is sufficiently large to disentangle the competing roles of galaxy mass and environment. As a result, we can address the following three key questions:

1. What is the physical role of environment in galaxy evolution?

2. What is the interplay between gas flows and galaxy evolution?

3. How are mass and angular momentum built up in galaxies?

Hector will build on SAMI using a new instrument with higher spectral resolution, a wider field of view, and the ability to target more galaxies at once. From the start of 2022 Hector will be carrying out a survey of up to 15000 galaxies.

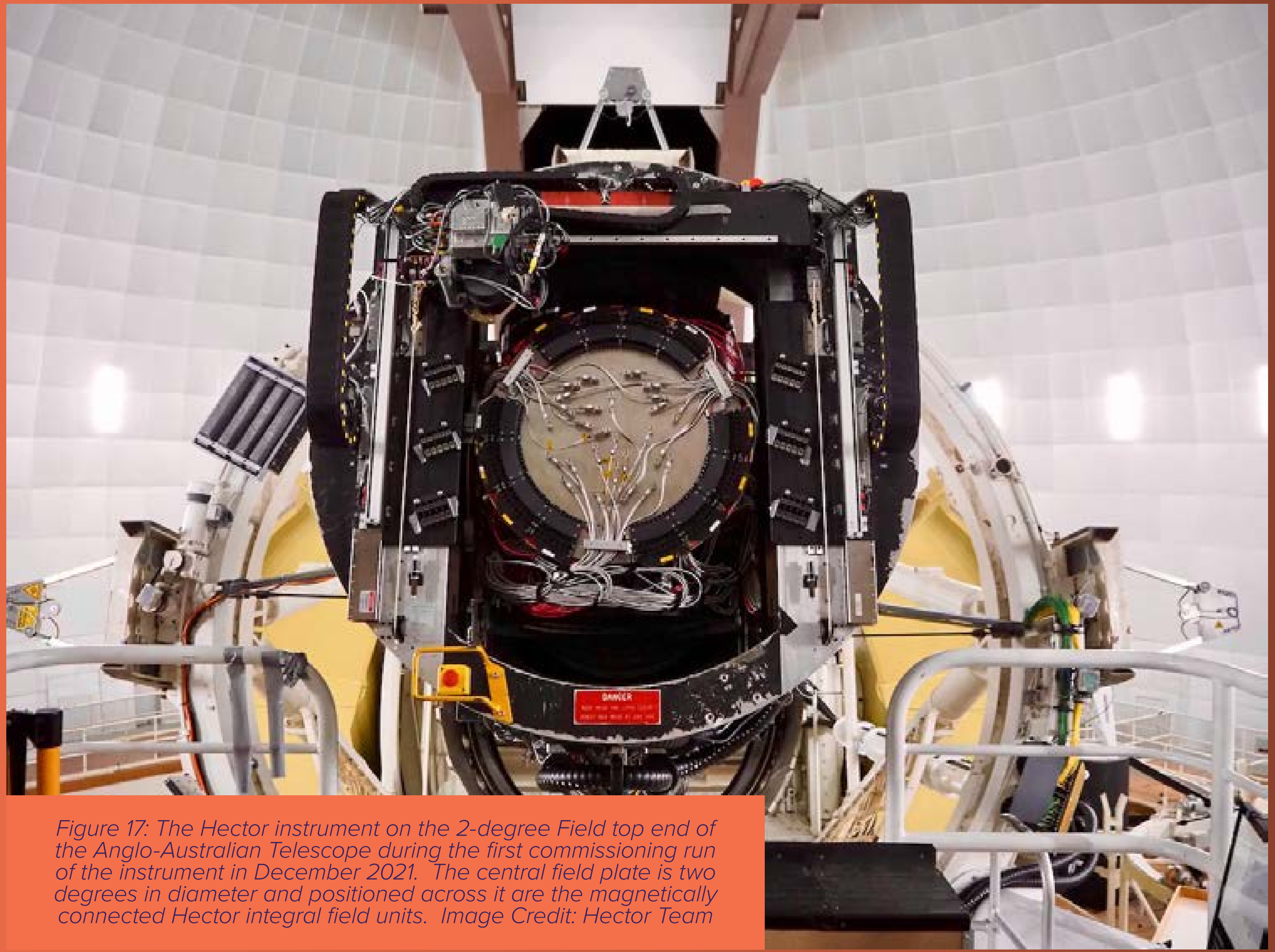


Figure 17: The Hector instrument on the 2-degree Field top end of the Anglo-Australian Telescope during the first commissioning run of the instrument in December 2021. The central field plate is two degrees in diameter and positioned across it are the magnetically connected Hector integral field units. Image Credit: Hector Team

2021 PROJECT HIGHLIGHTS

The project had 3 main aims for 2021. The first was to make the full SAMI data set public as part of SAMI Data Release 3. This happened in January 2021, with a data release that including the SAMI cluster targets for the first time.

The DR3 effort has been driven by ASTRO 3D members Scott Croom, Matt Owers, Nic Scott, Henry Poetrodjojo, Brent Groves, Jesse van de Sande, Tania Barone and Luca Cortese. Many other members of the team helped with quality control checks of the data products. The data is available through Data Central (see https://datacentral.org.au/) and described by Croom et al (2021). A press release associated with the paper gathered much attention both domestically and internationally (see https://ASTRO 3D.org.au/the-secrets-of-3000-galaxies-laid-bare/ .

The second focus of the team was to publish key papers on using the full SAMI sample, and 17 papers were published in 2021.

ASTRO 3D AI Jesse van de Sande (Sydney) has published his work showing that the spin of galaxies depends on both mass and environment independently. While the fraction of galaxies classified as slowly rotating is strongly dependent on mass, at a fixed mass galaxies in groups are more likely to be slow rotators. Even for regularly rotating galaxies, if they are in a higher density environment, they will be rotating more slowly.

PhD student Tomas Rutherford (Sydney) used an alternative method, based on mark correlation functions also demonstrate that the relation between spin and environment is significant not just due to galaxy mass.

In related work ASTRO 3D Affiliate Amelia Fraser-McKelvie (UWA) combined the SAMI data with the MaNGA Survey to examine how galaxy spin varied along the star-forming main sequence of galaxies. This is one of a number of papers that is starting to combine the mature SAMI data set with other samples, both locally and at higher redshift.

PhD Student Stefania Barsanti (Maquarie, now an ASTRO 3D postdoc at ANU) used bulge-disk decomposition of SAMI galaxies in clusters, combined with measurements of stellar age and metallicity, to show that cluster galaxies have redder bulges because of higher central metallicity, not due to older ages of the bulge stars.

Former ASTRO 3D postdoc Francesco D'Eugenio (ANU, now in Cambridge) used SAMI stellar kinematics to explore the fundamental plane of early type galaxies (a relationship between velocity dispersion, size and luminosity). Using SAMI measurements of stellar population parameters, Francesco was able to show that much of the remaining scatter in the fundamental plan is driven by varying stellar population age.

A major success for 2021 has been the completion of the Hector instrument. This went on sky for the first time in December 2021 (having been delayed during 2021 due to COVID-19 lockdowns). The Hector system is deployed on the Anglo-Australian Telescope, near Coonabarabran in NSW. The first of three planed commissioning runs have been completed, culminating in the first observations of galaxies with the Hector instrument. The Hector instrument and Survey is led by Julia Bryant (AI, Sydney), with many people contributing to the instrument build, including ASTRO 3D students Adeline Wang and Rebecca Brown (Sydney). Sree Oh (postdoc ANU), Nic Scott (AI Sydney) and Madusha Gunawardhana (postdoc Sydney) have led work on the data pipeline for Hector. ASTRO 3D postdoc Sam Vaughan has led the development of the Hector input catalogues.

The success of Hector commissioning sets up the team well for science operations in 2022 with an array of early science being targeted, including Milky Way analogue galaxies and galactic outflows, both of which will benefit from Hector's improved spectral resolution.

2021 PERSONNEL HIGHLIGHTS

Congratulations PhD students Mathew Varidel (Sydney), Stefania Barsanti (Macquarie) and Tania Barone (ANU) who completed their PhDs in 2021. Congratulations also to Masters students Murray Riding (Sydney) and Rebecca Brown (Sydney) also completed in 2021.

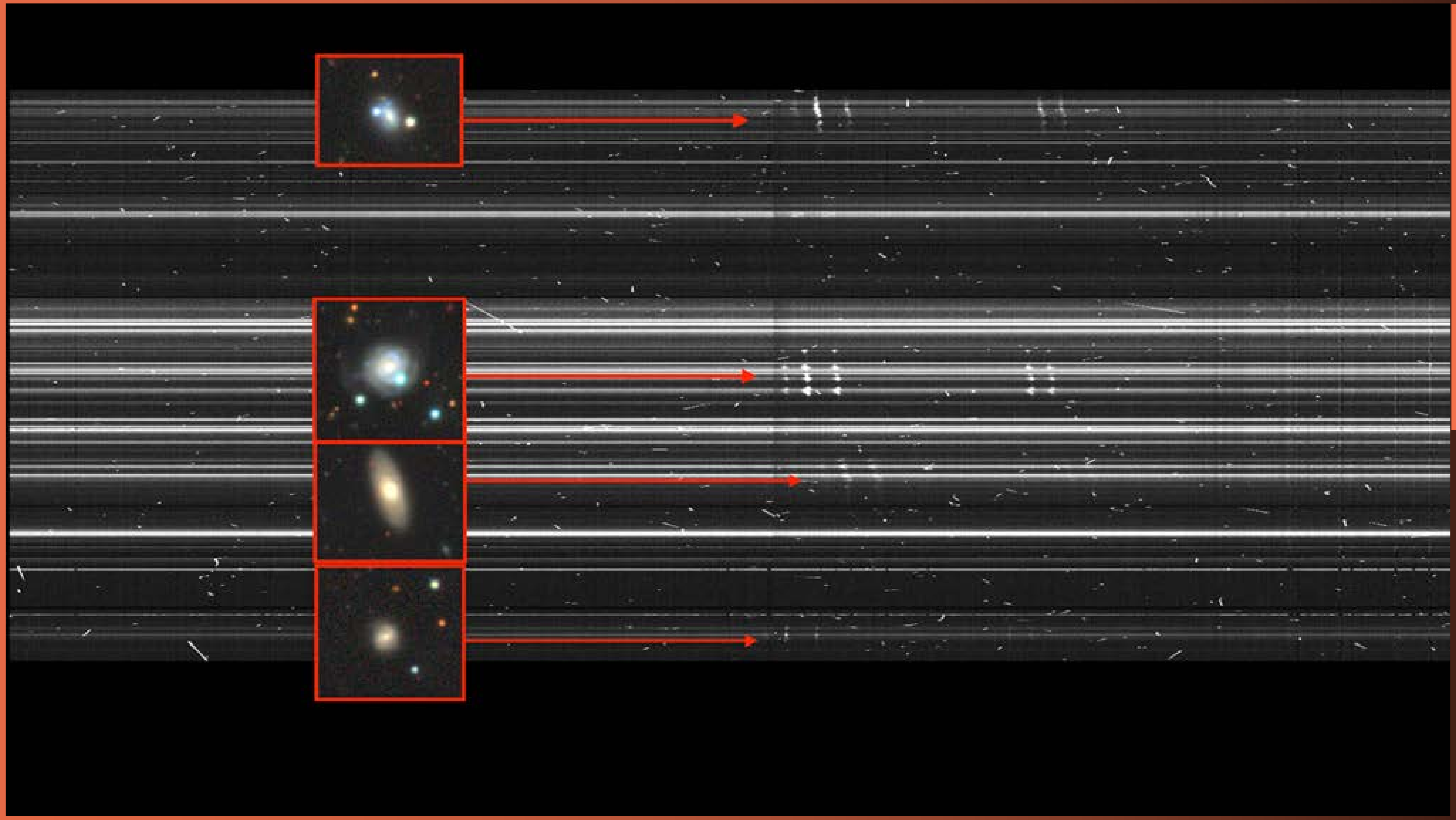


Figure 18: The first galaxy data from the Hector instrument in "row-stacked spectra" format. Each horizontal line is the spectrum from a single optical fibre (blue to the right, red to the left). Groups of fibres target galaxies. The near vertical lines that show small horizontal shifts are gas emission lines, with the shifts due to the rotation of the galaxies being observed. Example images of the galaxies being targeted are shown in the red boxes. Image Credit: Madusha Gunawardhana.

SAMI HECTOR

THE SECRETS OF 3000 GALAXIES LAID BARE

AUSTRALIAN-LED ASTRONOMY PROJECT SHEDS LIGHT ON THE EVOLUTION OF THE UNIVERSE

The complex mechanics determining how galaxies spin, grow, cluster and die have been revealed following the release of all the data gathered during a massive seven-year Australian-led astronomy research project.

The scientists observed 13 galaxies at a time, building to a total of 3068, using a custom-built instrument called the Sydney-AAO Multi-Object Integral-Field Spectrograph (SAMI), connected to the 4-metre Anglo-Australian Telescope (AAT) at Siding Spring Observatory in New South Wales. The telescope is operated by the Australian National University.

Overseen by the ARC Centre of Excellence for All Sky Astrophysics in 3 Dimensions (ASTRO 3D), the project used bundles of optical fibres to capture and analyse bands of colours, or spectra, at multiple points in each galaxy.

The results allowed astronomers from around the world to explore how these galaxies interacted with each other, and how they grew, sped up or slowed down over time.

No two galaxies are alike. They have different bulges, haloes, disks and rings. Some are forming new generations of stars, while others haven't done so for billions of years. And there are powerful feedback loops in them fuelled by supermassive black holes.

"The SAMI survey lets us see the actual internal structures of galaxies, and the results have been surprising," said lead author Professor Scott Croom from ASTRO 3D and the University of Sydney.

"The sheer size of the SAMI Survey lets us identify similarities as well as differences, so we can move closer to understanding the forces that affect the fortunes of galaxies over their very long lives."

The survey, which began in 2013, has already formed the basis of dozens of astronomy papers, with several more in preparation. A paper describing the final data release – including, for the first time, details of 888 galaxies within galaxy clusters – was published today on the arxiv pre-print server and in the journal Monthly Notices of the Royal Astronomical Society.

"The nature of galaxies depends both on how massive they are and their environment," said Professor Croom.

"For example, they can be lonely in voids, or crowded into the dense heart of galactic clusters, or anywhere in between. The SAMI Survey shows how the internal structure of galaxies is related to their mass and environment at the same time, so we can understand how these things influence each other."

Research arising from the survey has already revealed several unexpected outcomes.

One group of astronomers showed that the direction of a galaxy's spin depends on the other galaxies around it, and changes depending on the galaxy's size. Another group showed that the amount of rotation a galaxy has is primarily determined by its mass, with little influence from the surrounding environment. A third looked at galaxies that were winding down star-making, and found that for many the process began only a billion years after they drifted into the dense inner-city regions of clusters.

"The SAMI Survey was set up to help us answer some really broad top-level questions about galaxy evolution," said co-author Dr Matt Owers from Macquarie University in Australia.

"The detailed information we've gathered will help us to understand fundamental questions such as: Why do galaxies look different depending on where they live in the Universe? What processes stop galaxies forming new stars and, conversely, what processes drive the formation of new stars? Why do the stars in some galaxies move in a highly ordered rotating disk, while in other galaxies their orbits are randomly oriented?"

Professor Croom added, "The survey is finished now, but by making it all public we hope that the data will continue to bear fruit from many, many years to come."

Co-author Associate Professor Julia Bryant from ASTRO 3D and the University of Sydney said: "The next steps in this research will make use of a new Australian instrument – which we've called Hector – that will start operation in 2021, increasing the detail and number of galaxies that can be observed."

When fully installed in the AAT, Hector will survey 15,000 galaxies.

The final data release paper has 41 authors, drawn from Australia, Belgium, the US, Germany, Britain, Spain and The Netherlands.

The full data set is available online through Australian Astronomical Optics (AAO) Data Central.

Press Release by Science in Public

Image: A/Prof Julia Bryant from the University of Sydney inside the SAMI instrument at the top end of the Anglo Australian Telescope.
Credit: Scott Croom/University of Sydney

Background GIF : Time lapse of Anglo Australian Telescope, showing the SAMI survey being conducted.
Credit: Ángel R. López-Sánchez (AAO-MQ)

PROFESSOR MATTHEW COLLESS

Chief Investigator
Node leader
Australian National University
SAMI Hector Survey Lead

ABOUT ME

I am a Chief Investigator, ANU Node Leader and the SAMI/Hector Survey Lead. My work involves using the SAMI instrument to look at stellar populations and the kinematics of galaxies. That means we're looking at the ages, metallicities and other properties of the stars and also, how the stars and the gas are moving around in the galaxies. We're interested in that because we want to see how the motions of the stars and the gas relate to the stellar populations. By analysing how those motions are different making sure we understand exactly how the stars are moving. Then by having accurate measures of the ages, metallicities and other properties of the populations, we can correlate the two and see whether the dynamics of galaxies, how they form and move actually affects how the stars are formed and when they're formed.

WHY ASTRONOMY?

I was always interested in Astronomy. When I was a young kid I had a little telescope and I'd sit out on my back lawn and look up at the stars, comets and the moon. And I just loved that!

I've always been drawn to the big questions. I've always wanted to know what was outside or beyond, so I was naturally drawn to astronomy and within astronomy, to Cosmology my main field which is the study of the Universe as a whole and that's just my natural bent towards asking really big questions and I found that incredibly satisfying in astronomy that you could not only ask those big questions but actually get some answers. You can ask big questions in philosophy or theology, but they're much harder to answer. In Astronomy, those of us that need instant gratification are more likely to be satisfied.

WHAT I LOVE ABOUT ASTRONOMY

Is the fact it is so surprising. I have been working as a professional astronomer now for almost 40 years and over that time I have never ceased to be surprised by the Universe. Every time we build a new telescope or put a new instrument on a telescope and look at the Universe, it finds some way to surprise us again, and I love that I can go to work every day and expect surprises.

....ABOUT BEING A CHIEF INVESTIGATOR

I do enjoy being a chief investigator. I love having the chance of being able to see a big picture and to have the resources to deploy to be able to achieve that goal. When you're a CI you get the opportunity to do bigger things that you can't do if you're on your own. Having a team, having a research group... being part of a CoE enables you to "reach for the stars" to use a corny metaphor.

WHAT I DON'T LOVE

There are more things you could do in the Survey than there are people to do them. So finding enough people and then deploying them on the most interesting problems is always a challenge .

Ones of the things that I've found after 40 years of working in astronomy, that things have got both faster and slower. For example, our ability to turn around a paper and get it published on the internet and in the archive is very rapid. You're getting feedback on your papers the day you publish them from people all around the world. But at the same time, the facilities where we need to do cutting edge science are getting bigger, more complex, more expensive and that means slower. There's a big dynamic time range in the scales you have to cope with and balancing those and keeping a good mix of those in your career and the goals you have for your team are difficult.

IF I WASN'T AN ASTRONOMER, I WOULD BE...

I would probably be a lot richer for one thing but if we leave that to one side, the thing that I really love actually is botany. I love plants and trees and I would have had a wonderful time as a field botanist living out in the field on my own, just cataloguing plants and trees. That to me would have been a lovely thing to do, and I've often thought about that as a second career in retirement.

A HIGHLIGHT IN 2021

A highlight of 2021 for me was having Hector delivered to the AAT! After a long wait (made longer by COVID), it's great to see this exciting new instrument start its commissioning.

In 2022 I'm hoping to see lots of beautiful new integral field spectroscopy of galaxies from Hector!

I SURVIVED COVID IN 2021 BY...

I survived COVID 2021 by listening to audiobooks on many long walks, visiting the past and the future, both on Earth and in galaxies far, far away, with old favourites like Frank Herbet's Dune and Patrick O'Brian's Master & Commander series, as well as new classics such as Amal El-Mohtar & Max Gladstone's This is How You Lose the Time War.

BEND IT LIKE EINSTEIN

ASTRONOMERS TURN GALAXIES INTO MAGNIFIERS

Astronomers have turned a cluster of galaxies into a gargantuan magnifying lens, using it to study another galaxy, 10.7 billion light years away, in unprecedented detail.

Taking advantage of a phenomenon known as "gravitational lensing", the team of scientists, led by NASA Goddard Space Flight Centre scientist Dr Soniya Sharma, identified star forming regions in the distant and ancient galaxy.

The research was funded by Australia's ARC Centre of Excellence in All Sky Astrophysics in 3 Dimensions (ASTRO 3D), and will be of direct benefit to NASA's next orbiting observer.

Without the use of the massive magnifying effect, the galaxy, dubbed cswa128, would be a tiny blur to even the most powerful telescopes on Earth. With it, the astronomers can see stars being formed just three billion years after the Big Bang.

"Our 'lens' is a cluster of galaxies roughly 3.3 billion light years away," explained Dr Sharma.

"The cluster is so huge that its gravity actually bends light, turning it into a sort of magnifying glass. The effect makes cswa128, which lies behind it and seven billion light years further away, appear much larger than it otherwise would from Earth.

"In fact, the galaxy appears about 10 times bigger. We can clearly see bright lights in clumps, which are tell-tale signs of stellar nurseries – parts of the galaxy that are making new stars."

The first formal prediction that light would bend around a massive object and magnify distant things was made by Albert Einstein in his General Theory of Relativity. Its confirmation during a solar eclipse in 1919 rocketed him to fame.

The idea lensing can operate on a galactic scale was demonstrated in 1979. Today, it is Dr Sharma's stock in trade.

Her team's current research – published in the journal Monthly Notices of the Royal Astronomical Society – marks a significant leap forward in the field. The scientists developed a sophisticated algorithm to accurately interpret the spectroscopic information for the target galaxy captured by the WM Keck Observatory in Hawaii.

"This magnifying phenomenon of nature comes at a cost," said co-author and former ASTRO 3D researcher Dr Tiantian Yuan.

"The enlarged images are stretched and distorted. Using the algorithm meant we were able to recover the true shape of the distant galaxy. We also found that it contains twice as many star-forming areas than previously reported."

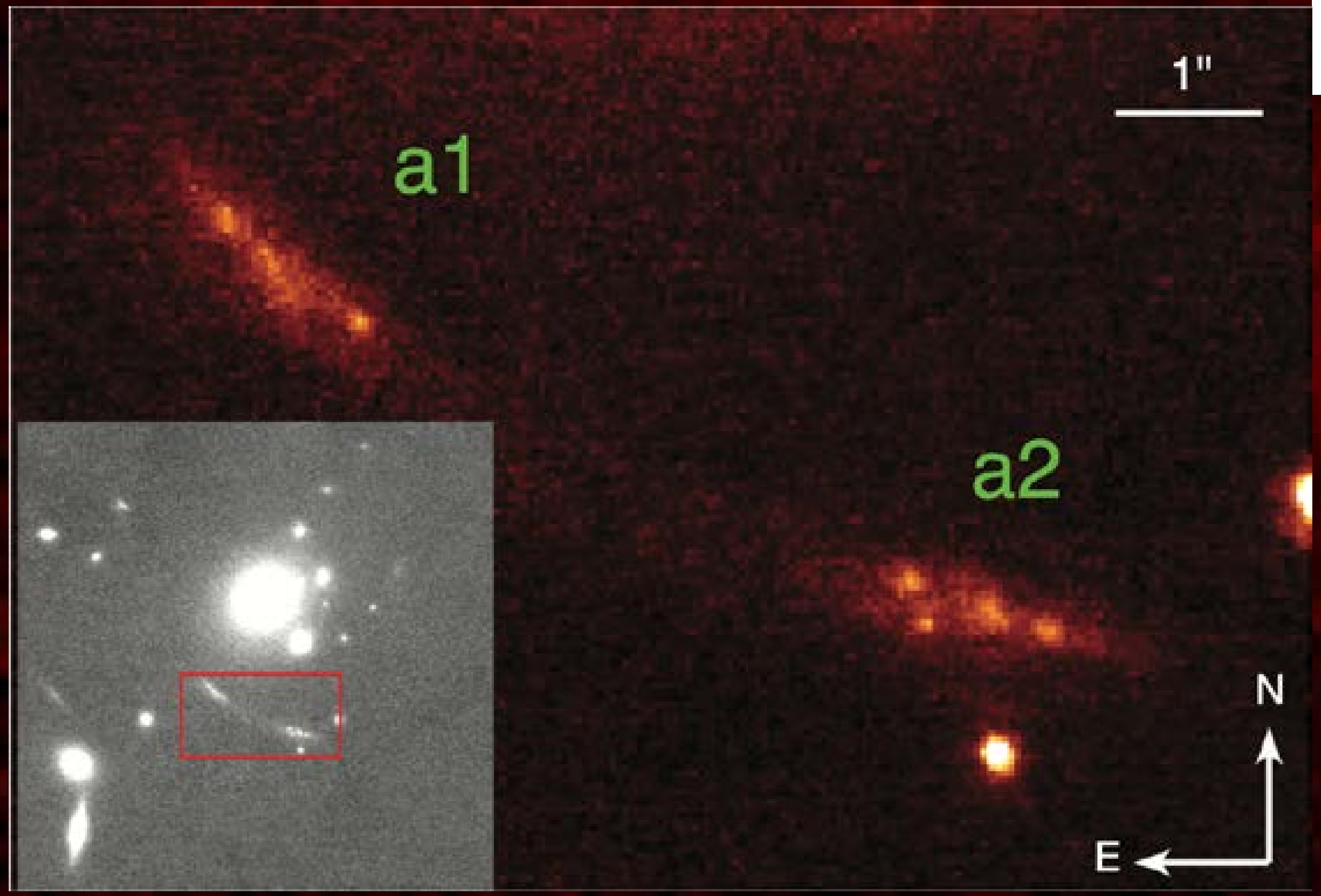
Professor Lisa Kewley, director of ASTRO 3D, added: "This new algorithm allows lensed galaxies to be reconstructed at much finer detail than ever before. It is like taking a dusty magnifying glass, cleaning it, and seeing a much clearer picture."

The success of the current research project is of particular importance to NASA.

"The algorithm we've developed will be used in interpreting the lensed galaxy observations to be conducted using the new James Webb Space Telescope, set for launch later this year," said Dr Sharma.

"It will help in the mission to interpret the mechanism that governs how stars are made, and thus how galaxies evolve and form in the Universe."

Figure 1. High resolution NIRC2 imaging data of cswa128, zoomed in to highlight the two multiple images a1 and a2 at z = 2.225. Inset shows the complete field of view (FOV) of the lensing galaxy group at z = 0.214. The spatial resolution is 0.04 arcsec . Please refer to Paper I for further details on this data.



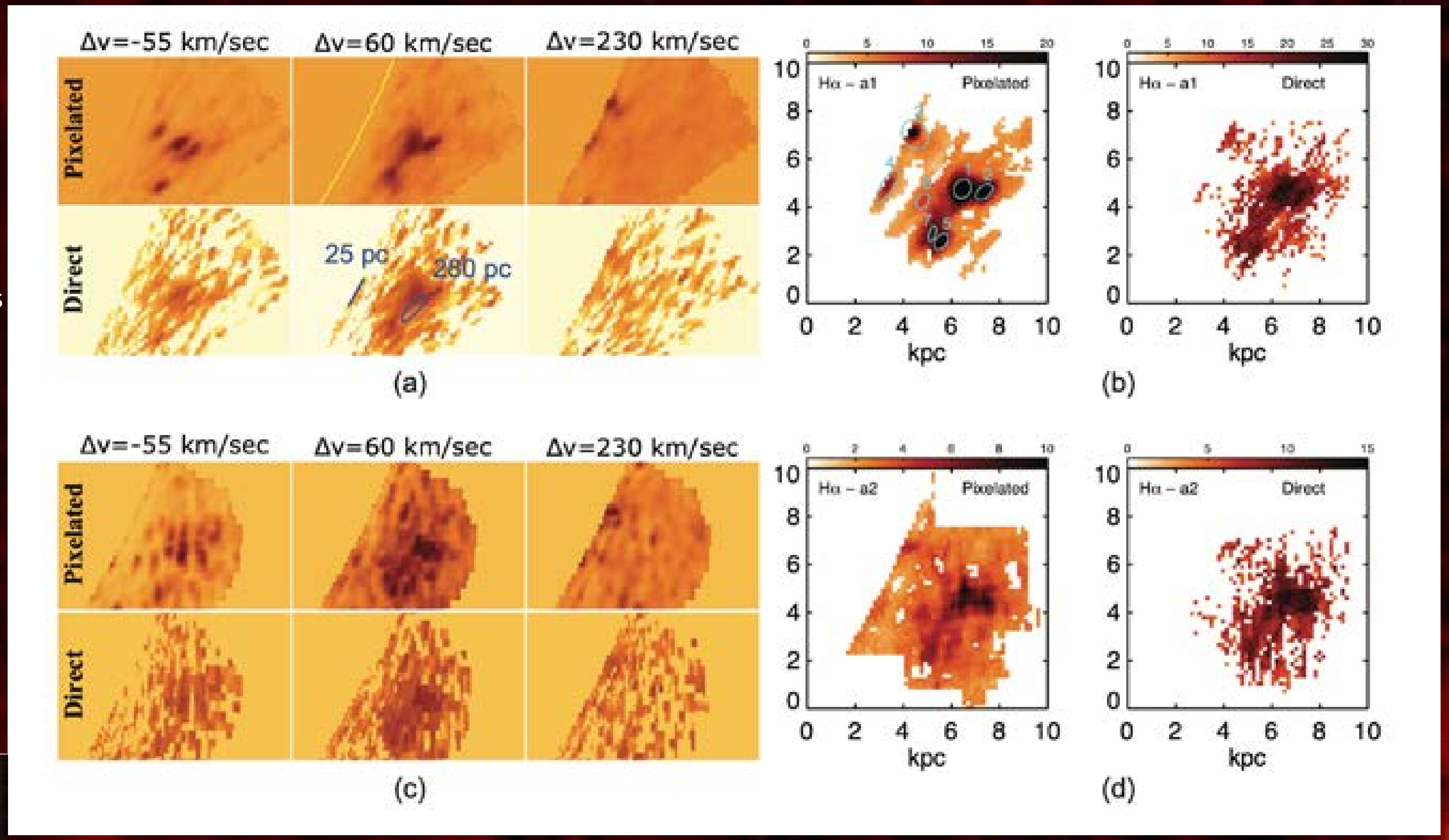


Figure 2. (a) Reconstruction of three wavelength channels with strong H a emission using the pixelated (upper panels) and direct (lower panels) methods of source reconstruction from the a1 datacube. Different values of v at the top of the panels represent the velocity offset from the systemic redshift of the source. The yellow curve shown in the middle panel represents caustics (regions of high magnification in the source plane) using the best- fitting lens model. The blue ellipses show the FWHM of the effective source-plane PSF at two different locations in the source plane. (b) Derived 2D source-plane H a intensity maps in units of 10^{-16} erg s^{-1} cm^{-2} $arcsec^{-2}$ using the pixelated and direct method of source reconstruction for the a1 lensed image. The cyan ellipses refer to the clumps detected by the ASTRODENDRO in the pixelated reconstruction of the a1 lensed image as described in Section 4. (c) and (d) same as (a) and (b) respectively, but for the lensed image a2.

Background Image: Star-forming areas of the galaxy cswa128, 10 billion light-years away, magnified by an intervening galaxy cluster. Credit: Sharma et al

GALAH - GALACTIC ARCHAEOLOGY WITH HERMES

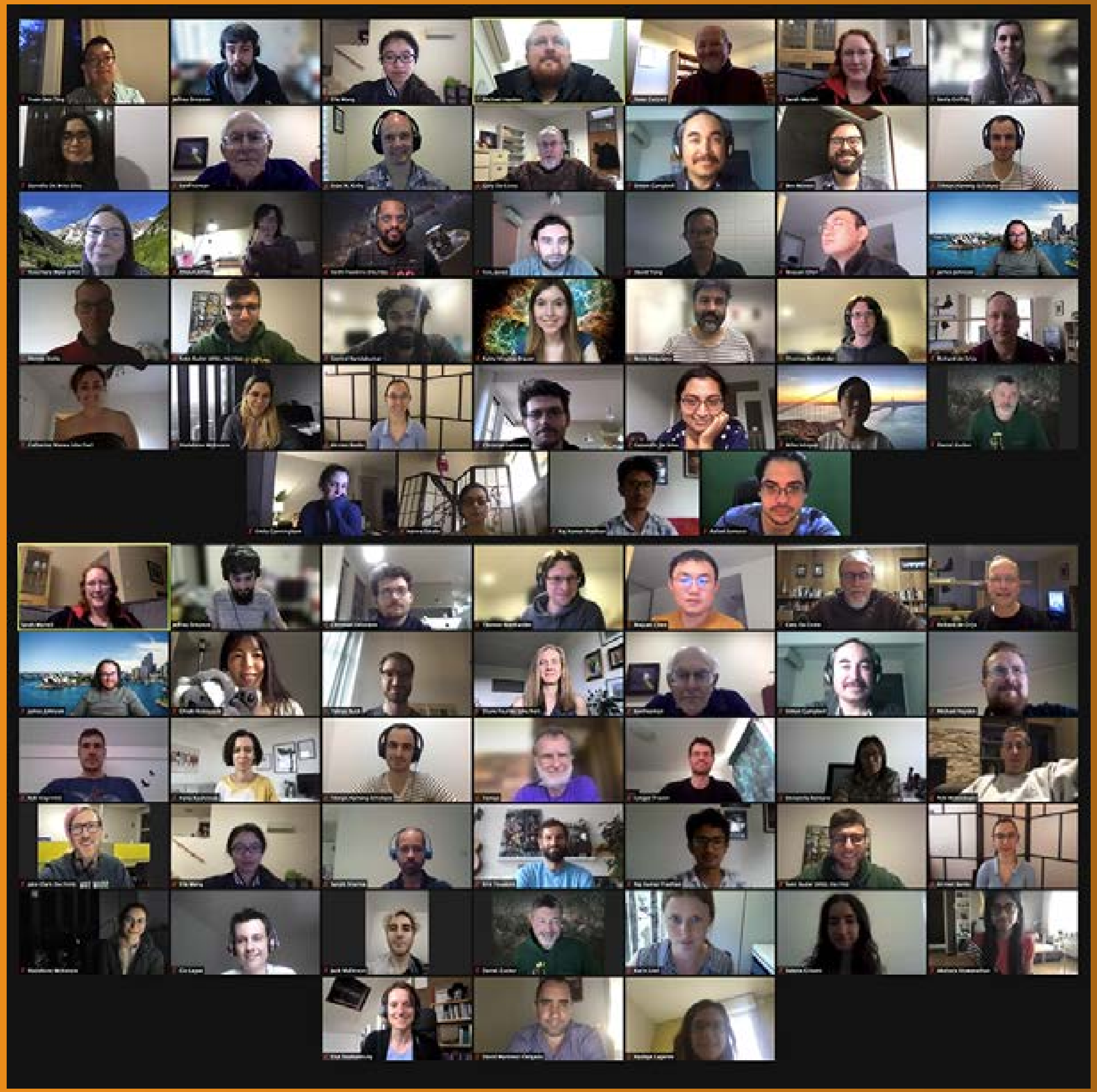
The Galactic Archaeology with Hermes (GALAH) survey is a large observing program using the Hermes Instrument with the Anglo-Australian Telescope

The formation and evolution of galaxies is one of the great outstanding problems of modern astrophysics. The goal of galactic archaeology is to uncover the history of the Milky Way and how it formed and evolved.

HERMES provides simultaneous spectra for 400 stars at a time. We are using this to obtain the highest spectral resolution multi-dimensional datasets for over a million stars of all ages and locations in the Milky Way to trace the full history of the Galaxy.

The GALAH Survey has been working for almost a decade to reveal the rich history of our Milky Way Galaxy by studying the current positions, motions, ages and chemistry of stars formed at different times and in different locations.

In 2019, we have changed gears when entering Phase 2 of the survey: While in Phase 1, we selected stars with a certain brightness randomly for our field-of-view, we are now prioritising the targets that will give us the most reliable combination of chemistry, orbits, and stellar ages. This holistic trinity will allow unprecedented studies of our solar neighborhood and uncover never-seen Galactic trends of elements over time and to recover stellar populations that have been almost or fully dispersed. In 2021, we were awarded another 155 nights along with long term status, for observations through 2022. With our current progress, we will reach the record-breaking number of 1 million spectra in 2022.



We had our largest and most impactful data release, GALAH DR3, in November 2020 (65 citations to the release description paper). It contains stellar parameters, abundances and value added quantities (e.g. age and mass) for 678,000 stellar targets. It also included about 1 TB of reduced spectra for all the observed targets. We had a coordinated release of 20 papers along with DR3, highlighting important science that can be done with our data. Since the release of our data, 31 papers outside our collaboration have explicitly made use of our data. To further increase the reach and impact of GALAH, a new website with more information has been developed by our members at GALAH-survey.org. Additionally, we organised a 3-day international science conference in July 2021 focussing on science with GALAH.

There is more to look forward to in the future. GALAH Phase-1 has highlighted the power of age in understanding the formation history of the Milky Way. Phase-2 with its new selection strategy is going to significantly enhance the number of stars with reliable ages and is also going to increase the precision of abundances due to the increase in exposure time. To complement the raw data quality, major upgrades to reduction and analysis are underway, which will significantly improve the accuracy of our stellar parameters and abundances. A new reduction pipeline has already been developed with a number of enhancements and new features. Work has also begun on a new analysis pipeline that makes use of machine learning techniques to improve the accuracy of the derived stellar parameters.

Figure 19. In June 2021, we held a conference in a hybrid format with over 200 registrations from around the world. About 20 people in Sydney were able to meet in-person while the rest were online.

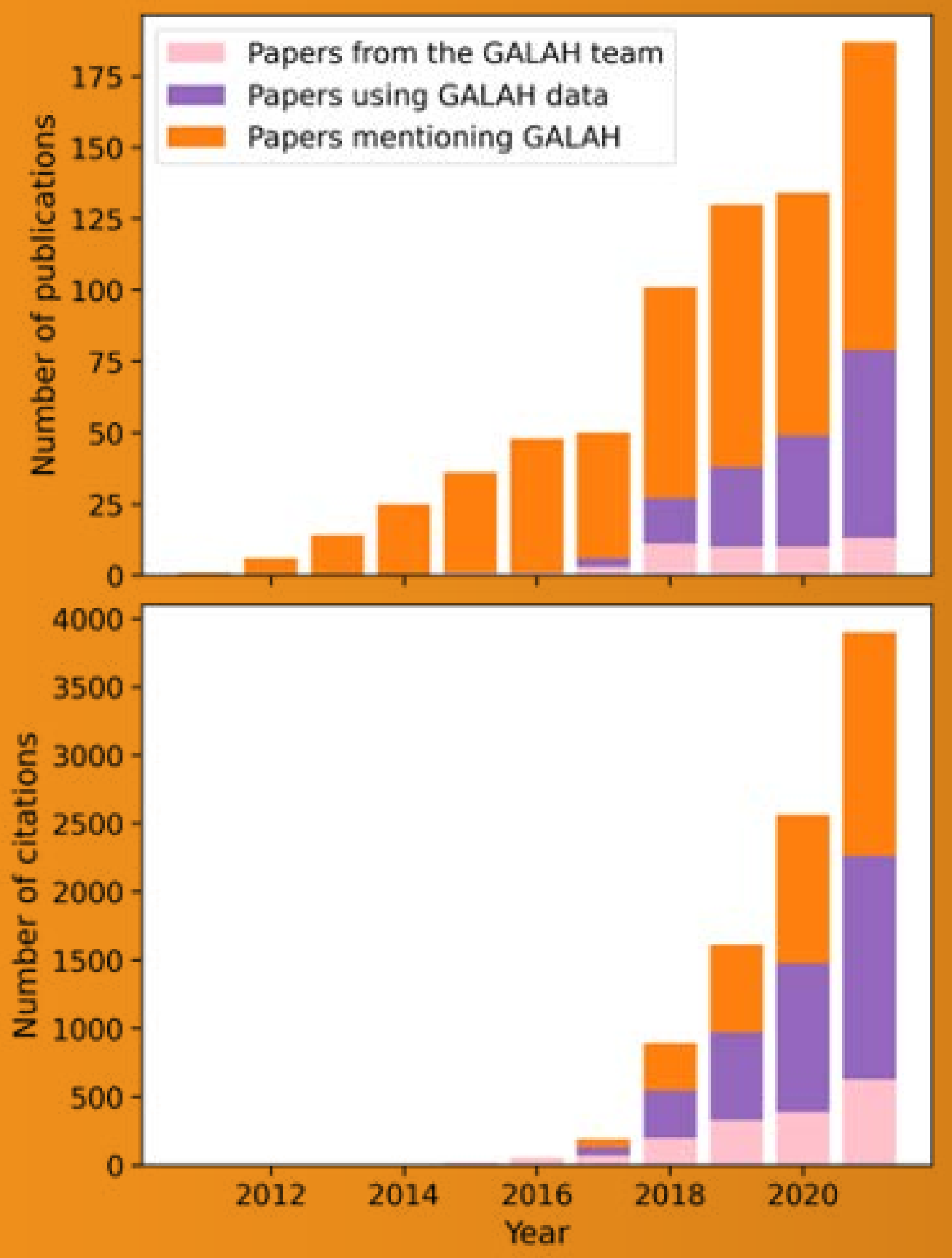
GALAH
GALactic Archaeology with HERMES

2021 PROJECT HIGHLIGHTS

The GALAH team has a steady publication record and impact and this is shown in Figure 9. The team has published 44 refereed papers since 2015 with a total of 1700 citations, including 12 papers in 2021. Additionally, there has been a steady increase in the number of astronomers outside of the collaboration that explicitly make use of the data collected by GALAH (a total of 151 papers with 3800 citations, 65 of these papers being in 2021). There are also a significant number of papers that just mention GALAH and this number has also been increasing steadily.

The data of GALAH DR3, published in November 2020, has already had a massive impact in the community. The ability to measure the lithium abundances of stars is a major power of GALAH. We resolved the puzzling disagreement of stellar Li abundances with predictions from Standard Big Bang Nucleosynthesis (Gao et al. 2020). Further progress was made on this cosmological lithium problem in Simpson et. al. (2021) where we demonstrated that stars formed in external galaxies show the same 'Lithium Spite Plateau' as Milky Way dwarfs. The existence of lithium-rich giant stars has long been a mystery and in Martell et al. (2021) we were the first to show that the internal structure of the star and the metallicity both play crucial roles in the occurrence rate of lithium richness. In Buder et al. (2021b), we found that certain chemical abundances can be used to identify stars that have been accreted by the Milky Way some 10 Gyr ago. Using a chemical selection via [Na/Fe] vs. [Mg/Mn], we have characterised the dynamical extent of the remnant of the last major merger - finding that almost ⅔ of its stars lay outside a dynamical region that was previously used to identify remnant stars.

The precise ages in GALAH DR3 have shed new light on the evolutionary history of the Milky Way. In Sharma et al. (2021a), we deduced the fundamental relations governing the velocity dispersion of stars in terms of age, angular momentum, and metallicity. This helped us to better understand the physical processes like scattering and radial migration that influence disk evolution. In Sharma et al (2020), we showed that the abundance of most elements can be predicted from just their age and metallicity. This suggests strong azimuthal mixing in the ISM. In Hayden et al (2020b), we showed that we can turn the argument around and in fact estimate age just from abundances. Using our newfound relations for velocity and dispersion, in Sharma et al (2021b) we explained the origin of the double sequence in the ([α/Fe], [Fe/H]) plane.



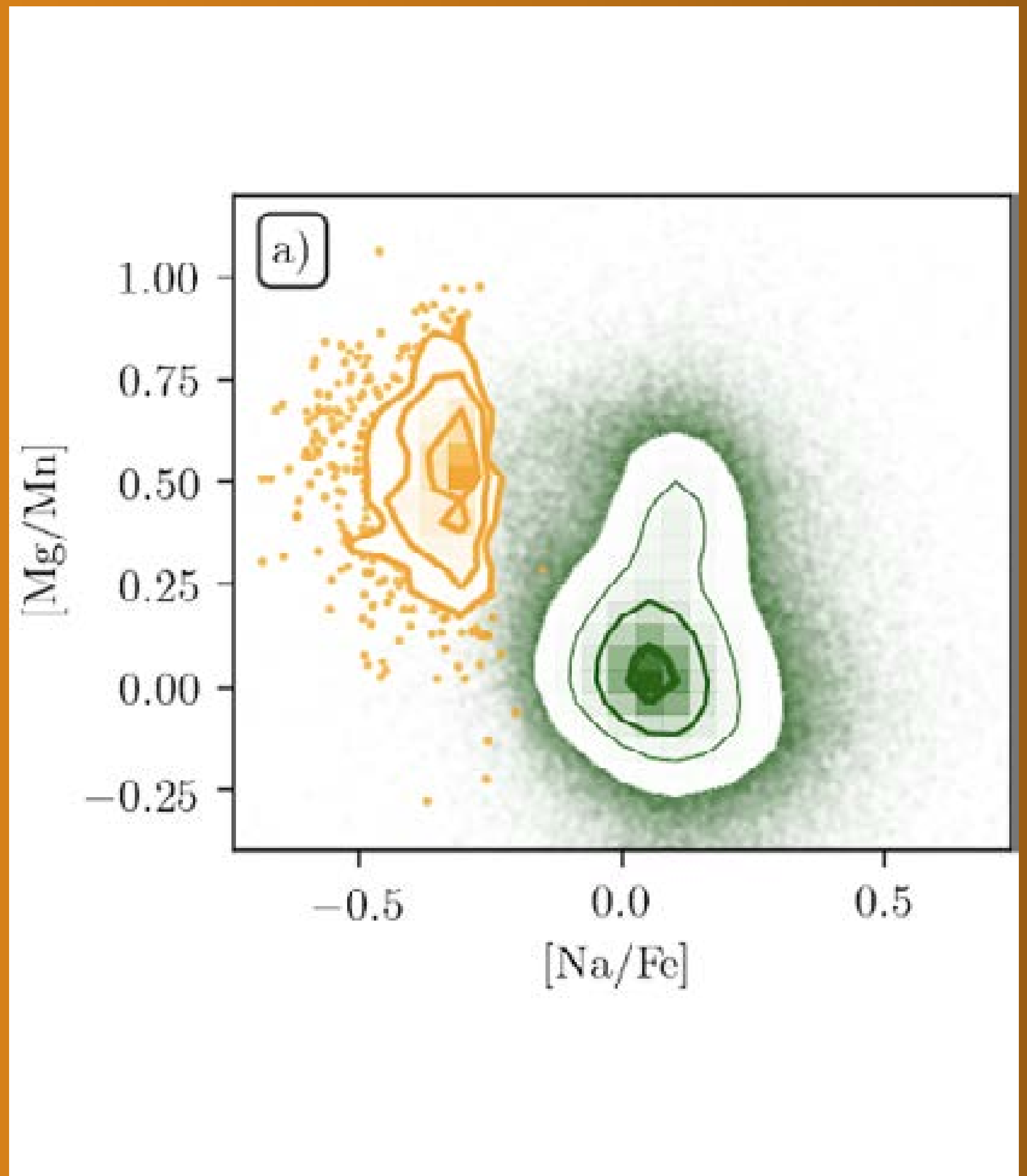


Figure 20: Left - The numbers of publications (top) and citations (bottom) mentioning the GALAH survey and using its data are evidence of GALAH's strong and increasing influence on and contribution to Galactic archaeology.

Figure 21: Right - When looking at the chemical composition of stars in the MilkyWay (measured by the GALAH survey), we can tell apart those born in it (green) and those born in other galaxies (orange). Figure from Buder et al. (2022)

2021 PERSONNEL HIGHLIGHTS

GALAH Phase-2 began in semester 2019A, and will effectively complete 148 nights of observing (including weather loss) in semester 2021B, marking a significant step towards our goal of a 256 night campaign. Prior to 2021A we had effectively observed 56 nights. In 2021A we were awarded a minimum of 155 nights (with provision of upto 200 nights) along with long term status, for observations from 2021A through 2022B. Semester 2021A was fruitful with 57% successful observing over 54 scheduled nights. Semester 2021B has been similar, with 56% successful observing time across 15 scheduled nights so far (out of 37).

In 2021, we welcomed new members Postdoctoral Researcher Dr Ioana Ciuča (ANU), Hillary Davis Masters Student (UniSyd) and PhD Student Nabo Mukty (UniSyd).

PRIZES

CI Prof. Joss Bland-Hawthorn at University of Sydney was awarded 2021 Walter Boas Medal in Physics for having laid the foundations for modern Galactic archaeology, near-field cosmology and astrophotonics, a field that lies at the interface of photonics and al instrumentation.

GALAH

KIRSTEN BANKS

PHD Student
University of New South Wales
GALAH Survey

ABOUT ME

My research entails studying two types of evolved stars, red clump and red giant branch stars. These stars have very similar surface features such as effective temperature and surface gravity, but their interiors are very different. Red clump stars burn helium in their cores, whereas red giant branch stars have inert helium cores. Red clump stars are also very effective standard candles and can be used to estimate distances through much of the Galaxy with high accuracy. Red giant branch stars, however, are not standard candles.

These stars can be effectively distinguished through asteroseismology. Their differing internal structures produce distinctive oscillations, but asteroseismic observations are time-intensive. Recently a spectro-seismic connection has been identified.

In my research, we investigate this connection further and look to identify a kind of spectral "blueprint" to effectively and efficiently distinguish the red clump from the red giant branch as well as investigate the astrophysical origin of this connection.

WHY ASTRONOMY?

I was always interested in the sky as a young child. When I was in primary school I dreamed of being a meteorologist and studying the weather but in high school, my science teachers took my year group on an excursion to go see a documentary about the Hubble Space Telescope. I remember sitting there, looking up at those incredible photos taken by this phenomenal telescope in awe of how amazing and mysterious the Universe is and how much I wanted to uncover those mysteries.

WHAT I LOVE ABOUT ASTRONOMY

When one question is answered, even more questions arise. The mystery never stops! I hope that I learn something new every day for the rest of my life and in astronomy that is almost guaranteed!

WHAT I DON'T LOVE

Sticking to one project. Everything is just so interesting! I often find myself reading papers that are almost completely unrelated to my research project instead of those that I probably should be reading for background information in my PhD...

IF I WASN'T AN ASTRONOMER, I WOULD BE...

A TEACHER. DURING MY TIME AS A SCIENCE COMMUNICATOR, I'VE FALLEN IN LOVE WITH TEACHING. MY FAVOURITE PART ABOUT IT IS WHEN SOMEONE FINALLY UNDERSTANDS WHAT YOU'RE TRYING TO EXPLAIN AND THEY HAVE THAT LIGHTBULB OR "AH-HA" MOMENT.

A HIGHLIGHT IN 2021

My highlight of 2021 has been having a tunnel boring machine named after me. Not just for the reason of having a massive Earth munching machine named after me but because of how it happened. My name was nominated in a naming competition by a young Indigenous boy and, very excitingly, won.

When I was young and dreaming of being a scientist, I didn't have anyone like me (a woman or Indigenous or both) visible in the public to look up to. A big reason why I strive to be visible online and in the media is so that I can be the person I didn't have for the next generation of budding scientists. And this shows that just that is happening and it fills my heart with joy.

I SURVIVED COVID IN 2021 BY...

One thing I did to help me relax during lockdown was sitting down on the couch, putting on my favourite tv show and solving jigsaw puzzles. This was a great way for me to forget about all the noise of the outside world for a little while. Oh, and buy and use LOTS of bath bombs!

GALACTIC ARCHAEOLOGY AND MODELLING THE MILKY WAY

RESEARCHERS HAVE CREATED A MODEL OF THE EVOLUTION OF THE MILKY WAY WHICH EXPLAINS HOW KEY CHEMICAL DISTRIBUTIONS IN THE GALAXY'S STARS CAME TO BE

One of the biggest questions in astronomy is related to how our home galaxy, the Milky Way, came to be in its current state. Whilst this might seem like it is a fairly straightforward set of answers, a long history of mergers, collisions and galactic cannibalism require consideration.

This history spreads over the deep time, edging back billions of years - so it's a little harder for us to look back and observe these events occurring, as we can for galaxies at far greater distances. However, astronomers do have a card up their sleeve - and it lies in the stars a little closer to home.

By reviewing two aspects of stars in our local region - firstly, their chemical signature as observed through their spectra, and secondly, their dynamical movement (i.e. the shape, speed and direction of their orbit), astronomers can start to piece together pieces of this historical puzzle.

These days, these studies are performed on grand scales using tools like the Gaia satellite which surveys billions of stars or the Australian-led GALAH spectroscopic survey, which also accounts for hundreds of thousands of stellar spectra. This newfound flood of data and knowledge has triggered a revolution in the understanding of our own galaxy.

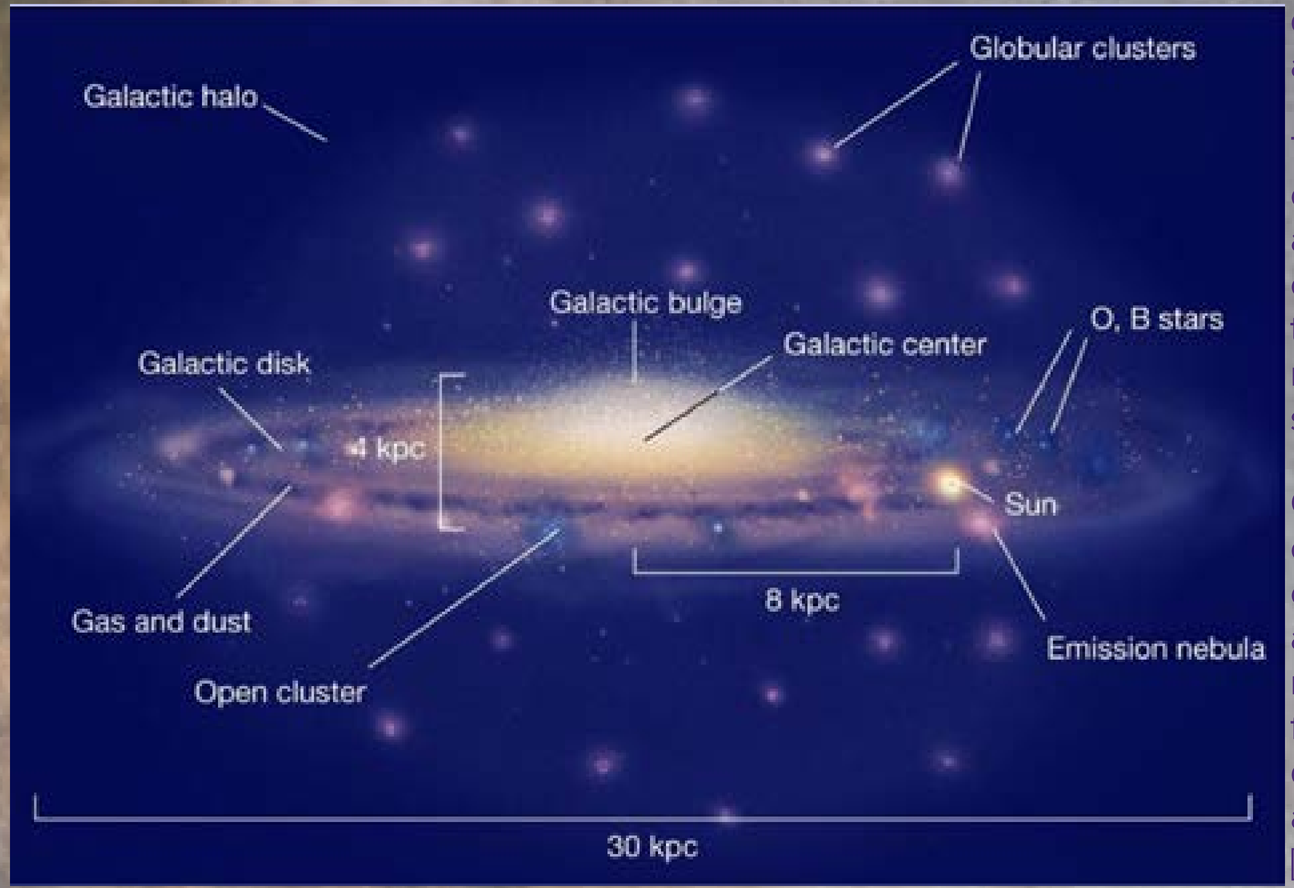
Now, a new research paper published in the Monthly Notices of the Royal Astronomical Society outlines how a group of astronomers have brought us one step closer to understanding the evolution of the Milky Way.

These researchers, all from the University of Sydney and the ARC Centre of Excellence for All-Sky Astrophysics in Three Dimensions (ASTRO-3D), have created a chemodynamical model which reproduces the distribution of stars with different chemical compositions throughout the galaxy.

The authors, in their paper, state that the creation of this model was possible due to new observational data, including large-scale spectroscopic surveys such as GALAH, which earlier this year published its third data release.

The Milky Way, like many observed spiral galaxies, is made up of several components, which include a thin disk and a thick disk. The thin disk contains the majority of the galaxy's stars, and also includes gas and dust, making up the main galactic plane. This thin disk is also enveloped by a thick disk which is roughly three times thicker than the thin one and is almost exclusively made up of stars.

The stars that populate and define these disks are different in their chemical compositions. Two parameters are derived to determine the main chemical ratios that are used to define some of the details relating to thick and thin disks, which are denoted by the values [α/Fe] and [Fe/H].



The Milky Way is made up of many components. The thin disk consists of the stars, gas, and dust within the galactic plane. The thick disk, which is almost entirely stars, envelopes this. Credit: Pearson Education Inc.

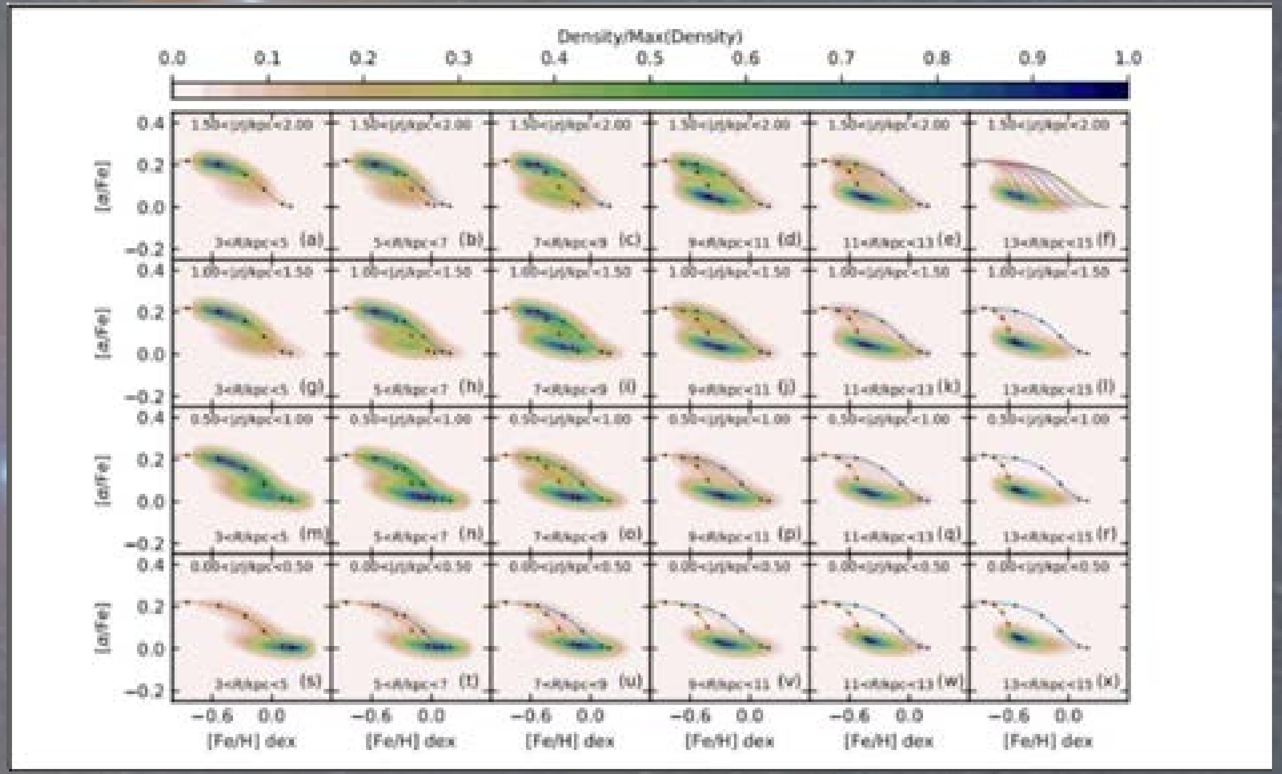
The former, [α/Fe], describes the abundance of alpha elements within a star, which are created through the process of alpha capture. That is, elements that are formed through reactions with alpha particles (helium nuclei) in stellar nucleosynthesis. Thick disk stars have a higher [α/Fe].

On the other hand, [Fe/H] is the metallicity of a star, and describes its abundance of elements that are heavier than hydrogen and helium. These heavier elements are the result of the original composition of the star from the pre-formation nebula and boosted during the lifetime of the star as the star aged, through nuclear reactions in the core. [Fe/H] also varies systematically across the galaxy, and we see that with higher metallicity comes less distinction between the thick and thin disks.

Previous models of galactic evolution have only partially addressed how the Milky Way has ended up with the thick and thin disks and its associated distributions of [α/Fe] and [Fe/H]. However, astronomers have reported that they have created a model which successfully explains these distributions.

Their model relies on the inclusion of radial migration, which relates to the migration of stars in or out from the galactic centre. They found that if radial migration is not included, then their model failed to produce both thick and thin disks. In including this mechanism, they successfully modelled the observed [α/Fe] and [Fe/H] distributions of the Milky Way.

The next steps for this model will be to continue using new data, such as that coming from GALAH and other surveys (both ground and space-based), to include analysis of more elements to build up a bigger picture of the Milky Way and its evolution.



Some of the model predictions produced for the distribution of [α/Fe] and [Fe/H] throughout the Milky Way. Credit: Sharma, Hayden and Bland-Hawthorne 2021.

Full pre-print of the paper is available to read from arXiv.org

Article from Space Australia written by Vanessa Chapman

Background Image: A photograph of the Milky Way from Earth. Credit: ESO/S. Guisard

BIG GALAXIES STEAL STAR-FORMING GAS FROM THEIR SMALLER NEIGHBOURS

Large galaxies are known to strip the gas that occupies the space between the stars of smaller satellite galaxies.

In research published today, astronomers have discovered that these small satellite galaxies also contain less ‘molecular’ gas at their centres. Molecular gas is found in giant clouds in the centres of galaxies and is the building material for new stars. Large galaxies are therefore stealing the material that their smaller counterparts need to form new stars.

Lead author Dr Adam Stevens is an astrophysicist based at UWA working for the International Centre for Radio Astronomy Research (ICRAR) and affiliated to the ARC Centre of Excellence in All Sky Astrophysics in 3 Dimensions (ASTRO 3D).

Dr Stevens said the study provides new systematic evidence that small galaxies everywhere lose some of their molecular gas when they get close to a larger galaxy and its surrounding hot gas halo.

“Gas is the lifeblood of a galaxy,” he said.

“Continuing to acquire gas is how galaxies grow and form stars. Without it, galaxies stagnate.

“We’ve known for a long time that big galaxies strip ‘atomic’ gas from the outskirts of small galaxies.

“But, until now, it hadn’t been tested with molecular gas in the same detail.”

ICRAR-UWA astronomer Associate Professor Barbara Catinella said galaxies don’t typically live in isolation.

“Most galaxies have friends,” she says.

“And when a galaxy moves through the hot intergalactic medium or galaxy halo, some of the cold gas in the galaxy is stripped away.

“This fast-acting process is known as ram pressure stripping.”

The research was a global collaboration involving scientists from the University of Maryland, Max Planck Institute for Astronomy, University of Heidelberg, Harvard-Smithsonian Center for Astrophysics, University of Bologna and Massachusetts Institute of Technology.

Molecular gas is very difficult to detect directly.

The research team took a state-of-the-art cosmological simulation and made direct predictions for the amount of atomic and molecular gas that should be observed by specific surveys on the Arecibo telescope in Puerto Rico and the IRAM 30-meter telescope in Spain.

They then took the actual observations from the telescopes and compared them to their original predictions. The two were remarkably close.

Associate Professor Catinella, who led the Arecibo survey of atomic gas, says the IRAM 30-meter telescope observed the molecular gas in more than 500 galaxies.

“These are the deepest observations and largest sample of atomic and molecular gas in the local Universe,” she says.

“That’s why it was the best sample to do this analysis.”

The team’s finding fits with previous evidence that suggests satellite galaxies have lower star formation rates.

Dr Stevens said stripped gas initially goes into the space around the larger galaxy.

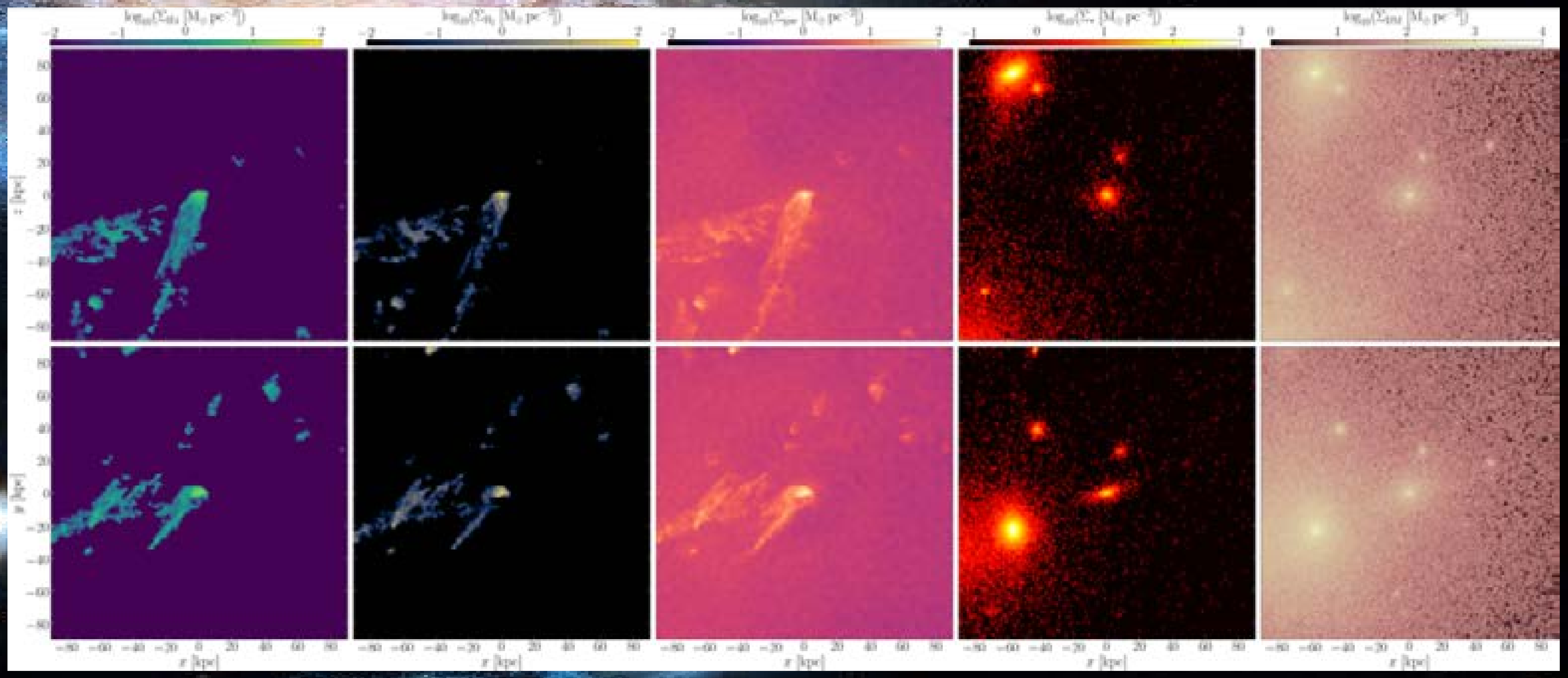
“That may end up eventually raining down onto the bigger galaxy, or it might end up just staying out in its surroundings,” he said.

But in most cases, the little galaxy is doomed to merge with the larger one anyway.

“Often they only survive for one to two billion years and then they’ll end up merging with the central one,” Dr Stevens said.

“So it affects how much gas they've got by the time they merge, which then will affect the evolution of the big system as well.

“Once galaxies get big enough, they start to rely on getting more matter from the cannibalism of smaller galaxies.”



Two viewing angles of a galaxy undergoing ram-pressure stripping in the IllustrisTNG simulation. Each column shows matter of a different form in the galaxy and its immediate surroundings. From left to right: (1) atomic gas; (2) molecular gas; (3) all gas; (4) stars; and (5) dark matter. Credit: Adam Stevens/ICRAR

COLLABORATION

CROSS-NODE AND CROSS-PROJECT COLLABORATION

ASTRO 3D has capitalised on Australia's astrophysics research strengths by uniting our top national astronomical universities with Australia's national optical observatory (Anglo Australian Telescope at Siding Spring Observatory), Australia's national radio facility (CSIRO Centre for Astrophysics and Space Sciences) and Australia's National Supercomputing Facility (the National Computational Infrastructure; NCI). Our international partners bring a tremendous amount of expertise and resources, linking to crucial research programs in field and elevating ASTRO 3D to a truly global Centre.

In our events and communications, the focus is firmly on collaborative science across projects and surveys, not on the node universities. Whilst each institution provides an administrative home, our ASTRO 3D events, meetings and reports are science-focussed. ASTRO 3D Annual Retreats provide updates from all surveys and projects and cross-project discussion sessions that lead to many cross-project collaborations.

Our Annual Science Meetings are focused on sharing exciting new science results with the entire team as well as collaborative breakout sessions. Multiple nodes and partners in each survey attend regular in-person or on-line busy weeks, where concentrated collaboration activity is conducted towards specific scientific and data analysis goals. These meetings and events have resulted in collaborations between observers and theorists, between different projects and surveys, and the sense that ASTRO 3D is larger than the sum of its parts, providing more and richer opportunities than any individual institution can provide alone.

In ASTRO 3D, no project is focussed solely at any one node; nodes contribute to many projects (Figure 3). This fosters collaboration both within institutions (across projects) and across institutions (within projects). While the expertise at some nodes underpins a project (e.g., Curtin and Melbourne for MWA, or UWA on ASKAP), other nodes are powerhouses of activity; ANU, Sydney, Melbourne, UWA, and Swinburne, have major collaborations 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 productive nature of collaboration in ASTRO 3D.

The cohesiveness of ASTRO 3D benefits tremendously from intertwined projects/surveys. Over the past three years, our surveys, projects and programs have become so deeply interrelated that we have moved away from dividing them into themes or threads which we feel creates artificial barriers. Our Survey/Project Leads drive the collaborations across our node and partner institutions, aided by Collaboration Leader Joss Bland-Hawthorn, who facilitates connections with international partners.

The author network of ASTRO 3D publications (Figure 2) shows our strong cross-project collaborations. Every ASTRO 3D project has more refereed publications with authors across other projects than internal (solely project-based) publications. Genesis has crucial links with all observational projects. ASKAP is critical for the Galaxy Evolution and the SAMI surveys. GALAH underpins work on the First Stars and the First Galaxies. This kind of cross-collaboration is crucial for properly understanding the cosmos, but is rarely possible without the support and scale of a collaborative Centre.

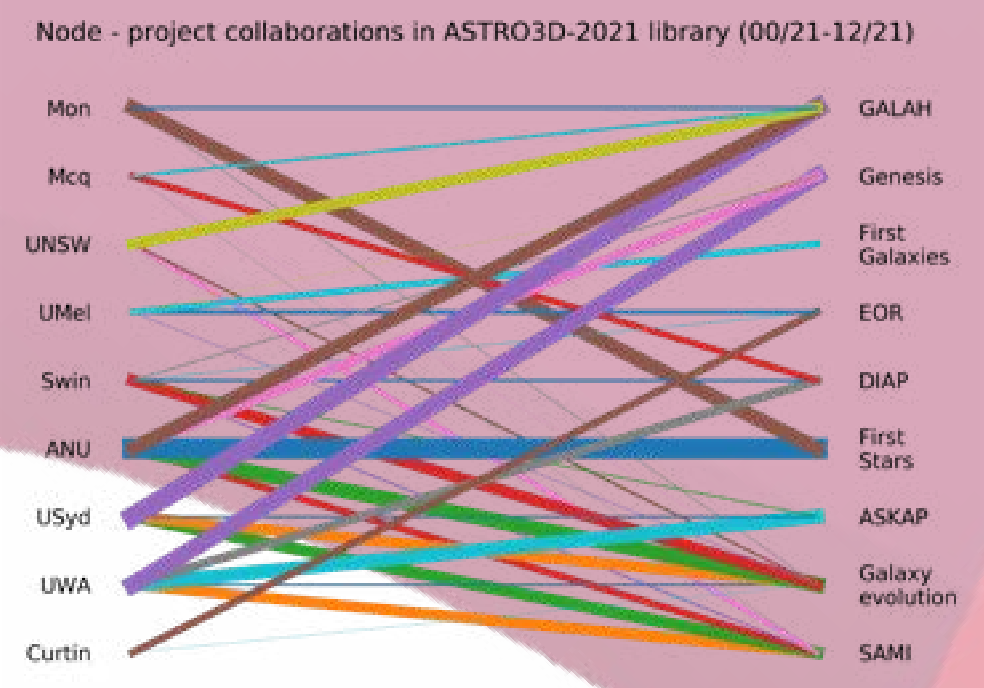


Figure 1 - Linkages between ASTRO 3D nodes and projects. The line thickness represents the number of unique publications involving a node and a project.

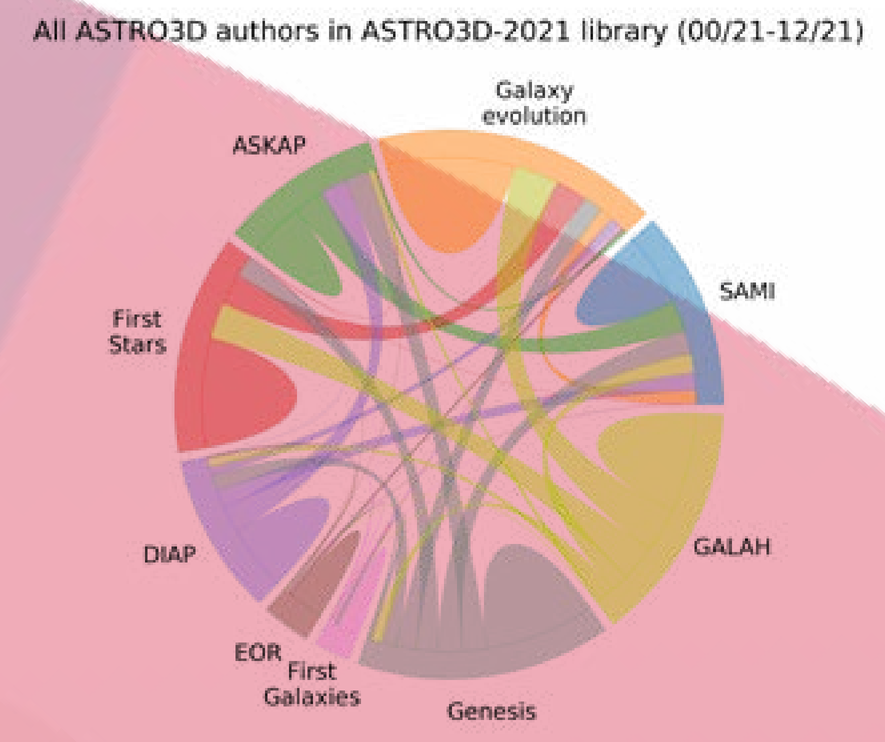


Figure 2 - Interdependence and collaboration of ASTRO 3D projects, measured by publication authorship. Hill size represents internal (survey-only) publications while chord thickness represents the number of cross-project publications

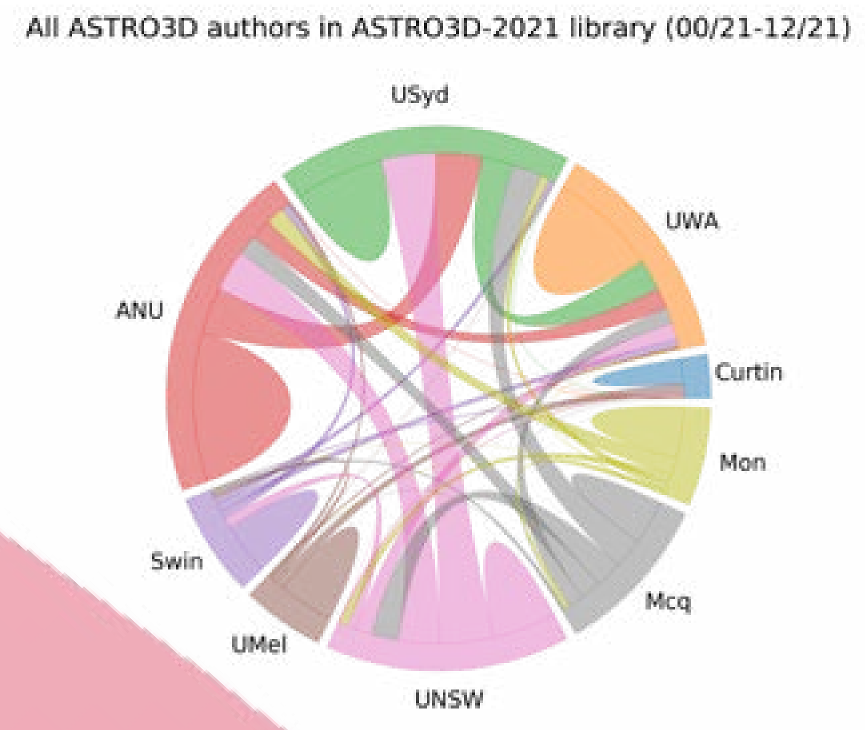


Figure 3 - Collaborations between nodes (left) and projects (right), measured by publications. Line thickness represents number of unique publications by node members on a project

ASTRO 3D collaborations have also led to new Australia-wide projects. SkyHopper is a mission concept for an Australian Infrared Cube Satellite led by CI Trenti at University of Melbourne with participation of multiple ASTRO-3D partners, including ANU, Macquarie, Swinburne, University of Sydney, UWA, Curtin and Macquarie. An industry-focussed spin-off to SkyHopper was funded in 2020 by the Australian Space Agency.

The MAGPI survey is the first Australian-led VLT large proposal (340 hours). Led by our Fellows across five nodes, and across four surveys and projects, MAGPI will provide a rich dataset to the galaxy evolution community in Australia and internationally.

Our Centre encourages industry engagement and collaborations. Genesis team members have close links with national facilities such as the National Computing Infrastructure, and we act in various advisory capacities for the astronomical community and the HPC sector. We are actively engaged with the Department of Industry and Department of Education in funding opportunities to meet the future supercomputing needs of the astronomy and physics community.

INTERDISCIPLINARY RESEARCH

RESEARCH IMPACT & INTERDISCIPLINARY RESEARCH

Through the Sydney Astrophotonic Instrumentation Laboratory (SAIL) led by CI Joss Bland-Hawthorn and AI Sergio Leon-Saval, we collaborate with other research groups worldwide to develop new materials and devices for astronomical instrumentation and space satellites.

In 2021, SAIL laboratories engaged with the Federal Defence Science and Technology Group in the development of optical systems and design including imaging sensors. SAIL received ongoing DSTG STaR Shot funding worth $400,000 on a project called Next Generation of Novel Spectral Imaging Technologies in collaboration with the Sydney DST Group, Littoral Sensing and Processing Team.

This includes the development of multiple systems including OpenHSI (Custom Hyperspectral Imager), and a system designed for education and outreach for enhancing local industrial capacity. The final goal of this project will be to develop a range of spectral imaging systems for Defence applications including:

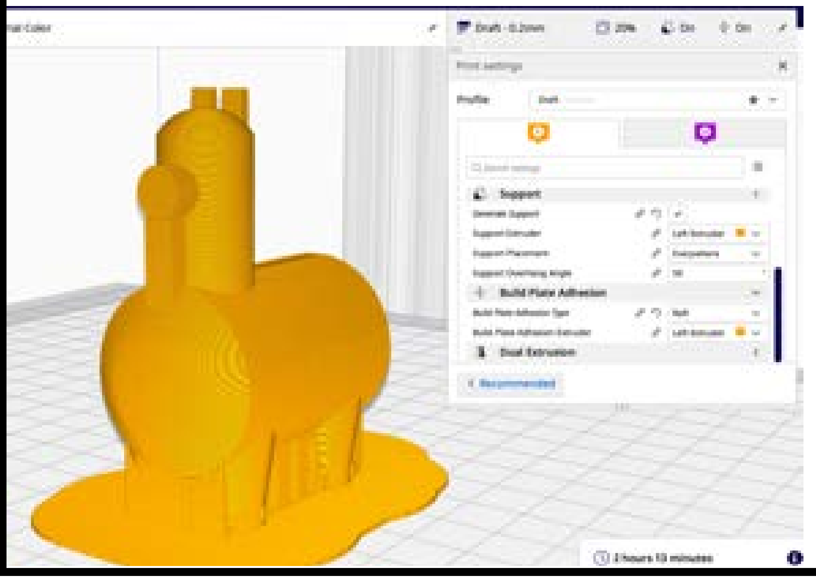
- Airborne spectral sensing of shallow water (surface – 10m) objects.
- Sea surface oblique imaging (e.g. OCIUS) for surface vessel to vessel identification.
- Sea floor spectral imaging (Stereo) for environmental classification.

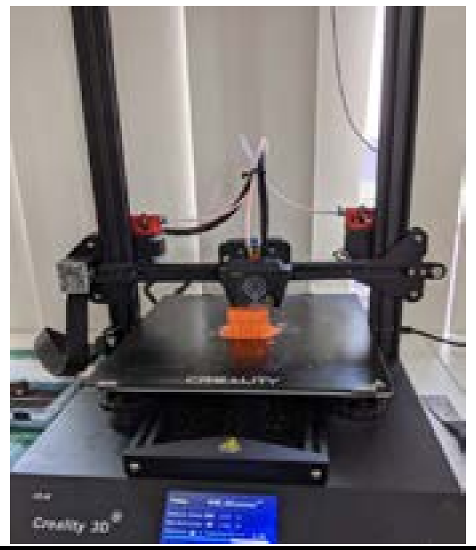
2021 also saw SAIL spin-out a start-up company called Sydney Photonics Pty Ltd led by CEO Dr Christopher Betters. Over the last few years, key individuals in SAIL have established a unique skill-set in how to manufacture and package unique optical devices (phonic lanterns) and instruments (spectrographs and hyper-spectral imagers like the OpenHSI). Sydney Photonics vision is the establishment of a company that can offer devices like the phonic lantern and OpenHSI as a product. This initiative supported by SAIL also helps establishing a sovereign capability within Australia in an industry that currently relies heavily on imported technology. Potential customers exist within the Defence, Agriculture and Mining industries, as well as non-USYD Academic programs.

CASE STUDY

ASTRO 3D member Dr Jane Lin, after finishing her PhD at the Australian National Australia undertook an Australian Postgraduate Research Internship program APR.intern is part of the Australian Mathematical Sciences Institute (AMSI) dedicated to strenghtening University and Industry collaboration, streamlining pathways for postgraduate research students to be industry-literate and career ready. It is Australia's only national PhD and Masters by Research internship program spanning all sectors and disciplines. As part of the program, Jane worked in a 5-month internship with the SPEE3D company under the industry supervision of co-founder Steven Camilleri and the academic mentorship of ASTRO 3D AI Dr Luca Casagrande. Jane used her astronomy knowledge to develop a program for comparing and visualising differences between 3D models in the context of 3D printing. Her program has been incorporated into the 3D printing tool-chain.

Images (left to right) CAD modelling of an object, and the second one the actual 3D printing of that object.





MENTORING PROGRAM 2021

Our Mentoring Program is a Centre-wide, voluntary program that complements existing mentoring programs within partner institutions.

The ASTRO 3D Mentoring Program continued in 2021, again utilising the Mentorloop platform to match mentors and mentees with the research area, career stage, and interests in areas such as data science, careers inside and outside astronomy, and work/life balance. In 2021, we had 33 active participants in our Program (up from 25 in 2020), with 15 as Mentees, 4 as Mentors, and 14 as Mentees and Mentors.

Feedback from the 2021 participants gave the Program a Mentoring Quality Score of 4.7/5, up from 4.6/5 in 2020 and above-average compared to similar industries.

All participants met with their mentoring partner via video conferencing, with COVID restrictions again preventing many meeting in person, which some preferred. 60% met 3-6 times throughout the year, but 20% met 7-12 times. Most were happy with the frequency they met.

The majority (80%) did not create a Mentoring Action Plan, preferring to be more fluid and discuss what was important to the Mentee at the time of the meeting. The participants who did create an Action Plan found it was helpful to have small goals to achieve each meeting.

Most Mentees reported that having a Mentor was a positive experience, helping with career progression both within the astronomy community and outside, looking for industry opportunities. The Program seemed particularly helpful for those PhD students moving to the next phase of their careers – to understand better what career paths were available to them and to have assistance when applying for jobs.

Based on participant feedback, in 2021, we will continue the Program in 2022. We will add some new elements, including:

- Mentee and Mentor introductory training sessions
- An in-person Mentoring/Coaching retreat (restrictions allowing) Quarterly Zoom catchups to check-in and provide feedback
- Options for Professional staff to participate

"Being at the end of my PhD, I was at a turning point in my career. Having the chance to talk to a mentor helped me realise what paths I could choose and also feel more confident when getting ready for interviews."

"It's helping me to be known by the Australian community and to be more strategic when choosing what to do next or which offers to accept."

"We did not create a formal plan, but I had a few specific goals I wanted to work towards that I had outlined early on."

MEDIA AND SOCIAL MEDIA 2021

2021 saw us continue our partnership with Science in Public to help publicise and disseminate the Centre's research outputs and outreach activity.

In the twelve months of 2021, we produced ten media releases highlighting significant research findings or outreach activity, including:

- At "cosmic noon" about 10 billion years ago, star formation in massive galaxies was at its peak. The research, led by Dr Anshu Gupta and Associate Professor Kim-Vy Tran from UNSW, showed that "puffy" galaxies, where the stars are widely distributed around the disk, formed stars for much longer than their compact disk counterparts.
- A team of astronomers led by Alex Cameron and Deanne Fisher from Swinburne used the Keck Observatory in Hawaii to show that what flows into a galaxy (mostly hydrogen and helium) is much 'cleaner' than what flows out (oxygen, carbon and iron) – the first time the complete cycle of accretion and expulsion had been confirmed in a galaxy other than the Milky Way.
- Observations of thick and thin disks of a nearby galaxy show that it didn't come about because of collisions with smaller galaxies but rather a more gentle addition of matter without catastrophic interventions. Dr Nicholas Scott and Dr Jesse van de Sande from the University of Sydney say this has implications for our Milky Way galaxy showing that the spiral structure and its formation are probably quite common.
- The discovery by led by David Yong, Gary Da Costa and Chiaki Kobayashi, of the first evidence of the destruction of a collapsed, rapidly spinning star (a magneto-rotational hypernova) is the most likely explanation for the presence of unusually high amounts of metal elements, including zinc, uranium, europium and possibly gold, in more significant amounts than other stars of similar age in our Milky Way.
- Dr Adam Stevens and Associate Professor Barbara Catinella from UWA systematically studied more than 500 galaxies using the Arecibo telescope in Puerto Rico and state-of-the-art cosmological simulations to find evidence that small galaxies everywhere lose some of their molecular gas (two or more atoms joined together in molecules) when they get close to a larger galaxy and its surrounding hot gas halo. Molecular gas is the building material for new stars. Therefore, large galaxies "steal" that material from smaller counterparts to make new stars, dooming the small galaxies to merge with the larger ones.
- Dr Christene Lynch and her team from Curtin University are one step closer to detecting the signals from the first light to illuminate the Universe, using new equipment installed at the Murchison Widefield Array in remote Western Australia. Dr Lynch ran a new sky experiment called the Long Baseline Epoch of Reionsation Survey (LoBES) to test the ability of the new antenna setup to detect the radio sources of the Epoch of Reionisation. This detection will be a very major achievement for astronomy.

SOCIAL MEDIA

Our social media engagement continues to grow, with the Centre's Twitter audience growing by 253 new followers to 1261, and our Facebook page now has 591 followers.

Our YouTube channel grew substantially, now with 411 subscribers. We added four new "ASTRO in the Home" videos and many science talks from our Virtual Science Meeting and the ECR Astronomers in Australia series.

2022 plans include Beyond ASTRO video series, highlighting the careers outside astronomy that astronomers have gone on to do, the continuation of our successful Communications Traineeship pilot program and a more strategic approach to social media content, now that we have an additional Education and Communications Officer at ANU.

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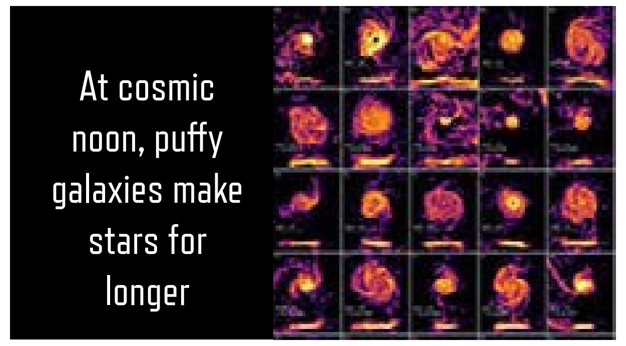

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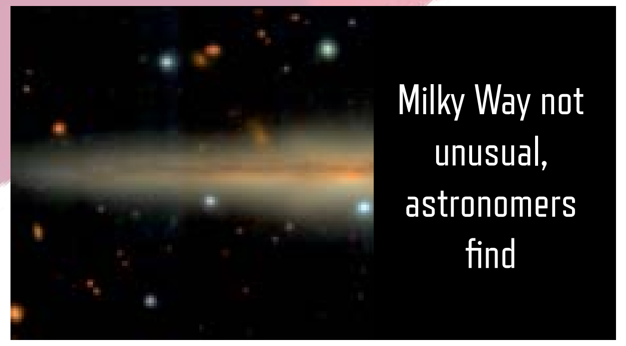

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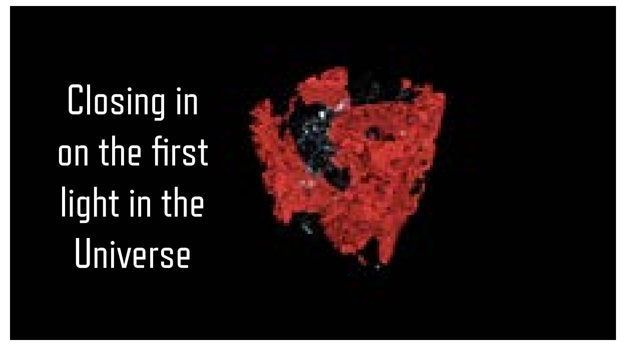


MORE THAN 60 YEARS TO ACHIEVE GENDER EQUITY

MODELLING SHOWS URGENT NEED TO REVAMP HIRING AND WORKING CONDITIONS FOR ASTRONOMERS

It will take until at least 2080 before women make up just one-third of Australia's professional astronomers, an analysis published today in the journal Nature Astronomy reveals.

"Astronomers have been leaders in gender equity initiatives, but our programs are not working fast enough," says Professor Lisa Kewley, director of the ARC Centre of Excellence for All-Sky Astrophysics in 3 Dimensions (ASTRO 3D).

Kewley is also an ARC Laureate Fellow at the Australian National University's Research School for Astronomy and Astrophysics. She developed workforce forward modelling that can predict the fraction of women at all levels in astronomy from 2021 to 2060, given different initiatives in hiring or retention. The models show that Australia's university leadership need to adopt 50:50 or affirmative action hiring and introduce exit surveys and retention initiatives.

"With these initiatives we can reach one-third in 11 years, growing to 50 per cent in 25," she said.

"The gender gap in astronomy was not unique to Australia. This is a worldwide issue, particularly at senior levels.

"The fraction of women in senior astronomy positions in the US, Germany, Canada, Australia, China and the UK has sat at 20 per cent or less for decades – even though women earn about 40 per cent of the PhDs in the field."

She said that female astronomers leave the industry two to three times more frequently than their male counterparts. Those who remain find advancement challenging due to a lack of senior role models at universities, and because they are often overlooked for invited seminars, grants, awards, and all-important telescope time.

In 2014, the Astronomical Society of Australia took steps to improve the ratio of women to men being hired and retained by introducing a gender equality rating system called the Pleiades Awards. The scheme triggered widespread change in many universities and other astronomy-centred research institutions.

Professor Lisa Kewley in her office at ASTRO 3D.
Credit: Cristy Roberts

These have made a difference, said Dr Anshu Gupta, an ASTRO 3D Fellow at Curtin University in Western Australia.

"I think the barriers to women in the field are lower than they used to be, but there are still serious reforms needed to retain and promote talented junior female academics into senior positions," she said.

Some institutions have also introduced hiring practices designed to attract and retain women. ASTRO 3D and the ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav) have hiring ratios of 50:50. The University of Sydney School of Physics recently hit a target of 78 per cent women appointed to permanent positions.

But hiring is not enough, Professor Kewley's research shows. Retention initiatives are also needed to stem the flow of women out of the sector.

She said that successful retention policies include exit surveys, improving work-life balance for department members, clear action against sexism, insults, microaggression, exclusionary behaviour, and the removal of structural barriers by creating more permanent and fewer fixed-term positions.

"If this sort of program becomes widespread, the discipline can reach the 30 per cent target in a decade or so," said Professor Kewley.

ANU Vice Chancellor and Nobel Laureate Brian Schmidt commented:

"We as university leaders need to step up in areas like astronomy, but also across all the academic areas in our institutions where the male-female imbalance is large.

"Professor Kewley's research shows that workforce forward modelling is highly effective way to assess the potential impact and utility of new diversity policies and initiatives. I encourage my peers across the research sector to take a close look and use the tools to drive positive change."

ASTRO 3D AWARDS 2021

The ASTRO 3D Awards Committee considers national and international scientific awards and prizes, and identifies members who may be suitable for nomination. Our aim is to actively reduce unconscious bias against traditionally underrepresented groups by ourselves having a diverse makeup, and by taking care to consider the membership base broadly.

The Committee was established in November 2020 and is comprised of members at all career stages at 6 nodes and 1 affiliate, including one member from the EDI Committee. In 2021 the Awards Committe had three meetings, aligned with calls for major scientific awards.

This year we have recommended the nomination of ASTRO 3D members for eight prizes including the ASA prizes, the Prime Minister's Prize for Science, and the Gruber Cosmology prize. We are refining the processes for identifying eligible candidates by gathering and cleaning information about career stage and extended periods of leave.

In 2022, the Committee will meet four times to discuss the next cohort of potential nominees. We will be calling for new members who are similarly passionate about people of all backgrounds being recognised for their outstanding science.

Sarah Sweet On behalf of the Awards Committee.

April 2021

ASTRO 3D DIRECTOR, PROFESSOR LISA KEWLEY

On 26 April 2021, Professor Kewley was elected to the US National Academy of Sciences (NAS) as an international member.

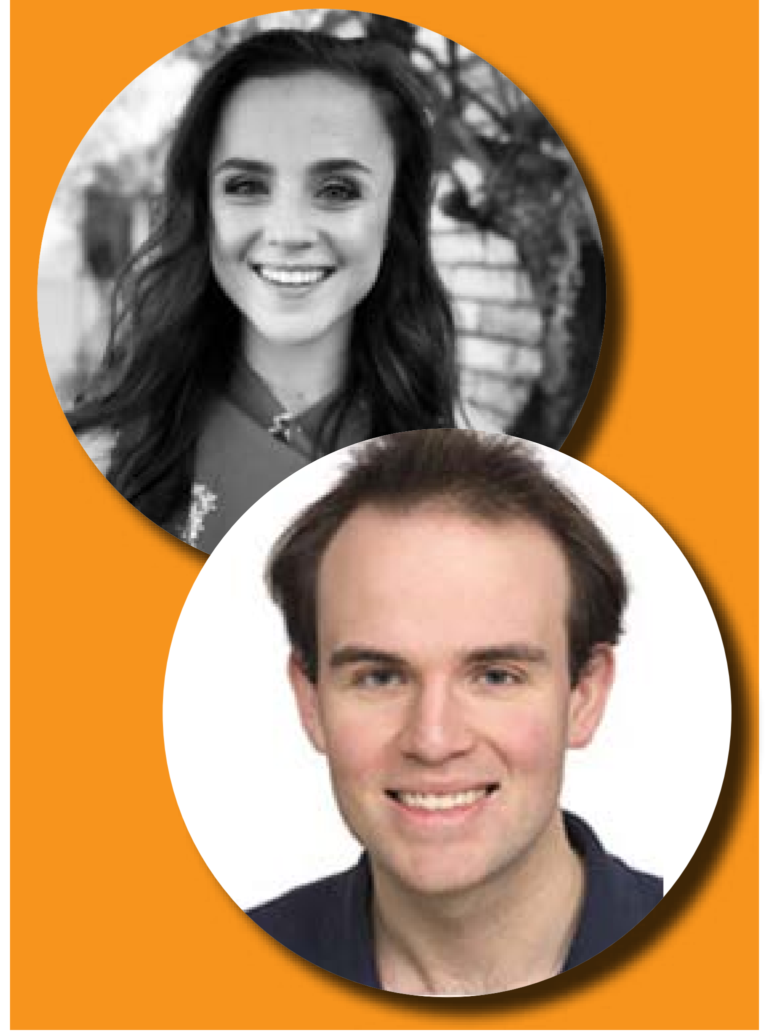
Professor Kewley's election to the NAS recognises her leadership in the field of astronomy and her "distinguished and continuing achievements in original research". Lisa was one of 30 international members elected this year, along with 120 members from the US. 59 of the new members are women - the most elected in a single year.

PRESS RELEASE HERE:

February 2021

ASTRO 3D PHD STUDENTS ALEX KEMP AND GIULIA CINQUEGRANA (MONASH)

Alex and Giulia both received a highly commended on their presentations at the recent online ANITA Conference.



March 2021

ASTRO 3D CHIEF INVESTIGATOR ASSOCIATE PROFESSOR CATH TROTT (CURTIN)

Assoc Professor Cath Trott was awarded the 2021 Nancy Mills Medal for Women in Science. Cath's outstanding contributions to science were been recognised by the Australian Academy of Science along with 24 of Australia's leading scientists receiving a 2021 honorific award.

March 2021

ASTRO 3D ASSOCIATE INVESTIGATOR DR MERIDITH JOYCE (ANU)

Meridith was awarded one of the European Union's prestigious Marie Skłodowska-Curie Actions Widening Fellowships to study the relationship between models of stellar interior mixing processes and age determinations with host Konkoly Observatory in Budapest, Hungary.

She is one of very few Australian-based scientists (less than 30) to receive this Fellowship and did so with a score of 91 in physics category.

April 2021

ASTRO 3D POSTDOCTORAL RESEARCHER DR REBECCA DAVIES (SWINBURNE)

Dr Davies was awarded a prestigious Gruber Foundation Fellowship in April this year. The IAU TGF Fellowship is awarded to a young postdoc working in any field of astrophysics, either theoretical, observational or experimental.

June 2021

ASTRO 3D PHD STUDENT MADDIE MCKENZIE (ANU)

The Bok Prize is awarded annually by the Astronomical Society of Australia to recognise outstanding research in astronomy or a closely related field, by an Honours student or eligible Masters student at an Australian university. Maddie was this year's receipent based on her research "*Simulating the Formation of Multiple Stellar Populations in Globular Clusters*".

July 2021

ASTRO 3D ASSOCIATE INVESTIGATOR PROFESSOR NAOMI MCCLURE-GRIFFITHS (ANU)

In July 2021, Assoc. Professor McClure-Griffiths was awarded an ARC Laureate Fellowship. Her proposal is entitled "Illuminating magnetic fields as the scaffold of gas in galaxies" and she plans to use the Australian Square Kilometre Array Pathfinder to study the magnetic fields in gas in the Milky Way and the Magellanic Clouds.

July 2021

ASTRO 3D PHD STUDENT STEPHANIE MONTY (ANU).

Stephanie won first place for Best Student Talk at the ASA meeting for her talk on her recently accepted paper "Towards Realistic Modeling of the Astrometric Capabilities of MCAO Systems: Detecting an Intermediate Mass Black Hole with MAVIS" (Monty et al. 2021) together with CI Associate Professor Richard McDermid and ASTRO 3D Fellow Dr Trevor Mendel.

July 2021

ASTRO 3D PHD STUDENT CARO DERKENNE (MACQ).

Caro placed second for Best Student Talk at the Astronomical Society of Australia's Annual Science Meeting for her presentation on her recently accepted paper "Total mass density slopes of early-type galaxies using Jeans dynamical modelling at redshifts 0.29<z<0.5" (Derkenne et al. 2021), together with ASTRO 3D CI and supervisor, Associate Professor Richard McDermid. Caro is extending this published work using the MAGPI sample as part of her PhD.

October 2021

ASTRO 3D AFFILIATE ASSOCIATE PROFESSOR SERGIO LEON-SAVAL (UNISYD)

In October 2021 Assoc. Prof Leon-Saval was awarded one of the highest distinctions for Spanish nationals abroad: the Knight's Cross of the Order of Isabel the Catholic, by the King of Spain, for his work promoting Spanish scientists and their research in Australia.

November 2021

POSTDOCTORAL RESEARCHER DR CRISTINA MARTINEZ LOMBILLA (UNSW).

Dr Martinez Lombilla continues the UNSW astro group tradition of being selected as an UNSW Women in Maths and Science Champion. UNSW Women in Maths and Science Champions is a 12-month career development program to support research students and early career scientists to encourage and inspire girls and women to pursue a career in maths and science.

December 2021

ASTRO 3D FELLOW DR CLAUDIO LAGOS (UWA)

In December, Dr Lagos was awarded the 2020 IUPAP C19 Young Astronomer Prize "*for her insightful contributions to the subject of the role of baryons (gas) in the evolution of galaxies, including its role in the chemical and angular momentum evolution of galaxies and in the promotion and suppression of the formation of stars.*"

The prize includes a medal, a certificate, and a cash prize.

December 2021

ASSOCIATE INVESTIGATOR DR NIC SCOTT (USYD)

Dr Scott was named in the Clarivate list of the most highly cited researchers for 2021.

The annual list identifies some 6,600 researchers from across the globe who demonstrated significant influence in their chosen field or fields through the publication of multiple highly cited papers during the last decade. The Highly Cited Researchers' names are drawn from the publications that rank in the top 1% by citations for field and publication year in the Web of Science™ citation index, and the list identifies the research institutions and countries where they are based.

December 2021

ASTRO 3D AFFILIATE DR CAROLINE FOSTER (UNSW)

Dr Foster was awarded a Future Fellowship project to leverage a new dataset that will help address how galaxies form and evolve across cosmic time.

September 2021

ASTRO 3D CI PROFESSOR JOSS BLAND-HAWTHORN

In September, Professor Bland-Hawthorn was awarded the 2020 Boas Medal by the Australian Institute of Physics. The Walter Boas Medal was established in 1984 to promote excellence in research in Physics and to commemorate the life and work of Walter Boas. The Medal is awarded annually and presented at either the AIP Congress or the Summer Meeting, for original research that makes an important contribution to physics in Australia. The Award consists of a medal, a certificate and one year membership of the AIP.

The medal citation read "*Professor Bland-Hawthorn laid the foundations for modern Galactic archaeology, near-field cosmology and astrophotonics, a field that lies at the interface of photonics and astronomical instrumentation.*"

Award announcement

DISCOVERY EARLY CAREER RESEARCHER AWARDS (DECRA)

ASTRO 3D Fellow Dr Katie Grasha (ANU) - Project - "Stars and Galaxies: The chemical abundance breakthrough. Measuring the chemical history of galaxies is critical to understand how galaxies form and evolve."

ASTRO 3D Affiliate Dr Sarah Sweet (UQ) - Project - "Understanding diversity: chemical and kinematic tracers of galaxy evolution."

ASTRO 3D AI Dr Yuan-Sen Ting (ANU) - Project - "A New Era of Galactic Archaeology with Large Surveys and Machine Learning."

ASTRO 3D Fellow Dr Manisha Caleb (USyd Fellow) - Project - "To use fast radio bursts to investigate the nature of stars and matter outside our galaxy".

AWARDED SUPERCOMPUTER TIME

June 2021 - ASTRO 3D Postdoctoral Researcher Dr Thomas Nordlander (ANU) led a proposal for the First Stars team that was granted 1.7 million CPU hours (3.4 MSU) for use on the NCI/Gadi supercomputer over the coming year. This represents 1/3 of the total time allocated in the recent Large Program call from ASTAC/AAL.

AWARDED TELESCOPE TIME

ASTRO 3D Fellow Dr Nikki Nielsen (Swinburne) along with fellow members and co-investigators Dr Deanne Fisher, Professor Glenn Kacprzak (both Swinburne), and Professor Chris Martin (Caltech) was awarded 5 orbits of Hubble time for the proposal "Direct imaging of CGM substructure with 50 parsec resolution."

The proposal aimed to image small (sub-kiloparsec sized) knots of emission that were observed with Keck/KCWI out to 30 kpc in the circumgalactic medium of a nearby starbursting galaxy. The HST imaging will determine if these knots are the cool condensing clouds of gas predicted by simulations that are accreting onto the galaxy, star-forming HII regions outside the galaxy disk, or dwarf satellite galaxies merging with the galaxy.

July 2021 - Dr Anshu Gupta (Curtin) and team consisting of ASTRO 3D members Anishya Harshan, Karl Glazebrook, Themiya Nanayakkara, Glenn Kacprzak, Katie Grasha, Ayan Acharyya and Director Lisa Kewley for their successful Xshooter proposal on EoR analogs. The proposal to characterise the gas-phase metallicity, ionisation parameters, test UV-optical diagnostics and explore the escape fraction via detection of LyC photons of z~3 galaxies was identified as strong and important preparatory work for higher redshift studies with the James Webb Space Telescope.

July 2021 - ASTRO 3D Affiliate, Professor Karl Glazebrook (Swinburne), won Hubble Space Telescope time with his Cycle 29 proposal, "A SNAPshot Legacy Survey of Bright Gravitational Lenses."

August 2021 - ASTRO 3D AI Dr Dougal Mackey (ANU). Dougal won 16 orbits of HST time with a pilot proposal to demonstrate the feasibility of measuring proper motions for globular clusters in the halo of the Andromeda galaxy. This is the first step towards obtaining full 6D orbital phase-space information for stellar substructures in Andromeda's halo, with the aim to accurately reconstruct the main events in its accretion history.

August 2021 - 3D AIs Dr David Yong (ANU) and Dr Yuan-Sen Ting (ANU). They were awarded 32 hours of VLT/UVES and 49.1 hours of VLT/ESPRESSO, with a proposal entitled "Characterising binary stars in the Gaia era." A similar version of the proposal was also successful in the 2021B round, receiving one night of Keck/HIRES (by Fan Liu from Swinburne) and three nights of Magellan/MIKE (by AI Dr Yuan-Sen Ting).

August 2021 - PhD student Wei Shen Oh (ANU). Wei Shen was awarded 28 hours of VLT/UVES time with a proposal "UVES follow-up of Extremely Metal-Poor Stars in the LMC." The aim is to obtain high-resolution spectra of seven extremely metal-poor stars in the Large Magellanic Cloud that he has discovered as part of his PhD research using SkyMapper photometry and ANU 2.3m follow-up observations.

August 2021 - ASTRO 3D AI Professor Gary Da Costa (ANU). Gary led a successful proposal entitled "UVES follow-up of SkyMapper Extremely Metal-Poor Star Candidates", and was awarded 6.6 hours of priority A VLT time.

September 2021 - Fellow Elisabete da Cunha and AI Luca Cortese led a successful ALMA Cycle 8 proposals as leading PIs (PIs not affiliated with any of the ALMA regions)! Combined, they secured ~90% of the time allocated by ALMA to high-priority (grade A+B) proposals in the “Open Sky Category.”

Eclipsed Moon at Paranal
Credit: Y. Beletsky (LCO)/ESO

VIRTUAL SCIENCE MEETING

Our annual Science Meeting was originally scheduled to go ahead as an in-person event, with remote options, but COVID lockdowns meant it was postponed and again held as a fully virtual event via Zoom on 1-3 September.

Our Science Organising Committee, headed up by early career researchers Dr Stefania Barsanti and Dr Sven Buder, did an amazing job of selecting and scheduling the talks over the three days and the quality of talks was really high. Each talk has been available to watch on our YouTube Channel. Speakers had a chance to respond to questions after their presentation and great discussions followed on our SLACK channel

SCIENCE TALKS AWARDS

The ASTRO 3D community was given a chance to vote for their favourite talks and a trophy presented to each of the 10 winners.

Best Presentation by a Student (PhD, Masters or Honours)
Kirsten Banks (UNSW) - Mapping Stellar Interiors with Spectroscopy
Highly commended
Bronwyn Reichard-Chu (Swinburne) and Madeline McKenzie (ANU)

Best Presentation by a Postdoc or Fellow
Kate Harborne (UWA) - The MAGPI Theory Thread: Making consistent comparisons with observations
Highly commended
Thomas Nordlander (ANU) and Michael Hayden (Sydney)

Best Presentation by an Associate Investigator/Affiliate
Jesse van de Sande (Sydney) - Through thick and thin: dissecting the anatomy of the Galaxy through chemodynamic analysis of its siblings
Highly commended
Amelia Fraser-McKevlie (UWA) and Simon O'Toole (Macquarie)

Best Presentation by a Chief Investigator
Emma Ryan-Weber (Swinburne) - A cautionary tale of Lyman-continuum escape fraction estimates
Highly Commended
Kim-Vy Tran (UNSW) and Richard McDermid (Macquarie)

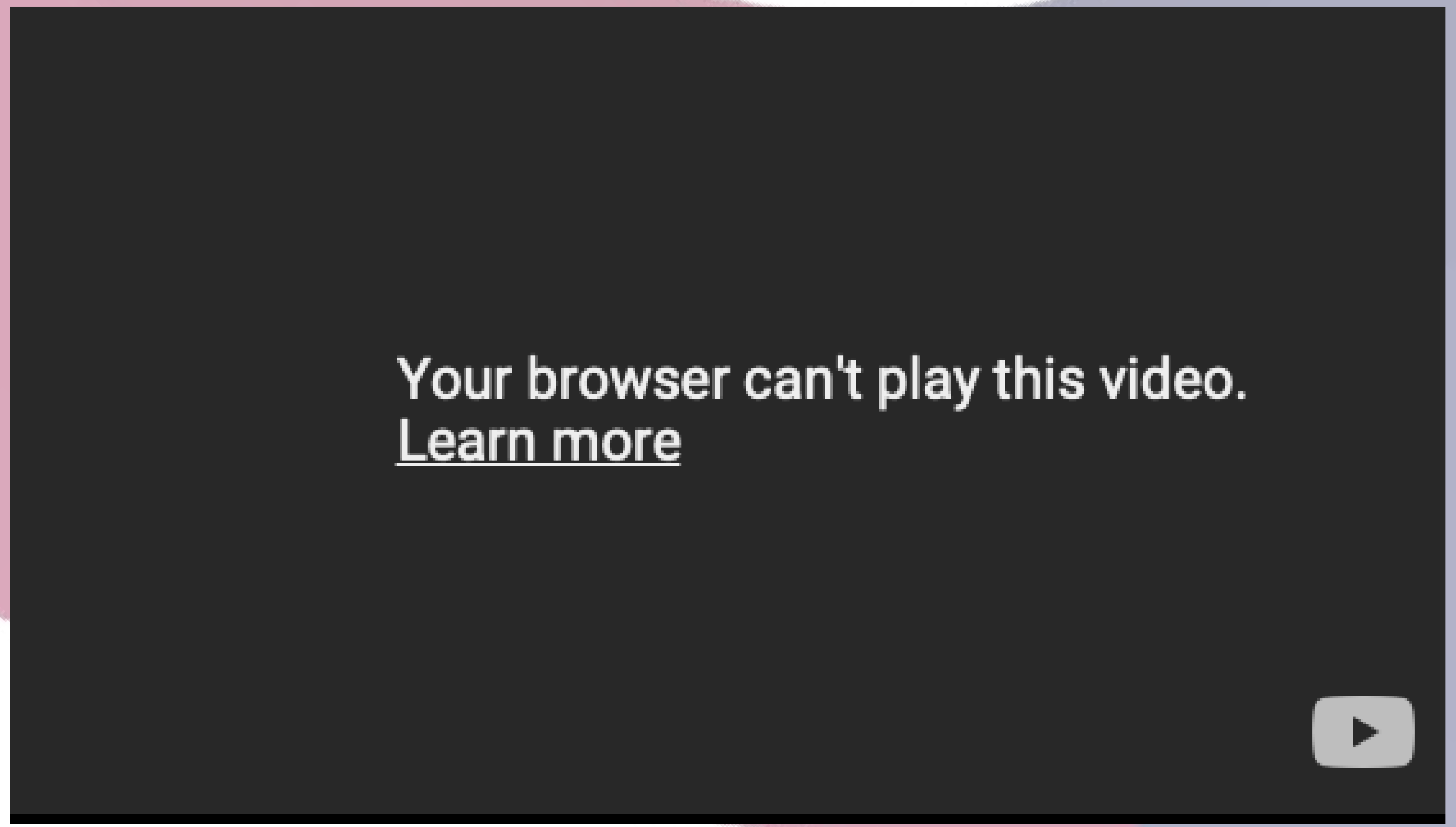
Best Sprint Talk
Ruby Wright (UWA) - The build-up of gas in simulated galaxies
Highly Commended
Yuan-Sen Ting (ANU) and Mike Kriel (Curtin)

Most Exciting Discovery by a Junior Researcher (Student/Postdoc/Fellow)
Thomas Nordlander (ANU) - First Stars: evidence for an unusual supernova in the early Universe
Highly Commended
Ruby Wright (UWA) and Bronwyn Reichardt-Chu (Swinburne)

Most Exciting Discovery by a Senior Researcher (AI/Affiliate/CI)
Amelia Fraser-McKelvie (UWA) - The drivers of stellar and gas-phase metallicity differences in SAMI galaxies
Highly Commended
Jesse van de Sande (Sydney) and David Yong (ANU)

Best Use of Slides
Bronwyn Reichardt-Chu (Swinburne) - Mapping Outflows in Starbursting Disk Galaxies with the DUVET Survey

Highly commended
Madeline McKenzie (ANU)



Best Tweet of Meeting
Katie Grasha (ANU) and Pebbles
Highly commended
Kirsten Banks (UNSW) and ASTRO 3D Account/Ingrid

Best Use of Humour
Jesse van de Sande (Sydney)
Highly commended
Kirsten Banks

ANNUAL RETREAT










FAIRMONT RESORT, BLUE MOUNTAINS,

6-10 DECEMBER

After a hiatus in 2020 due to COVID, ASTRO 3D members were excited to participate in an in-person, four-day annual retreat in December 2021. Due to WA colleagues being unable to travel, an east coast hub was hosted at Fairmount Resort in the Blue Mountains in NSW and a west coast hub hosted at the University of Western Australia in Perth. Members who could not travel at all could Zoom in to sessions.

The program was organised to consider the three-hour time difference, with the WA hub being able to Zoom into both key and breakout sessions. Both hubs also conducted site-specific activities, including social events.

The focus of the meeting was about reconnecting with colleagues, collaboration opportunities, highlighting Centre successes over what was another challenging year, and strategic discussions between projects and surveys.

HIGHLIGHTS INCLUDED:

- Aboriginal Cultural Awareness training to give members a better awareness of the issues and barriers facing Aboriginal people and a better understanding of the history of policy and practices that have disadvantaged Aboriginal people and communities;
- student and ECR pre-conference sessions including speakers Dr Fang Yuan (Geoscience Australia) on moving from academia to industry and ASTRO 3D CI Emily Wisnioski on building a career in academia;
- twenty-three Poster and new members Sparklers giving members enticing snapshots of ASTRO 3D research;
- an opening address by Director Lisa Kewley, who gave an overview of the Centre's successes, including outcomes of the mid-term review from the ARC, results of the climate survey and progress on equity and diversity;
- science project/survey updates by Chris Power, Lister Staveley-Smith, Richard McDermid, Cath Trott, Gary Da Costa, Elaine Sadler, Emma Ryan-Weber, Matt Owers and Michael Hayden;
- breakout sessions for cohorts, project/surveys, cross-project discussions and professional staff;
- Sustainability; Equity, Diversity and Inclusion; Early Career Researchers and Black Lives Matter Committee updates;
- an Education and Outreach update by Brad Tucker and Delese Brewster; and
- a range of social activities in each hub and a trivia and awards night.

We also trialled an additional style of breakout session based around member-defined topics to complement the traditional cross-project meetings. The goal was to initiate discussions that might lead to new ideas and collaborations. Topics identified were Indigenous science engagement, galaxy evolution through the lens of the Milky Way, Chemical evolution/abundances at high z and gas inflow/outflow and the CGM. One of the outcomes from the discussion on Indigenous science engagement was the formation of an Indigenous Advisory Board with Aboriginal members.

The hybrid model of delivery for an annual retreat had its challenges. After seeking feedback from members, we will be looking to improve processes to ensure any future hybrid events are a success for all involved.

> 'BREAKOUT SESSION OVER SPECIFIC TOPICS AND CROSS-PROJECT COLLABORATIONS WERE EXTREMELY USEFUL. THEY ALWAYS BRING OUT LOTS OF POTENTIAL COLLABORATION IDEAS.'
> - ANONYMOUS








PHD COMPLETIONS 2021

January

DR. LUCIE BAKELS
UNIVERSITY OF WESTERN AUSTRALIA

"Haloes, subhaloes, and galaxies: The impact of orbital history on dark matter haloes and their galaxies, and improving models for stellar feedback"

February

DR. MATT VARIDEL
UNIVERSITY OF SYDNEY

"Analysing Gas Kinematics in Star-Forming Galaxies using Disc Modelling

March

DR. ALEX JAMES CAMERON
UNIVERSITY OF MELBOURNE

"Observational methods towards constraining the chemical evolution of galaxies"

April

DR. BELLA NASIRUDIN
CURTIN UNIVERSITY

"Towards More Realistic Reionisation Studies and Experiments."

June

DR. STEFANIA BARSANTI
AUSTRALIAN NATIONAL UNIVERSITY

"Disentangling the stellar population properties of bulges and disks in cluster galaxies"

June

DR. KEVEN REN
UNIVERSITY OF MELBOURNE

"The diversity and environments of the rarest objects during cosmic dawn"

July

DR. ROBIN COOK
UNIVERSITY OF WESTERN AUSTRALIA

"The connection between cold gas reservoirs and morphology in galaxies."

July

DR GARIMA CHAUHAN
UNIVERSITY OF WESTERN AUSTRALIA

"The connection between atomic hydrogen, galaxies and dark matter in galaxy simulations."

August

DR. CHANDRASHEKAR MURUGESHAN
SWINBURNE

"The effects of angular momentum and environment on the HI properties of disc galaxies"

October

DR. DIAN (PIPIT) TRIANI
SWINBURNE

"Dust in galaxy evolution and SED modelling"

October

DR. JAMES ESDAILE
SWINBURNE

"Massive Galaxies in the Early Universe"

November

DR. JAMES DAVIES
UNIVERSITY OF MELBOURNE

"Simulating the epoch of reionisation"

November

DR. MELANIE HAMPEL
MONASH UNIVERSITY

"Nucleosynthesis models of the intermediate neutron-capture process"

December

DR. KRYSTOF ROZGONYI
UNIVERSITY OF WESTERN AUSTRALIA

"Deep interferometric spectral line imaging by gridded visibilities"

December

DR. ADAM WATTS
UNIVERSITY OF WESTERN AUSTRALIA

"Constraining gas kinematics and distributions with spatially unresolved HI observations"

EDUCATION AND OUTREACH

THE EFFECTS OF COVID 19 ON ASTRO 3D'S EDUCATION AND OUTREACH PROGRAMS

2021 was a challenging year for the ASTRO 3D Education and Outreach (E&O) team. Due to the waves of travel restrictions, lockdowns and home-schooling, the range of activities E&O officers could organise and then deliver, was severely impacted. Often in-person outreach had to be presented virtually at the last minute. There were delays in the development of programs and the repeated postponement of entire programs. Two team members also left their roles during the year.

SCIENTISTS TAKING ASTRONOMY TO REGIONAL SCHOOLS (STARS)

Even with a slow start to 2021 due to difficulties in procuring telescopes and accessories because of supply chain issues, the STARS program visited three secondary schools in northern Tasmania in March. Peter Swanton, Gamilaraay/Yuwaalaraay man, astrophysics graduate from the Australian National University and ASTRO 3D Education Affiliate member joined Dr Brad Tucker in delivering the program. They spoke to groups of students, did community star gazing nights and presented to a large group of Year 6 students brought together from primary schools in Ulverstone.

In May, Brad and Peter visited schools in Cowra and Orange in central-western NSW. Due to the changing travel restrictions, it was decided to concentrate on regional schools not far from Canberra. Jindabyne Central School and Bungendore Primary School were visited in June and July respectively. The program received some excellent media interest on local radio and local news.

A well-developed plan to visit schools in the Townville (North Queensland) region needed to be postponed in July, as was a Kalgoorlie Consolidated Gold Mines grant-supported visit to Kalgoorlie and Esperance schools in WA. A preliminary program of visits in late September to the NT—Elcho Island, Groote Eylandt and Nhulunbuy—was also delayed.

While school visits on the eastern side of the continent were restricted, the ASTRO 3D Education and Outreach team in WA embarked on a road trip to remote schools in Meekathara, Mullewa and Mt Magnet to run a STARS program, deliver telescopes and participate in the Mt Magnet Astrofest. Telescopes were also dispatched to One Arm Point Remote Community School, Derby District High School and Carnarvon Community College. Online support is being provided.

While not initially intended as part of the STARS program, the local delivery of telescopes in WA has been very successful. This local program will continue in 2022.

So even though only thirteen schools were recipients of the program in 2021 (half of what was intended) the good news is that ASTRO 3D has purchased all 50 telescopes and Smartphone camera adapters as part of the Federal Government grant. These are ready to ship to schools when the program of visits is scheduled for 2022. The other good news is that the grant period has been extended from mid-2022 until mid-2023. This will enable STARS to get to all 50 schools.

Images left to right:
Brad Tucker talking to students at Exeter High School, Tasmania (Image credit: Greg Finnigan)

Teacher-aide and student from Mullewa District High School check out their new telescope. (Image credit: Greg Rowbotham)

Teresa Slaven-Blair at the Mt Magnet Astrofest. (Image credit: Greg Rowbotham)

The STARS telescope (Image credit: Kylie Waters)

VIRTUAL REALITY (VR) EDUCATION PROGRAM

The central hub of the VR package – the Universe 3D transporter room – was finalised in 2021, and the development of the five accompanying activities commenced. The transporter room is the first environment the user encounters when entering VR and is a vital part of the experience, firstly to engage the user in the 'story' and secondly to provide an avenue for induction. As the user enters, they see they are on the U3D Space Telescope, and their role as astronomers is to research the origins of the Universe. To fulfil this role, on their first visit they must participate in some training in the transporter room.

Guiding them through this induction is ASTRO 3D PhD student Kirsten Banks. Kirsten was scanned using 3D technology and an avatar created. In the VR program, Kirsten 'plays' herself. Her voice has been recorded so Kirsten's avatar can guide the users through the activities and explain the science.

Inside the transporter room, users learn how to move around the room, use the virtual measurement tools, put on a space suit and teleport 'through' the 12m x 2m (in virtual space) Universe timeline to reach the activities. The induction in the transporter room was tested on ASTRO 3D members at the 2021 Annual Retreat in the Blue Mountains and was a great success.

Specific activities for the users in VR include, measuring the properties of sub-atomic particles just after the Big Bang, building the first atoms and placing them in the Periodic table, being immersed in the Epoch of Reonisation by dialling down the temperature of the Universe and riding a photon after it is released along the 21cm line of hydrogen.

When completed in 2022, the program will be stored on class sets of Oculus Quest 2 headsets. These will be stored in robust cases that ASTRO 3D can lend to schools for a multi-week period so teachers can incorporate the VR into a unit on the evolution of the Universe.

ASTRO 3D was co-awarded an ANU Research School of Astronomy and Astrophysics Strategic Initiatives grant of $22,000 to purchase headsets so the VR experience can support education and outreach activities at both Mt Stromlo and Siding Spring Observatories.

Images clockwise from top left: Kirsten Banks 'watching' her avatar and testing the VR program at the Annual Retreat. (Image credit: Delese Brewster), Screenshot of the astronomer avatar, Kirsten Banks, Screenshot of the transporter room in VR. Angel R. López-Sánchez and Delese Brewster testing the VR Program at the Annual Retreat. (Image credit: Cristy Roberts), Background Image: PhD Student Di Wang tries out the VR program. (Credit Cristy Roberts)

"It was a fantastic opportunity for my students to make the connection between what they are learning in the classroom and real-world applications. I have two students seriously considering astrophysics as a career path."

Feedback from a teacher

Main image: Depth Study students in front of the AAT at Siding Spring Observatory, May 2021. (Image credit: Matt Dodds)

Inset top left: Depth Study students completing a Hertzsprung-Russell diagram, May 2021.(Image credit: Matt Dodds)

Inset top right: Virtual WEX program led by Assoc. Prof. Emma Ryan-Weber (Image credit: Emma Barnett)

YEAR 12 DEPTH STUDY AT SIDING SPRING OBSERVATORY

On 10-11 May, fifty Year 12 students (and their teachers) from seven regional NSW secondary schools participated in a depth study on astronomy and astrophysics. The two-day program was organised by ASTRO 3D Education Affiliate Matt Dodds and was sponsored by ASTRO 3D. The group toured the 3.9m AAT telescope and viewed the instrumentation in the basement. Drs Katie Grasha and Andrew Battisti and Associate Professor Chris Lidman (Director of the SSO) presented to the students.

The students also participated in workshops on finding Hubble's Constant, spectroscopy, building the Hertzsprung-Russell diagram and exploring Wein's Law. Other highlights included stargazing through Dobsonian telescopes in the evening.

VIRTUAL WORK EXPERIENCE @ SWINBURNE

Forty Victorian students participated in four ASTRO 3D Swinburne's online work experience programs in 2021. Over a week, students worked through a research project both on Zoom and then on their own. They participated in Q&As with other researchers to learn more about the life of an astronomer and attended online colloquia and group meetings. Students were introduced to python programming, experienced VR by OzGrav, and built origami stars and Smartphone spectroscopes.

INDIGENOUS WORK EXPERIENCE PROGRAM

In April 2021, ASTRO 3D E&O was awarded a $20,000 Federal Government grant to run a 5-day pilot program for 10-12 Aboriginal Year 10 students from ACT and NSW schools. This funding would enable the Centre to cover the cost of travel and accommodation for each student and a parent or carer. Applications were sought and twelve students selected. The program was scheduled to take place at Mt Stromlo Observatory, 21-25 June with ASTRO 3D members Peter Swanton and Kirsten Banks involved as mentors.

Unfortunately, the program had to be postponed due to COVID concerns. Rescheduled to run 15-17 September with the same group of students attending, plans were developing well when COVID struck again and the program had to be postponed.

The IWEX program is now scheduled for 4-8 April 2022 and ASTRO 3D thanks the Department of Industry, Science and Energy and Resources for extending the duration of the grant.

OUTREACH

ASTRO IN THE HOME

The ASTRO 3D Education and Outreach team's contribution to National Science Week in 2021 was the release of four new ASTRO in the Home videos.

All sixteen videos are available on the ASTRO 3D YouTube channel.

PERTH ASTROFEST

ASTRO 3D Outreach Officer Teresa Slaven-Blair coordinated an ASTRO 3D stall at the Perth Astrofest at Curtin University on 13 November. Teresa and ASTRO 3D volunteers from both UWA and Curtin nodes hosted the famous 'Epoch of Bubbles' activity as well as the 'DIY radio telescope' in the outdoor area.

TACTILE UNIVERSE

Tactile Universe provides an avenue for the blind and visually impaired to experience the stunning photos of space through turning images into 3D prints. Science communicators and teachers are taken through the process of choosing and editing appropriate images and using the Tactile In 2021, Curtin node Outreach Coordinator, Teresa Slaven Blair ran workshops for the Communicate to Inspire and Future Science conferences in Perth.

PLAYDOUGH GALAXY

For an astronomy themed activity and observing night at a Perth based primary school in mid 2021, Teresa created a playdough-based galaxy activity for some of the galaxy experts from UWA who were volunteering at the event. Using an A3 printed combo template and info sheet, the children built up their own Milky Way galaxy using different coloured playdough, starting with a supermassive black hole in the centre, including major features like the spiral arms and finishing with the Sun.

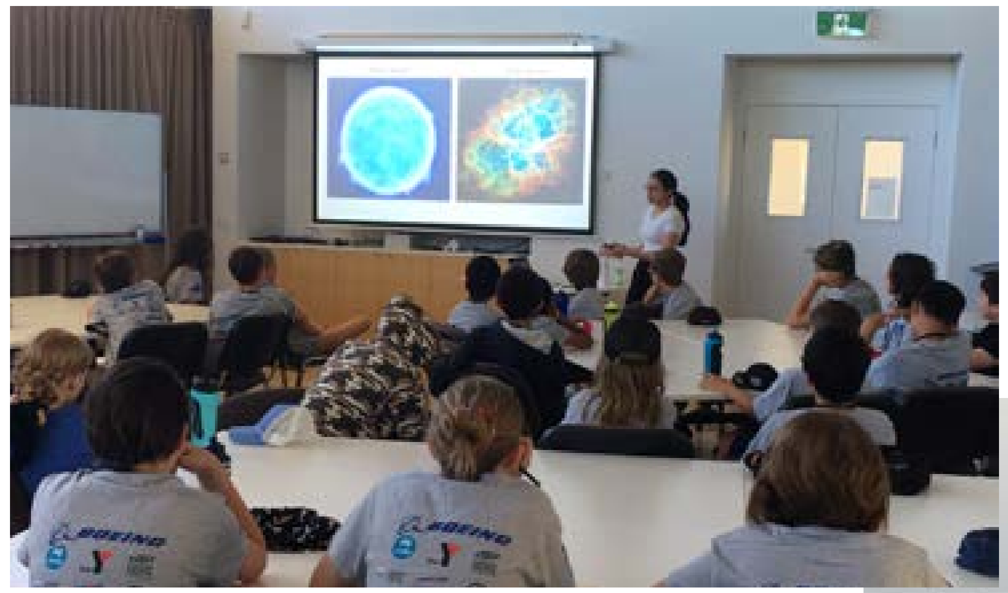
Images from left to right::
Screenshot of Postdoctoral Researcher Phil Taylor's ASTRO in the home video - Spin your way through angular momentum.

Children participating in the Epoch of Bubbles activity and Playdough galaxy activity at Perth Astrofest (Image credits: Teresa Slaven-Blair)

Workshop participants creating astronomical images to 3D print for Tactile Universe. (Image credit: Teresa Slaven-Blair)

CANBERRA YMCA SPACE SQUAD

ASTRO 3D once again supported the YMCA Space Squad programs in January and April 2021 (the July and September camps were cancelled due to COVID). ASTRO 3D researchers did presentations, conducted Mt Stromlo site tours, ran workshops and sat on a panel to discuss their research and pathways into astronomy. This was for both the youth camps and, for the first time, a senior camp for Year 10-12 students. E&O Coordinator, Delese Brewster ran two workshops for junior space squad cadets (Years 2-5) where they looked at modelling. They made the scale model of the Solar System and a model of the Milky Way galaxy.



Senior Space Squad panel discussion L-R: Patrick Armstrong, Jane Lin, Wei Shen Oh, Stephanie Monty; Ingrid McCarthy (facilitator). (Image credit: Delese Brewster)

Youth Space Squad listening to Ella Wang's presentation on spectroscopy. (Image credit: Delese Brewster)

Background Image: Junior Space Squad cadet making a model Milky Way galaxy. (Image credit: Delese Brewster)

DR DELESE BREWSTER

Senior Education and Outreach Coordinator
Australian National University

ABOUT ME

I coordinate and manage the ASTRO 3D national education programs, including Scientists Taking Astronomy to Regional Schools (STARS), ASTRO in the Classroom, 'Unlocking the Universe' virtual reality education package and Indigenous work experience. Through these programs, I aim to inspire school students (mid-primary – senior secondary) to learn about astronomy and the science of ASTRO 3D and to embrace Science, Technology, Engineering and Maths (STEM) at school. We need to encourage young people to always ask questions about the natural phenomena they see around them, so they become critical thinkers and develop a range of 21st century skills.

HOW I CAME TO ASTRO 3D

I have a background in education and Near Eastern Archaeology and have spent many years managing the development of science resources for teachers and students. So, I was very keen to start a role at ASTRO 3D in late 2019 that enabled me to try something new but still let me follow my passion. The most challenging part of the role has been upskilling my understanding of ASTRO 3D science.

The role of the teacher in facilitating this is often understated. Given that teachers are the main influencers on students, only second to their parents, enabling teachers is essential.

WHAT I LOVE

My true passion is supporting teachers, particularly primary teachers who often have difficulty understanding and teaching space science concepts.

WHAT I DON'T LOVE

2021 has been a 'patchy' year in terms of delivering education and outreach activities. Due to various COVID outbreaks and related supply chain issues, the Indigenous Work Experience program was postponed twice, and we only managed to deliver the STARS program to thirteen schools. Five of these were in WA, where local delivery helped enormously. We are hoping for the freedom to travel in 2022 and visit many more schools.

IF I WASN'T IN SCIENCE EDUCATION, I WOULD BE...

If I wasn't in science education, I think I would be an astrophysicist working on the Epoch of Reionisation and the 21cm line of neutral hydrogen or even a galactic archaeologist – an excellent combination of astronomy and archaeology. Either way, I would need to work on my maths!

2021 HIGHLIGHT

The highlight for me in 2021 came late in the year when I was able to share the first stage of the virtual reality program with ASTRO 3D researchers at the Retreat in the Blue Mountains. Watching reactions and hearing the range of emotions from squeals of amazement and wonder to howls of frustration was terrific. The response was all positive and those involved provided some helpful feedback. I look forward to sharing the final iteration of the VR program soon.

I SURVIVED COVID IN 2021 BY...

Making sourdough bread, walking the dog in the middle of the day and connecting with friends and family via Zoom.

FREE TELESCOPES FOR LAUNCESTON, EXETER AND ULVERSTONE SCHOOLS

SKY-GAZERS VISIT THE REGION TO GET KIDS DANCING WITH THE STARS

Three schools in Launceston, Exeter and Ulverstone will be visited by astronomers, who will present them with powerful telescopes and show eager students how to use them to unlock the secrets of the stars.

Dr Brad Tucker, from the Centre of Excellence for All-Sky Astrophysics in 3D (ASTRO 3D) and the Australian National University, together with Mr Peter Swanton, also from ANU, will give the telescopes to Riverside, Exeter and Ulverstone high schools on April 29 and 30.

The scientists will talk to students about astronomy and show them how to use the telescopes, known as "eight-inch Dobsonians". Once the sun goes down, they will host star-gazing events for the public.

"In areas like the north of Tasmania, away from city lights, the skies are very dark and filled with stars everywhere, a truly breathtaking sight," said Dr Tucker.

"But by using a good quality telescope you can see so much more. We hope that the students, schools and the communities will be able to make good, continuing use of the ones we bring. I hope they go on to develop detailed and inspiring astronomy projects for years to come, as well as a passion and love of science."

Mr Swanton is a Gamilaraay/Yuwaalaraay man from Mackay, in Queensland. He currently works at ANU's Tjabal Indigenous Higher Education Centre.

"I'm looking forward to meeting with Indigenous students in the area and introducing them – and the wider community – to Indigenous interpretations of the night sky," he said.

The school visits are the first of many planned for around Australia. They are part of the project called Scientists Taking Astronomy to Regional Schools, or STARS, organised by ASTRO 3D and ANU.

The project will see working astronomers and PhD candidates visit dozens of primary and secondary schools. They will conduct workshops, hold star-gazing evenings and show students how to operate the telescopes and properly record the data they gather.

"Regional kids can study science, technology, engineering and maths (STEM) subjects at school, but access to STEM professionals and specialist programs is difficult because they are mainly located in larger towns and cities," said ASTRO 3D's Dr Delese Brewster, one of the architects of the program.

"But regional kids have a huge advantage in astronomy. Our countryside has big skies with minimal light pollution. This program aims to inspire children across Australia to look up and explore the Universe."

STARS is funded by a Federal Government Maker Projects: Community STEM Engagement grant, aimed at encouraging STEM education in schools.

Press Release by Science in Public

TRAINING AND WORKSHOPS

Some of our 2021 schedule of training and workshops for our members was delayed due to COVID-19 and accompanying restrictions. This meant that many of our plans either could not go ahead or pivoted to virtual workshops.

We are keenly aware that people are suffering from "Zoom-fatigue", what with many of our regular meetings now being held on Zoom or other teleconference systems, so rather than try to deliver all of our training virtually, we will hopefully be able to deliver these workshops in person in 2022.

Normally, we fund ASTRO 3D led workshops and conferences, however, with COVID-19 restrictions preventing travel for much of the year, we received no applications and therefore, many of the workshops and conferences we would have highlighted here did not happen.

Planned in-person workshops, including rapid prototyping, women's leadership and writing retreats, have been postponed until 2022.

We did manage a few online options, however, and of course, we did have our Annual Retreat in in December before Omicron (with a separate Western Australian hub for our UWA and Curtin members).

MEDIA TRAINING:

Each year, we offer all our researchers the opportunity to upskill their communications in talking to the media. In 2021, twelve of our students, ECRs and senior researchers took the opportunity to undertake the Media and Communications Masterclass, delivered either in-person or virtually by Science in Public.

This Masterclass helps researchers find their story in their science and to learn how to achieve media coverage that is true to their science AND engages their audience. Journalists from television, print and radio explain what makes news for them. Researchers get the chance to ask questions and to be interviewed by journalists, get feedback and practical advice.

The course covers:

- television (with practice interviews);
- radio (with practice interviews);
- handling tricky questions and staying out of trouble;
- print and online media;
- developing your communication plan;
- social media and
- becoming an 'expert'.

"Listening to the external speakers provided many useful insights and viewpoints to aid developing myself as a supervisor."

BECOMING AN EFFECTIVE SUPERVISOR

In April this year, our Junior ECR Committee asked ASTRO 3D to help craft a workshop that would help their cohort become effective supervisors. Often, Postdocs get the opportunity to supervise an Honours or Masters Students, but apart from having been a student themselves, they are never given guidance in how to develop their supervisory skills.

So, our COO put together a virtual workshop, with timings that suited both east and west coast to cover the most important parts of being an academic supervisor. We had the following interactive sessions with 23 participants from all over ASTRO 3D:

- Developing doctoral writers (it's more than feedback on drafts!) – Dr Cally Guerin, Researcher Developer Unit, ANU
- Leading positive conversations – Damien Hughes, Enlighten Leadership
- Panel discussion on what it takes to be a good supervisor (these ASTRO 3D members were nominated by ECRs as having been excellent supervisors) – Lisa Kewley (ANU), Kim-Vy Tran (UNSW), Matthew Colless (ANU) and Luca Cortese (UWA)

The feedback we received from participants was an average of 4/5 for overall satisfaction.

ASTRO 3D AND OZGRAV ECR PROFESSIONAL DEVELOPMENT WEBINAR SERIES

In 2021, ASTRO 3D partnered with the Centre of Excellence for Gravitational Wave Discovery (OzGrav) to run a series of ECR professional development webinars held every two months. The webinars alternated monthly with our joint OzGrav+ASTRO 3D Equity, Diversity and Inclusion Journal Club.

Dr Shari Walsh, a qualified psychologist facilitated the three webinars; Creating Career opportunities; Building a positive work future; and Managing difficult conversations.

Shari also gave a well-received webinar last year on resilience in research and stress survival tips.

SBS CULTURAL COMPETENCE PROGRAM

As part of ASTRO 3D's Equity, Diversity and Inclusion Action Plan, we provided online training via the SBS Cultural Competence Program to all members to help improve our knowledge and awareness of cultural diversity.

The course explored topics including cross-cultural communication, addressing stereotypes, unconscious bias, diversity and the benefits of multiculturalism in the workplace. There were over 60 animations and films, including real people telling real stories. Members completed interactive activities, plus options for further reading. The course provided a solid foundation in understanding what culture, diversity, inclusion and cultural competence mean, and how this contributes to competitive advantage.

90% of ASTRO 3D members completed this training during 2021, and we received some excellent feedback.

"I really enjoyed and learned a lot from the Culture Course. It was really useful know about diversity of spoken and unspoken rules of interaction in different cultures."

CRUXES INNOVATION BASE PROGRAM

As part of our training in transferrable skills, in 2021, we offered the BASE Program, run by Cruxes Innovation to our students and ECRs, in order to help our researchers transfer their research skills and capabilities to a wide variety of potential employers.

The BASE Program helps researchers develop:

- Communication skills to articulate the value of your research
- Tools and methods to identify and engage with potential industry, government and community partners
- Skills to uncover the problems that potential partners want to solve, and how your research might help

We had two researchers take up this opportunity and in 2022, we are working with Cruxes and OzGrav to co-design a workshop that targets astronomers and to develop a program that takes into account their particular skillset and experience. Writing Retreats

COVID again prevented us from having many in-person retreats this year, but we did manage to have 4 events:

- East Coast Retreat at Batemans Bay in April;
- Virtual Writing Retreat in August;
- ANU Writing Retreat in August;
- West Coast Retreat at Rottnest Island in November.

We received excellent feedback on all events and hopefully they produced many papers or chapters of theses!

MOCK FELLOWSHIP/ACADEMIC POSITION APPLICATION WORKSHOP

Held in August, this workshop was geared towards researchers who have had limited experience with leading proposals. This workshop helped demystify the process of applying for fellowships (DECRA, Future, Hubble) and faculty jobs for students, postdocs, and ECRS. A series of interactive sessions spread over 3 days included advice from experts, tips from successful applicants, and an overview of the reviewing process. Individual feedback was available for attendees with drafts of fellowship or job applications, or at minimum a draft research statement.

GALAH SURVEY SCIENCE MEETING, 22-24 JUNE 2021

The 2021 GALAH Survey Science Meeting, was held from 22 to 24 June 2021. It had a hybrid format with people both online and meeting in-person in Sydney, Australia.

The GALAH Survey is an ongoing, ambitious stellar spectroscopic survey of the local Galactic volume, acquiring high-resolution optical spectra for over one million stars with the HERMES spectrograph at the Anglo-Australian Telescope.

GALAH had its Third Data Release in November 2020, which provided reduced spectra, stellar parameters, elemental abundances, and radial velocities for about 600, 000 stars. Subsequent to this release was the Third Early Data Release from the Gaia astrometric mission. The combination of these two data releases has provided an unprecedented view of our Galaxy. This meeting brought together researchers to present the latest research taking place using the GALAH survey, Gaia, and other stellar surveys.

MINI WORKSHOP EOR AND FIRST GALAXIES

The mini-workshop on “the Epoch of Reionisation and First Galaxies” was held in June. The format was 15 minutes talks by 4 key speakers followed by an hour long discussion on how to integrate the three themes of ASTRO 3D: Galaxy Evolution, Epoch of Reionisation and First Galaxies. The key speakers were: Cathryn Trott (Curtin University), Chris Power (UWA), Emma Ryan-Weber (Swinburne) and Bradley Greig (Melbourne University).

MAGPI BUSY WEEK

The MAGPI busy week was in June, with 3 sessions during the Australian work day and two sessions during the European work day. With 15 fields in hand and data products being produced, the goal for the busy week was to get more science projects underway this year. The meeting was fully accessible via Zoom with an in-person component at ANU.

CHIEF INVESTIGATORS (CI)

PROFESSOR JOSS BLAND-HAWTHORN

GALAH SURVEY LEAD COLLABORATION LEAD UNIVERSITY OF SYDNEY

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.

ASSOCIATE PROFESSOR BARBARA CATINELLA

NODE LEADER UNIVERSITY OF WESTERN AUSTRALIA

Associate Professor 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.

PROFESSOR MATTHEW COLLESS

SAMI/HECTOR SURVEY CO-LEAD 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.

PROFESSOR SCOTT CROOM

SAMI/HECTOR SURVEY CO-LEAD 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 instrument at the end of 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.

PROFESSOR DARREN CROTON

GENESIS SIMULATIONS THREAD CO-LEAD SWINBURNE UNIVERSITY OF TECHNOLOGY

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 galaxy formation models. 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.

ASSOCIATE PROFESSOR DEANNE FISHER

SWINBURNE UNIVERSITY OF TECHNOLOGY

Associate Professor Deanne Fisher received her PhD from the University of Texas in 2010. She has since been a CARMA Research Fellow, Swinburne Director's Fellow and ARC Future Fellow. She is an Associate Professor in the Centre for Astrophysics and Supercomputing.

Her research focuses on multiwavelength studies of galaxies from the very nearby Universe at z=0 to galaxies just emerging from Reionisation at z=5. Fisher works in detailed observations spanning from UV observations, common use of Hubble Space Telescope and 10 m Keck and VLT optical telescopes and further to infrared and radio interferometry.

Along with a career in research she has been awarded for her efforts in equity and diversity, not just in astronomy, but within the national academic sector. She is among the founding members of the first nationwide, Australian LGBTQI support organisation for scientists.

ASSOCIATE PROFESSOR AMANDA KARAKAS

NODE LEADER MONASH UNIVERSITY

Associate Professor Amanda Karakas is a leading expert in the field of theoretical stellar evolution and nucleosynthesis for low and intermediate-mass stars, and on the impact of these stars on the chemical evolution of galaxies. In particular, she specialises in the evolved phases of stellar evolution, which is when stars produce metals and heavy elements deep inside their interiors. In recent years she has concentrated on the production of elements heavier than iron, which are produced in low-mass stars via the "slow neutron capture process".

Within the GALAH project the chemical evolution models that utilise Amanda's predictions will be compared to the abundances of stars in the Milky Way Galaxy, and within the First Stars project her theoretical models can be directly compared to carbon enhanced metal-poor stars, which can result from binary mass transfer from an evolved companion. These comparisons improve our understanding of element formation at the earliest times.

PROFESSOR LISA KEWLEY

DIRECTOR
AUSTRALIAN NATIONAL UNIVERSITY

Lisa Kewley is a Professor and Australian Research Council Laureate Fellow at the Australian National University. She obtained her PhD in 2002 from the Australian National University on the connection between star-formation and supermassive black holes in galaxies. She was a Harvard-Smithsonian Center for Astrophysics Fellow and a NASA Hubble Fellow.

Her awards include the 2006 American Astronomical Society Annie Jump Cannon Award, the 2008 American Astronomical Society Newton Lacy Pierce Prize, and the 2020 US National Academy of Science James Craig Watson Medal.

In 2014, Kewley was elected Fellow of the Australian Academy of Science "for her fundamental advances in understanding of the history of the Universe, particularly star and galaxy formation", and in 2015, Kewley was awarded an ARC Laureate Fellowship, Australia's top fellowship to support excellence in research.

ASSOCIATE PROFESSOR RICHARD MCDERMID

THREAD LEAD: DATA INTENSIVE ASTRONOMY
NODE LEADER 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.

Richard leads the Macquarie University ASTRO 3D Node, and works closely with Data Central as part of the Data-Intensive Astronomy thread. He 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.

DR MATT OWERS

MACQUARIE UNIVERSITY

Dr Matt Owers is an extragalactic astronomer with extensive experience in using large-scale surveys to understand the impact of environment on galaxy properties. He is best known for his work on galaxy clusters at X-ray and optical wavelengths.

Matt has made significant contributions to the SAMI Galaxy Survey, where he led both the target selection and quenching-related science undertaken for the cluster portion of the SAMI galaxy survey. Matt is the Science Lead (Environments/halos) for the Hector Galaxy Survey, and is also leading the target selection and characterisation of the cluster regions.

PROFESSOR CHRIS POWER

PROFESSOR EMMA RYAN-WEBER

PROFESSOR ELAINE SADLER

PROFESSOR LISTER STAVELEY-SMITH

ASSOCIATE PROFESSOR KIM-VY TRAN

GENESIS SIMULATIONS PROJECT LEAD UNIVERSITY OF WESTERN AUSTRALIA

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? - and galaxy formation - 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 supercomputer simulations (comprising of ~100 billion particles) to construct the most detailed and sophisticated prescriptions for galaxy formation that we have.

GALAXY EVOLUTION PROJECT CO-LEAD NODE LEADER SWINBURNE UNIVERSITY OF TECHNOLOGY

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. Emma is currently leading the metal absorber work package for the ESO Large Program XQR-30 - the most ambitious program to date for follow-up spectroscopy of redshift 6 quasars.

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~3–4 and developing calibrations for escaping flux. The results will be applied to galaxies at higher redshifts to ultimately understand how the Universe was reionised.

ORIGIN OF MATTER AND THE PERIODIC TABLE THEME LEADER ASKAP SURVEYS LEAD UNIVERSITY OF SYDNEY/CSIRO

Professor Elaine Sadler's research expertise covers both optical and radio astronomy and she has led several large radio surveys of the southern sky. She is a Professor of Astrophysics at the University of Sydney and also serves as ATNF Chief Scientist at CSIRO. Within ASTRO 3D Elaine leads the 'Origin of Matter and Periodic Table' Theme and the 'ASKAP Surveys' project, and is co-PI of the ASKAP FLASH survey. She also brings extensive science management experience.

Elaine is a Fellow of the Australian Academy of Science, and in 2019 she was appointed as an 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.

DATA INTENSIVE ASTRONOMY THREAD CO-LEADER ASKAP HI SURVEYS CO-LEADER UNIVERSITY OF WESTERN AUSTRALIA

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 co-leading the ASKAP HI Surveys project and is PI of ASKAP WALLABY project to image the southern sky in the 21-cm line of neutral hydrogen. Lister is also co-leader of the Data Intensive Astronomy Programme which facilitates the analysis of our petascale datasets, provides curation, visualisation and cross-linking capability for advanced data products, and provides the means to compare with theoretical models.

GALAXY EVOLUTION PROJECT CO-LEAD NODE LEADER UNIVERSITY OF NEW SOUTH WALES

Associate Professor 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. Kim-Vy is the Executive Chair of the ASTRO 3D Galaxy Evolution project that bridges the first galaxies and the present-day Universe by tracking the mass assembly, chemical evolution and ionising radiation in galaxies. She co-leads the AGEL, MOSEL, ZFIRE, and ZFOURGE galaxy surveys that integrate multi-wavelength imaging and spectroscopic campaigns to track how galaxies evolve.

Kim-Vy is currently President of the Galaxies & Cosmology 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 a range of professional development workshops at ASTRO 3D meetings.

PROFESSOR MICHELE TRENTI

FIRST GALAXIES PROJECT CO-LEAD UNIVERSITY OF MELBOURNE

Professor Michele Trenti is an expert on cosmic dawn who has built an 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.

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.

Michele is not only a user of space telescopes, but he is also leading the development of the first space mission funded by the Australian Space Agency, the SpIRIT satellite, which will both promote space industry growth and carry out innovative observations of the variable sky at high energies (gamma and x-rays) with the ambition to spot Gamma Ray Bursts originating at cosmic dawn.

PROFESSOR CATH TROTT

MWA EOR PROJECT CO-LEAD NODE LEADER CURTIN UNIVERSITY

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.

PROFESSOR RACHEL WEBSTER

MWA EOR PROJECT CO-LEAD UNIVERSITY OF MELBOURNE

Professor Rachel Webster is a Redmond Barry Distinguished Professor in the University of Melbourne School of Physics. She is an expert in the field of reionisation and is a member of the Board of Directors for Australian Astronomy Limited (AAL). She brings extensive leadership expertise to ASTRO 3D.

Rachel is co-leading the data reduction and analysis of the Epoch of Reionisation signals observed with the MWA. The improvement in the measured limits on the signal are 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.

DR EMILY WISNIOSKI

AUSTRALIAN NATIONAL UNIVERSITY

Dr. Emily Wisnioski specialises in studies of the interstellar medium and its evolution over cosmic time. She is a world-recognised expert on early star-forming galaxies. As a PI of the MAGPI Survey, a 340hr ESO MUSE Large Program, she is co-leading a group of 60+ researchers across Australia, Europe, Asia, and South America facilitating science across a range of key questions in galaxy evolution. Her extensive experience utilising the facilities provided by VLT/ESO, in particular with spatially resolved spectroscopy, has led to her scientific leadership in a number of planned instrumentation projects on 8-30m class telescopes. As part of the near-infrared IFU KMOS3D survey at cosmic noon she led pioneering work on the turbulent evolution of marginally stable disk galaxies.

Within the Galaxy Evolution thread, Emily is leading efforts to connect resolved kinematics and metallicity information at early times to local galaxies including studies of the Milky Way from the GALAH team.

PROFESSOR STUART WYITHE

DEPUTY DIRECTOR GENESIS SIMULATIONS THEME CO-LEAD NODE LEADER UNIVERSITY OF MELBOURNE

Professor Stuart Wyithe is an international leading authority in the theoretical simulation of the Epoch of Reionisation and Gravitational Lensing and also currently the Head of the School of Physics at the University of Melbourne.

Stuart's theoretical expertise spans the Epoch of Reionisation to first stars and galaxy formation and evolution, and he also brings important strategic planning experience to ASTRO 3D. Stuart is working closely with Chris Power to ensure the Genesis Simulations are incorporated with the Meraxes semi-analytic model infrastructure, and mock data are produced for the Centre's surveys.

His research interests lie in the field of quasar formation and reionisation in the early Universe. In particular, he is interested in the evolution of the earliest galaxies and how this evolution may be studied with the next generation of radio telescopes.

PARTNER INVESTIGATORS (PI)

Professor Roberto Abraham, University of Toronto, Galaxy Evolution

Professor Andrew Bunker, Oxford University, First Galaxies
Galaxy Evolution

Professor Julianne Dalcanton, University of Washington, Galaxy Evolution

Professor Roger Davies, Oxford University, SAMI

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Professor Di Li, CAS - Chinese Academy of Sciences, ASKAP - WALLABY

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Associate Professor Julia Bryant, The University of Sydney, SAMI/Hector
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PERFORMANCE INDICATORS

PERFOMANCE MEASURE		2017 ACTUAL	2018 ACTUAL	2019 ACTUAL	2020 ACTUAL	2021 TARGET	2021 ACTUAL
Number of research outputs	Papers in refereed journals	11	110	213	227	150	269
	Media releases	1	5	7	11	12	10
	Centre Videos	-	-	15	64	12	93
	Facebook Page posts	-	-	73	71	26	33
	Twitter posts	-	-	228	119	52	229
	Exhibition or performance	-	-	3	2	1	3
	STEM Education workshops	-	-	6	5	6	4
	Website News Updates	-	-	7	21		
	VR Program Development	-	-	1	1	1	1
Quality of research outputs	% of refereed papers in journals with impact factor > 2.5	100%	100%	100%	100%	80	100
Number of training courses held/offered by the Centre	Professional skills workshop	1	4	2	1	1	1
	ECR training day	1	1	2	1	1	3
	Writing workshops	2	5	6	3	6	4
	Transferrable Skills workshop	-	-	1	3	1	2
Number of workshops/ conferences held/ offered by the Centre	International conference	0	2	2	2	2	2
	National conference/ workshop	1	2	2	2	2	2

PERFOMANCE MEASURE		2017 ACTUAL	2018 ACTUAL	2019 ACTUAL	2020 ACTUAL	2021 TARGET	2021 ACTUAL
Number of additional researchers working on Centre research	Postdoctoral researchers	16	14	3	8	10	0
	Honours students	2	1	3	5	2	3
	Masters by coursework	0	2	3	0	2	4
	PhD students	28	13	20	15	12	5
Number of presentations/ briefings	Public briefings/lectures	3	123	230	246	90	56
	Government briefings	5	22	29	35	4	7
	Industry briefings	0	12	39	42	2	7
	Non-government organisation briefings	0	5	6	7	6	1
	Briefings to professional organisations & bodies	4	36	6	6	4	1
	Professional conferences/ workshops presentations	68	163	123	221	40	209
Number of new organisations collaborating with, or involved in, the Centre	New collaborative relationships	5	7	15	11	4	4
	New participating organisation	-	-	0	3	1	1
Maintain a collaborative and cohesive structure	Cross-node authorship of publications	36%	46%	83%	37%	85%	43%
	Project team meetings with cross-node collaboration	4	12	6	6	6	6
	Centre-wide climate survey	0	1	0	0	1	1

PERFOMANCE MEASURE		2017 ACTUAL	2018 ACTUAL	2019 ACTUAL	2020 ACTUAL	2021 TARGET	2021 ACTUAL
Create a diverse Centre	Females at all levels	38%	39%	40%	42%	50%	46%
	At least 35% travel funds to females	28%	42%	42%	51%	50%	n/a
	Female visitors	44%	50%	58%	n/a	50%	n/a
	Child care at all Centre-suported conferences	100%	100%	100%	n/a	100%	100%
Build the expertise for the next-generation telescopes	Students working on optical GMT pathfinder instruments	13%	29%	25%	37%	20%	54%
	Students working on radio SKA pathfinder instruments	10%	16%	31%	20%	20%	19%
	Students working on space telescope data	13%	16%	6%	15%	10%	24%
	Students with data intensive research experience	19%	80%	51%	44%	40%	49%
Train the next generation of scientists	% satisfaction with Centre-run skills workshops	-	-	87%	87%	80%	82%
	% of PhD students and ECRs attending skills workshops	-	-	31%	30%	20%	29%
	% ECRs achieving prestigious fellowships	-	-	28%	27%	20%	27%
	% PhD students or ECRs achieving high quality jobs in other fields	-	-	-	24%	20%	16%

2021 FINANCIAL STATEMENT

NOTES TO FINANCIAL STATEMENTS

1. ARC CONTRACT & GOVERNANCE

a) During the 2021 financial year, ASTRO 3D involved nine Australian Universities and nine 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 was conducted in June 2021, and future funding was agreed.

b) In line with strategic objectives, three new node organisations were approved by the Australian Research Council as at January 2021, and funding agreements were signed during the year. The new structure of the Centre now encompasses 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 Chief Operating Officer for the Centre providing Consolidated Financial Reports for review by the Director.

2. INCOME

a) Income received from the ARC for 2021 amounted to $4.732m, including an amount relating to indexation of $382k.

b) University Contributions are contributions provided at Node level. Please note that we did not receive the full contribution agreed by Sydney University, who provided only 50% of the agreed amount in the Funding Agreement. All other Nodes provided the full agreed contributions.

c) In 2021, ASTRO 3D received a NSW State Government grant from their Kickstart Program for events, which was used to offset the cost of the Annual Retreat, held in the Blue Mountains, NSW.

d) Other income is negative due to incorrect accounting in 2020 of reimbursement of travel costs to ANU Node, invoiced costs associated with various programs including the Indigenous Program, and the COVID-19 financial support program.

3. EXPENDITURE

a) Expenditure for the year was $6.22m against a budget of $8.8m (70%). This variance primarily relates to the impact of COVID at a general level on Centre activities. Travel was again severely restricted, which also impacted events, although we were able to hold our Annual Retreat. Delays in signing Funding Agreements with the new Nodes, and travel restrictions have caused in Postdoctoral appointments, which will be carried into 2024.

b) The carried forward balance still largely relates to the late start of the Centre, and will be used in 2024. Carry forward also relates now to lack of expenditure in travel over 2020 and 2021 due to COVID and the late start of Postdoctoral contracts, which should be expended in 2024.

4. FINANCIAL MANAGEMENT

a) 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.

b) Centre-wide financial policies relating to reporting and budgeting were developed and implemented to ensure consistency of financial management across the Centre.

	2021 ACTUAL ($)
INCOME	$
ARC Grant	4,732,503
State Government Grants	3,650
Other Grants	4,500
University Contributions	1,721,637
Partner Contributions	0
Other Income	(237,148)
Total income	**6,225,142**
EXPENSES	$
Salaries	4,911,416
Travel and Visitor Support	405,010
Equipment	25,264
Workshops and Conferences	230,509
Management and Administration	307,625
Education, Outreach and Communications	178,828
PHD Support	162,337
TOTAL EXPENSES	**6,220,989**
Net Surplus (Deficit)	4,153
Brought Forward Balance	6,309,267
CARRY FORWARD BALANCE	6,313,420

2021 PUBLICATIONS

1. Abbot, H. J., Munro, J., Travouillon, T., Lidman, C., Tucker, B. E. (2021) "Archival Weather Conditions at Siding Spring Observatory", Publications of the Astronomical Society of the Pacific, 133, 095001. (figure 1)
2. Adams, N. J., Bowler, R. A. A., Jarvis, M. J., Häußler, B., Lagos, C. D. P. (2021) "Evolution of the galaxy stellar mass function: evidence for an increasing M* from z = 2 to the present day", Monthly Notices of the Royal Astronomical Society, 506, 4933.
3. Alger, M. J., Livingston, J. D., McClure-Griffiths, N. M., Nabaglo, J. L., Wong, O. I., Ong, C. S. (2021) "Interpretable Faraday complexity classification", Publications of the Astronomical Society of Australia, 38, e022.
4. Allison, J. R. (2021) "A statistical measurement of the H I spin temperature in DLAs at cosmological distances", Monthly Notices of the Royal Astronomical Society, 503, 985.
5. Allison, J. R., Sadler, E. M., Mahony, E. K., Moss, V. A., Yoon, H. (2021) "The gaseous natal environments of GPS and CSS sources with ASKAP-FLASH", Astronomische Nachrichten, 342, 1062.

Figure 1: Publication 1: Top down view of site, with contours pulled from Geoscience Australia (Minty et al. 2009). The highest peak lies at 1165 m, nearby the SkyMapper telescope. The telescope sites included in this study are labeled. Weather station locations are located nearby, but not necessarily under the blue dots.

6. Arentsen, A., Starkenburg, E., Aguado, D. S., Martin, N. F., Placco, V. M., Carlberg, R., González Hernández, J. I., Hill, V., Jablonka, P., Kordopatis, G., Lardo, C., Mashonkina, L. I., Navarro, J. F., Venn, K. A., Buder, S., Lewis, G. F., Wan, Z., Zucker, D. B. (2021) "The Pristine Inner Galaxy Survey (PIGS) III: carbon-enhanced metal-poor stars in the bulge", Monthly Notices of the Royal Astronomical Society, 505, 1239.
7. Armstrong, P., Tucker, B. E., Rest, A., Ridden-Harper, R., Zenati, Y., Piro, A. L., Hinton, S., Lidman, C., Margheim, S., Narayan, G., Shaya, E., Garnavich, P., Kasen, D., Villar, V., Zenteno, A., Arcavi, I., Drout, M., Foley, R. J., Wheeler, J., Anais, J., Campillay, A., Coulter, D., Dimitriadis, G., Jones, D., Kilpatrick, C. D., Muñoz-Elgueta, N., Rojas-Bravo, C., Vargas-González, J., Bulger, J., Chambers, K., Huber, M., Lowe, T., Magnier, E., Shappee, B. J., Smartt, S., Smith, K. W., Barclay, T., Barentsen, G., Dotson, J., Gully-Santiago, M., Hedges, C., Howell, S., Cody, A., Auchettl, K., Bódi, A., Bognár, Z., Brimacombe, J., Brown, P., Cseh, B., Galbany, L., and 22 colleagues (2021) "SN2017jgh: a high-cadence complete shock cooling light curve of a SN IIb with the Kepler telescope", Monthly Notices of the Royal Astronomical Society, 507, 3125.
8. Arora, R., Krumholz, M. R., Federrath, C. (2021) "Quantifying stochasticity-driven uncertainties in H II region metallicities", Monthly Notices of the Royal Astronomical Society, 508, 3290.
9. Bakels, L., Ludlow, A. D., Power, C. (2021) "Pre-processing, group accretion, and the orbital trajectories of associated subhaloes", Monthly Notices of the Royal Astronomical Society, 501, 5948.
10. Barsanti, S., Owers, M. S., McDermid, R. M., Bekki, K., Bland-Hawthorn, J., Brough, S., Bryant, J. J., Cortese, L., Croom, S. M., Foster, C., Lawrence, J. S., López-Sánchez, Á. R., Oh, S., Robotham, A. S. G., Scott, N., Sweet, S. M., van de Sande, J. (2021) "The SAMI Galaxy Survey: Bulge and Disk Stellar Population Properties in Cluster Galaxies", The Astrophysical Journal, 906, 100.
11. Barsanti, S., Owers, M. S., McDermid, R. M., Bekki, K., Bryant, J. J., Croom, S. M., Oh, S., Robotham, A. S. G., Scott, N., van de Sande, J. (2021) "The Colors of Bulges and Disks in the Core and Outskirts of Galaxy Clusters", The Astrophysical Journal, 911, 21.
12. Bassett, R., Ryan-Weber, E. V., Cooke, J., Meštrić, U., Kakiichi, K., Prichard, L., Rafelski, M. (2021) "IGM transmission bias for z ≥ 2.9 Lyman continuum detected galaxies", Monthly Notices of the Royal Astronomical Society, 502, 108.
13. Batten, A. J., Duffy, A. R., Wijers, N. A., Gupta, V., Flynn, C., Schaye, J., Ryan-Weber, E. (2021) "The cosmic dispersion measure in the EAGLE simulations", Monthly Notices of the Royal Astronomical Society, 505, 5356.
14. Beattie, J. R., Mocz, P., Federrath, C., Klessen, R. S. (2021) "A multishock model for the density variance of anisotropic, highly magnetized, supersonic turbulence", Monthly Notices of the Royal Astronomical Society, 504, 4354.
15. Bellstedt, S., Robotham, A. S. G., Driver, S. P., Thorne, J. E., Davies, L. J. M., Holwerda, B. W., Hopkins, A. M., Lara-Lopez, M. A., López-Sánchez, Á. R., Phillipps, S. (2021) "Galaxy and mass assembly (GAMA): the inferred mass-metallicity relation from z = 0 to 3.5 via forensic SED fitting", Monthly Notices of the Royal Astronomical Society, 503, 3309.
16. Bešlić, I., Barnes, A. T., Bigiel, F., Puschnig, J., Pety, J., Herrera Contreras, C., Leroy, A. K., Usero, A., Schinnerer, E., Meidt, S. E., Emsellem, E., Hughes, A., Faesi, C., Kreckel, K., Belfiore, F. M. C., Chevance, M., den Brok, J. S., Eibensteiner, C., Glover, S. C. O., Grasha, K., Jimenez-Donaire, M. J., Klessen, R. S., Kruijssen, J. M. D., Liu, D., Pessa, I., Querejeta, M., Rosolowsky, E., Saito, T., Santoro, F., Schruba, A., Sormani, M. C., Williams, T. G. (2021) "Dense molecular gas properties on 100 pc scales across the disc of NGC 3627", Monthly Notices of the Royal Astronomical Society, 506, 963.
17. Bland-Hawthorn, J., Tepper-García, T. (2021) "Galactic seismology: the evolving 'phase spiral' after the Sagittarius dwarf impact", Monthly Notices of the Royal Astronomical Society, 504, 3168.
18. Bollig, R., Yadav, N., Kresse, D., Janka, H.-T., Müller, B., Heger, A. (2021) "Self-consistent 3D Supernova Models From -7 Minutes to +7 s: A 1-bethe Explosion of a 19 M Progenitor", The Astrophysical Journal, 915, 28.
19. Bonaldi, A., An, T., Brüggen, M., Burkutean, S., Coelho, B., Goodarzi, H., Hartley, P., Sandhu, P. K., Wu, C., Yu, L., Zhoolideh Haghighi, M. H., Antón, S., Bagheri, Z., Barbosa, D., Barraca, J. P., Bartashevich, D., Bergano, M., Bonato, M., Brand, J., de Gasperin, F., Giannetti, A., Dodson, R., Jain, P., Jaiswal, S., Lao, B., Liu, B., Liuzzo, E., Lu, Y., Lukic, V., Maia, D., Marchili, N., Massardi, M., Mohan, P., Morgado, J. B., Panwar, M., Prabhakar, P., Ribeiro, V. A. R. M., Rygl, K. L. J., Sabz Ali, V., Saremi, E., Schisano, E., Sheikhnezami, S., Vafaei Sadr, A., Wong, A., Wong, O. I. (2021) "Square Kilometre Array Science Data Challenge 1: analysis and results", Monthly Notices of the Royal Astronomical Society, 500, 3821.
20. Bose, S., Dong, S., Kochanek, C. S., Stritzinger, M. D., Ashall, C., Benetti, S., Falco, E., Filippenko, A. V., Pastorello, A., Prieto, J. L., Somero, A., Sukhbold, T., Zhang, J., Auchettl, K., Brink, T. G., Brown, J. S., Chen, P., Fiore, A., Grupe, D., Holoien, T. W.-S., Lundqvist, P., Mattila, S., Mutel, R., Pooley, D., Post, R. S., Reddy, N., Reynolds, T. M., Shappee, B. J., Stanek, K. Z., Thompson, T. A., Villanueva, S., Zheng, W. (2021) "ASASSN-18am/SN 2018gk: an overluminous Type IIb supernova from a massive progenitor", Monthly Notices of the Royal Astronomical Society, 503, 3472.
21. Brown, T., Wilson, C. D., Zabel, N., Davis, T. A., Boselli, A., Chung, A., Ellison, S. L., Lagos, C. D. P., Stevens, A. R. H., Cortese, L., Bahé, Y. M., Bisaria, D., Bolatto, A. D., Cashmore, C. R., Catinella, B., Chown, R., Diemer, B., Elahi, P. J., Hani, M. H., Jiménez-Donaire, M. J., Lee, B., Leidig, K., Mok, A., Olsen, K. P., Parker, L. C., Roberts, I. D., Smith, R., Spekkens, K., Thorp, M., Tonnesen, S., Vienneau, E., Villanueva, V., Vogel, S. N., Wadsley, J., Welker, C., Yoon, H. (2021) "VERTICO: The Virgo Environment Traced in CO Survey", The Astrophysical Journal Supplement Series, 257, 21.
22. Buck, T., Rybizki, J., Buder, S., Obreja, A., Macciò, A. V., Pfrommer, C., Steinmetz, M., Ness, M. (2021) "The challenge of simultaneously matching the observed diversity of chemical abundance patterns in cosmological hydrodynamical simulations", Monthly Notices of the Royal Astronomical Society, 508, 3365.
23. Buder, S., Sharma, S., Kos, J., Amarsi, A. M., Nordlander, T., Lind, K., Martell, S. L., Asplund, M., Bland-Hawthorn, J., Casey, A. R., de Silva, G. M., D'Orazi, V., Freeman, K. C., Hayden, M. R., Lewis, G. F., Lin, J., Schlesinger, K. J., Simpson, J. D., Stello, D., Zucker, D. B., Zwitter, T., Beeson, K. L., Buck, T., Casagrande, L., Clark, J. T., Čotar, K., da Costa, G. S., de Grijs, R., Feuillet, D., Horner, J., Kafle, P. R., Khanna, S., Kobayashi, C., Liu, F., Montet, B. T., Nandakumar, G., Nataf, D. M., Ness, M. K., Spina, L., Tepper-García, T., Ting, Y.-S., Traven, G., Vogrinčič, R., Wittenmyer, R. A., Wyse, R. F. G., Žerjal, M., GALAH Collaboration (2021) "The GALAH+ survey: Third data release", Monthly Notices of the Royal Astronomical Society, 506, 150. (Figure 2)

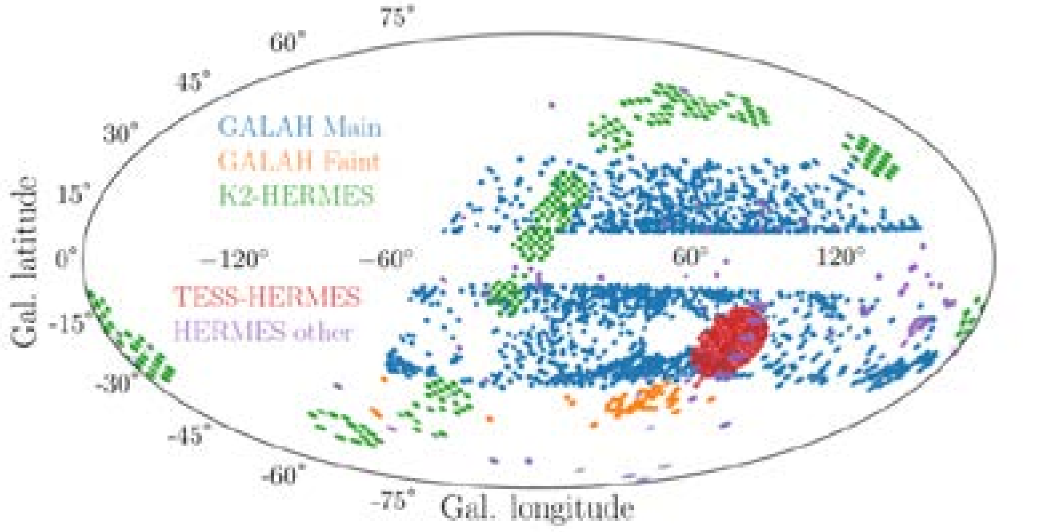

Figure 2. Publication No. 23 Overview of the distribution of stars included in this data release in Galactic coordinates with the centre of the Galaxy at the origin. Shown are the GALAH main (blue) and faint (orange) targets, which avoid the Galactic plane. The targets of the K2-HERMES follow-up (green) fall within with the K2 campaigns along the ecliptic and show the characteristic tile-pattern of the Kepler telescope. The TESS-HERMES observations (red) are focused on the TESS Southern Continuous Viewing Zone. Other HERMES targets (purple) are distributed across the sky and were observed during independent programs.

24. Calette, A. R., Avila-Reese, V., Rodríguez-Puebla, A., Lagos, C. del P., Catinella, B. (2021) "The H I and stellar mass bivariate distribution of centrals and satellites for all, late-, and early-type local galaxies", Monthly Notices of the Royal Astronomical Society, 505, 304.

25. Calette, A. R., Avila-Reese, V., Rodríguez-Puebla, A., Lagos, C. del P. (2021) "The galaxy H I-(sub)halo connection and the H I spatial clustering of local galaxies", Monthly Notices of the Royal Astronomical Society, 506, 1507.

26. Callanan, D., Longmore, S. N., Kruijssen, J. M. D., Schruba, A., Ginsburg, A., Krumholz, M. R., Bastian, N., Alves, J., Henshaw, J. D., Knapen, J. H., Chevance, M. (2021) "The centres of M83 and the Milky Way: opposite extremes of a common star formation cycle", Monthly Notices of the Royal Astronomical Society, 505, 4310.

27. Cameron, A. J., Fisher, D. B., McPherson, D., Kacprzak, G. G., Berg, D. A., Bolatto, A., Chisholm, J., Herrera-Camus, R., Nielsen, N. M., Reichardt Chu, B., Rickards Vaught, R. J., Sandstrom, K., Trenti, M. (2021) "The DUVET Survey: Direct Te-based Metallicity Mapping of Metal-enriched Outflows and Metal-poor Inflows in Markarian 1486", The Astrophysical Journal, 918, L16.

28. Cameron, A. J., Yuan, T., Trenti, M., Nicholls, D. C., Kewley, L. J. (2021) "Spatially resolved direct method metallicity in a high-redshift analogue local galaxy: temperature structure impact on metallicity gradients", Monthly Notices of the Royal Astronomical Society, 501, 3695.

29. Casagrande, L., Lin, J., Rains, A. D., Liu, F., Buder, S., Horner, J., Asplund, M., Lewis, G. F., Martell, S. L., Nordlander, T., Stello, D., Ting, Y.-S., Wittenmyer, R. A., Bland-Hawthorn, J., Casey, A. R., De Silva, G. M., D'Orazi, V., Freeman, K. C., Hayden, M. R., Kos, J., Lind, K., Schlesinger, K. J., Sharma, S., Simpson, J. D., Zucker, D. B., Zwitter, T. (2021) "The GALAH survey: effective temperature calibration from the InfraRed Flux Method in the Gaia system", Monthly Notices of the Royal Astronomical Society, 507, 2684.

30. Casey, A. R., Ji, A. P., Hansen, T. T., Li, T. S., Koposov, S. E., Da Costa, G. S., Bland-Hawthorn, J., Cullinane, L., Erkal, D., Lewis, G. F., Kuehn, K., Mackey, D., Martell, S. L., Pace, A. B., Simpson, J. D., Zucker, D. B. (2021) "Signature of a Massive Rotating Metal-poor Star Imprinted in the Phoenix Stellar Stream", The Astrophysical Journal, 921, 67.

31. Casey, C. M., Zavala, J. A., Manning, S. M., Aravena, M., Béthermin, M., Caputi, K. I., Champagne, J. B., Clements, D. L., Drew, P., Finkelstein, S. L., Fujimoto, S., Hayward, C. C., Dekel, A. M., Kokorev, V., Lagos, C. del P., Long, A. S., Magdis, G. E., Man, A. W. S., Mitsuhashi, I., Popping, G., Spilker, J., Staguhn, J., Talia, M., Toft, S., Treister, E., Weaver, J. R., Yun, M. (2021) "Mapping Obscuration to Reionization with ALMA (MORA): 2 mm Efficiently Selects the Highest-redshift Obscured Galaxies", The Astrophysical Journal, 923, 215.

32. Cecil, G., Wagner, A. Y., Bland-Hawthorn, J., Bicknell, G. V., Mukherjee, D. (2021) "Tracing the Milky Way's Vestigial Nuclear Jet", The Astrophysical Journal, 922, 254.

33. Chauhan, G., Lagos, C. del P., Stevens, A. R. H., Bravo, M., Rhee, J., Power, C., Obreschkow, D., Meyer, M. (2021) "Unveiling the atomic hydrogen-halo mass relation via spectral stacking", Monthly Notices of the Royal Astronomical Society, 506, 4893.

34. Chauhan, G., Lagos, C. del P., Stevens, A. R. H., Obreschkow, D., Power, C., Meyer, M. (2021) "Erratum: The physical drivers of the atomic hydrogen-halo mass relation", Monthly Notices of the Royal Astronomical Society, 503, 2763.

35. Chege, J. K., Jordan, C. H., Lynch, C., Line, J. L. B., Trott, C. M. (2021) "Simulations of ionospheric refraction on radio interferometric data", Publications of the Astronomical Society of Australia, 38, e028.

36. Chen, Q., Meyer, M., Popping, A., Staveley-Smith, L. (2021) "Interferometric cubelet stacking to recover H I emission from distant galaxies", Monthly Notices of the Royal Astronomical Society, 502, 2308.

37. Chen, Q., Meyer, M., Popping, A., Staveley-Smith, L., Bryant, J., Delhaize, J., Holwerda, B. W., Cluver, M. E., Loveday, J., Lopez-Sanchez, A. R., Zwaan, M., Taylor, E. N., Hopkins, A. M., Wright, A., Driver, S., Brough, S. (2021) "Measuring cosmic density of neutral hydrogen via stacking the DINGO-VLA data", Monthly Notices of the Royal Astronomical Society, 508, 2758.

38. Chokshi, A., Line, J. L. B., Barry, N., Ung, D., Kenney, D., McPhail, A., Williams, A., Webster, R. L. (2021) "Dual polarization measurements of MWA beampatterns at 137 MHz", Monthly Notices of the Royal Astronomical Society, 502, 1990. Figure 3

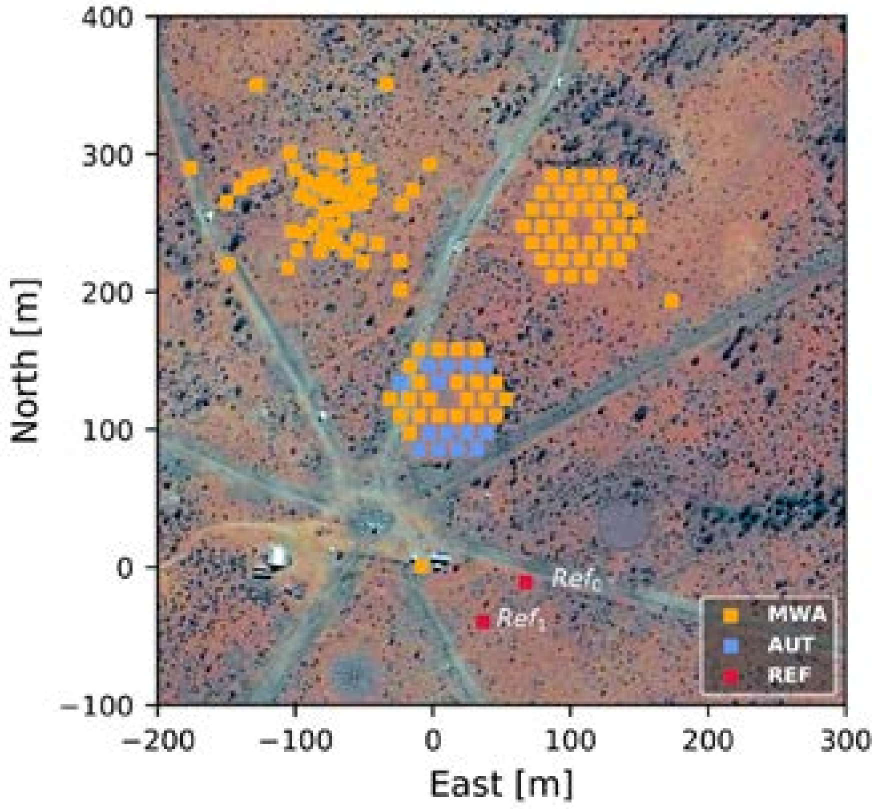

Figure 3: Publication no. 38 - The positions of the AUTs (blue) and the Reference antennas (red). The ochre points represent the rest of the compact core of the MWA.

39. Clark, J. T., Clerté, M., Hinkel, N. R., Unterborn, C. T., Wittenmyer, R. A., Horner, J., Wright, D. J., Carter, B., Morton, T. D., Spina, L., Asplund, M., Buder, S., Bland-Hawthorn, J., Casey, A., De Silva, G., D'Orazi, V., Duong, L., Hayden, M., Freeman, K., Kos, J., Lewis, G., Lin, J., Lind, K., Martell, S., Sharma, S., Simpson, J., Zucker, D., Zwitter, T., Tinney, C. G., Ting ( ), Y.-S., Nordlander, T., Amarsi, A. M. (2021) "The GALAH Survey: using galactic archaeology to refine our knowledge of TESS target stars", Monthly Notices of the Royal Astronomical Society, 504, 4968.

40. Cordoni, G., Da Costa, G. S., Yong, D., Mackey, A. D., Marino, A. F., Monty, S., Nordlander, T., Norris, J. E., Asplund, M., Bessell, M. S., Casey, A. R., Frebel, A., Lind, K., Murphy, S. J., Schmidt, B. P., Gao, X. D., Xylakis-Dornbusch, T., Amarsi, A. M., Milone, A. P. (2021) "Exploring the Galaxy's halo and very metal-weak thick disc with SkyMapper and Gaia DR2", Monthly Notices of the Royal Astronomical Society, 503, 2539.

41. Cortese, L., Catinella, B., Smith, R. (2021) "The Dawes Review 9: The role of cold gas stripping on the star formation quenching of satellite galaxies", Publications of the Astronomical Society of Australia, 38, e035.

42. Crocker, R. M., Krumholz, M. R., Thompson, T. A. (2021) "Cosmic rays across the star-forming galaxy sequence - I. Cosmic ray pressures and calorimetry", Monthly Notices of the Royal Astronomical Society, 502, 1312.

43. Croft, R. A. C. (2021) "Direct geometrical measurement of the Hubble constant from galaxy parallax: predictions for the Vera C. Rubin Observatory and Nancy Grace Roman Space Telescope", Monthly Notices of the Royal Astronomical Society, 501, 2688.

44. Croom, S. M., Owers, M. S., Scott, N., Poetrodjojo, H., Groves, B., van de Sande, J., Barone, T. M., Cortese, L., D'Eugenio, F., Bland-Hawthorn, J., Bryant, J., Oh, S., Brough, S., Agostino, J., Casura, S., Catinella, B., Colless, M., Cecil, G., Davies, R. L., Drinkwater, M. J., Driver, S. P., Ferreras, I., Foster, C., Fraser-McKelvie, A., Lawrence, J., Leslie, S. K., Liske, J., López-Sánchez, Á. R., Lorente, N. P. F., McElroy, R., Medling, A. M., Obreschkow, D., Richards, S. N., Sharp, R., Sweet, S. M., Taranu, D. S., Taylor, E. N., Tescari, E., Thomas, A. D., Tocknell, J., Vaughan, S. P. (2021) "The SAMI Galaxy Survey: the third and final data release", Monthly Notices of the Royal Astronomical Society, 505, 991.

45. Croom, S. M., Taranu, D. S., van de Sande, J., Lagos, C. D. P., Harborne, K. E., Bland-Hawthorn, J., Brough, S., Bryant, J. J., Cortese, L., Foster, C., Goodwin, M., Groves, B., Khalid, A., Lawrence, J., Medling, A. M., Richards, S. N., Owers, M. S., Scott, N., Vaughan, S. P. (2021) "The SAMI Galaxy Survey: the role of disc fading and progenitor bias in kinematic transitions", Monthly Notices of the Royal Astronomical Society, 505, 2247. Figure 4.

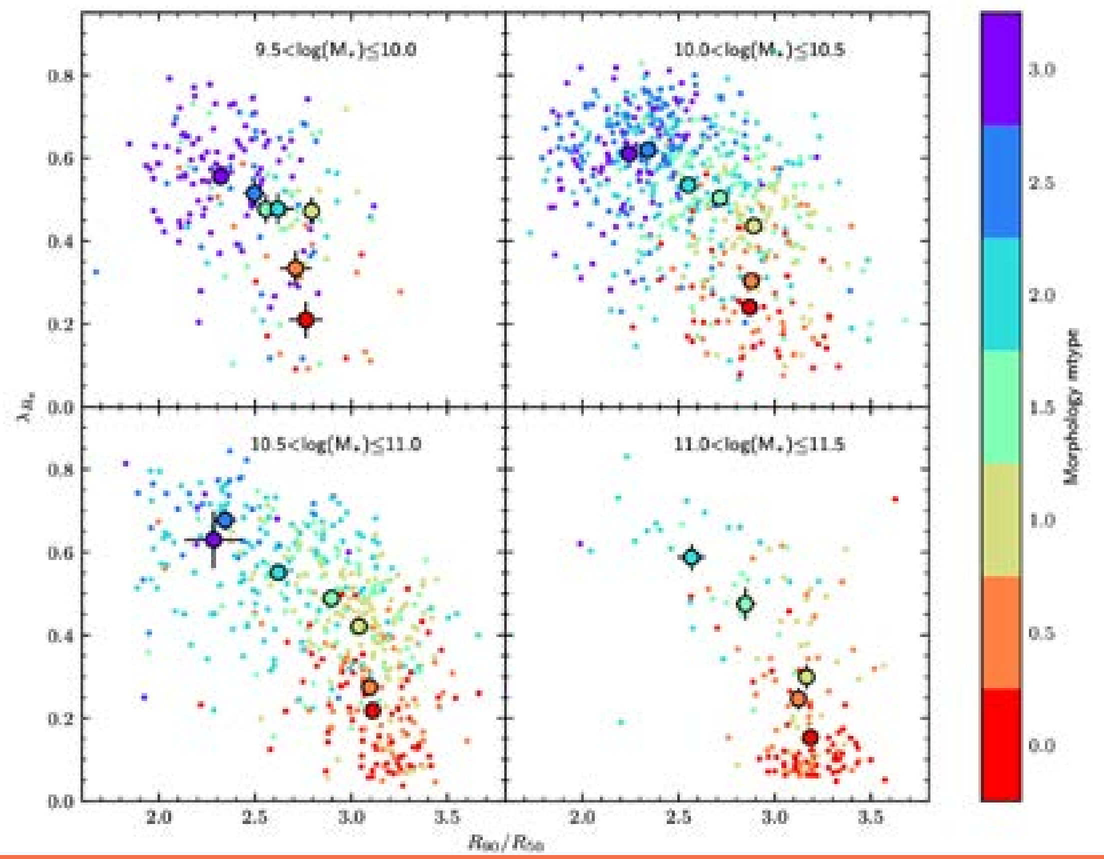

Figure 4: Publication no. 45 - The distribution of our SAMI galaxies in the λ_R–concentration plane (corrected for seeing effects). Galaxies are separated into 0.5 dex intervals of stellar mass and then colour–coded by morphology (small points) from mtype=0 (ellipticals, red points) to mtype=3 (late spirals, purple points). The large points show the mean λ_R and concentration values for each morphology, and are only plotted when there are at least 5 galaxies to average. The error bars on the large points show the error on the mean and are often smaller than the points.

46. D'Eugenio, F., Colless, M., Scott, N., van der Wel, A., Davies, R. L., van de Sande, J., Sweet, S. M., Oh, S., Groves, B., Sharp, R., Owers, M. S., Bland-Hawthorn, J., Croom, S. M., Brough, S., Bryant, J. J., Goodwin, M., Lawrence, J. S., Lorente, N. P. F., Richards, S. N. (2021) "The SAMI Galaxy Survey: stellar population and structural trends across the Fundamental Plane", Monthly Notices of the Royal Astronomical Society, 504, 5098.

47. da Cunha, E., Hodge, J. A., Casey, C. M., Algera, H. S. B., Kaasinen, M., Smail, I., Walter, F., Brandt, W. N., Dannerbauer, H., Decarli, R., Groves, B. A., Knudsen, K. K., Swinbank, A. M., Weiss, A., van der Werf, P., Zavala, J. A. (2021) "Measurements of the Dust Properties in z 1-3 Submillimeter Galaxies with ALMA", The Astrophysical Journal, 919, 30.

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PUBLICATIONS

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50. Davies, R. L., Förster Schreiber, N. M., Genzel, R., Shimizu, T. T., Davies, R. I., Schruba, A., Tacconi, L. J., Übler, H., Wisnioski, E., Wuyts, S., Fossati, M., Herrera-Camus, R., Lutz, D., Mendel, J. T., Naab, T., Price, S. H., Renzini, A., Wilman, D., Beifiori, A., Belli, S., Burkert, A., Chan, J., Contursi, A., Fabricius, M., Lee, M. M., Saglia, R. P., Sternberg, A. (2021) "The KMOS3D Survey: Investigating the Origin of the Elevated Electron Densities in Star-forming Galaxies at 1 z 3", The Astrophysical Journal, 909, 78.

51. de Graaff, A., Bezanson, R., Franx, M., van der Wel, A., Holden, B., van de Sande, J., Bell, E. F., D'Eugenio, F., Maseda, M. V., Muzzin, A., Sobral, D., Straatman, C. M. S., Wu, P.-F. (2021) "The Fundamental Plane in the LEGA-C Survey: Unraveling the M/L Ratio Variations of Massive Star-forming and Quiescent Galaxies at z 0.8", The Astrophysical Journal, 913, 103.

52. Deeley, S., Drinkwater, M. J., Sweet, S. M., Bekki, K., Couch, W. J., Forbes, D. A., Dolfi, A. (2021) "The two formation pathways of S0 galaxies", Monthly Notices of the Royal Astronomical Society, 508, 895.

53. Derkenne, C., McDermid, R. M., Poci, A., Remus, R.-S., Jørgensen, I., Emsellem, E. (2021) "Total mass density slopes of early-type galaxies using Jeans dynamical modelling at redshifts 0.29 < z < 0.55", Monthly Notices of the Royal Astronomical Society, 506, 3691.

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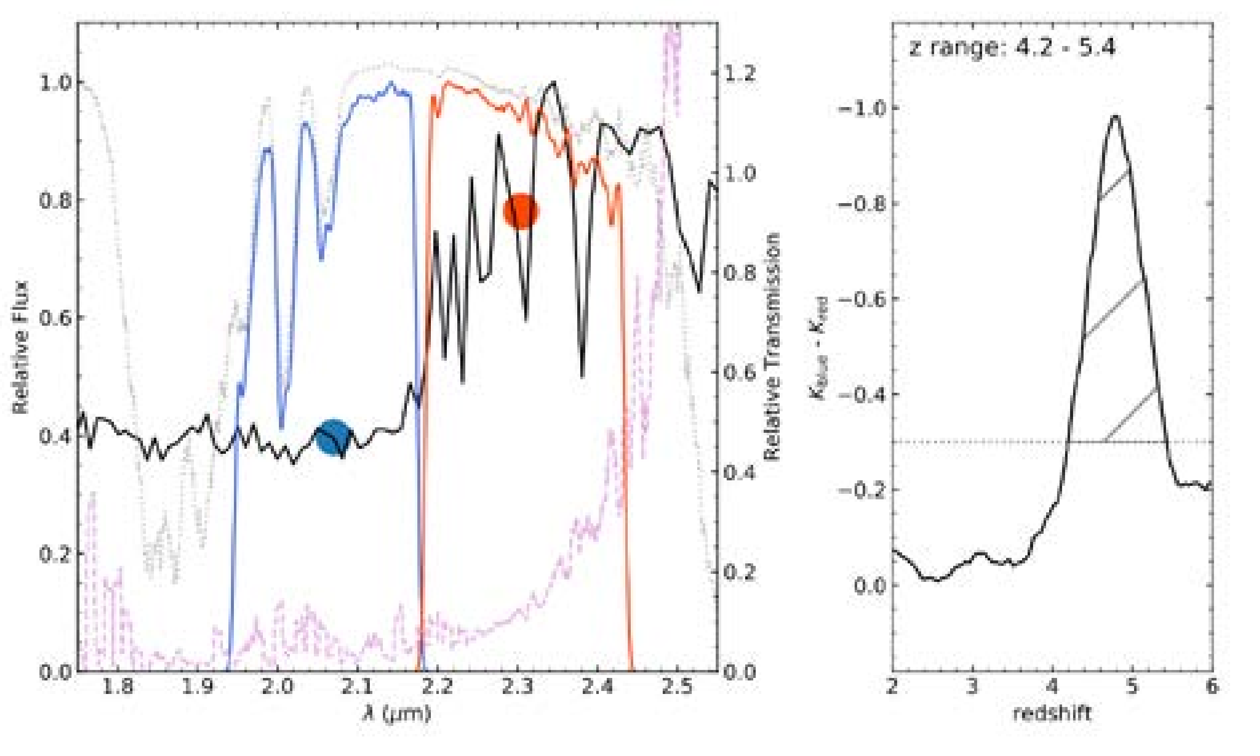

Figure 5: Publication no. 59 - Filter design simulation for the dual filter set- up. Left panel: K_{blue} and K_{red} filters, including atmospheric absorption (shown in blue and red respectively). Black solid line is the fiducial 0.4 Gyr SSP model SED at z = 4.6. The mauve dashed line is the Cerro Pacho´n background + tele- scope emission spectrum and the gray dotted line is the at- mospheric transmission for a 2.3 mm water vapour column. Red and blue dots are the synthetic photometry for K_{blue} and K_{red} respectively. Right panel: K_{blue} - K_{red} color as a function of redshift. The solid line is the predicted color as our model SED is redshifted from 2 to 6. The horizontal dashed line shows the 3σ color threshold used to approximate the redshift range probed by the filter configuration.

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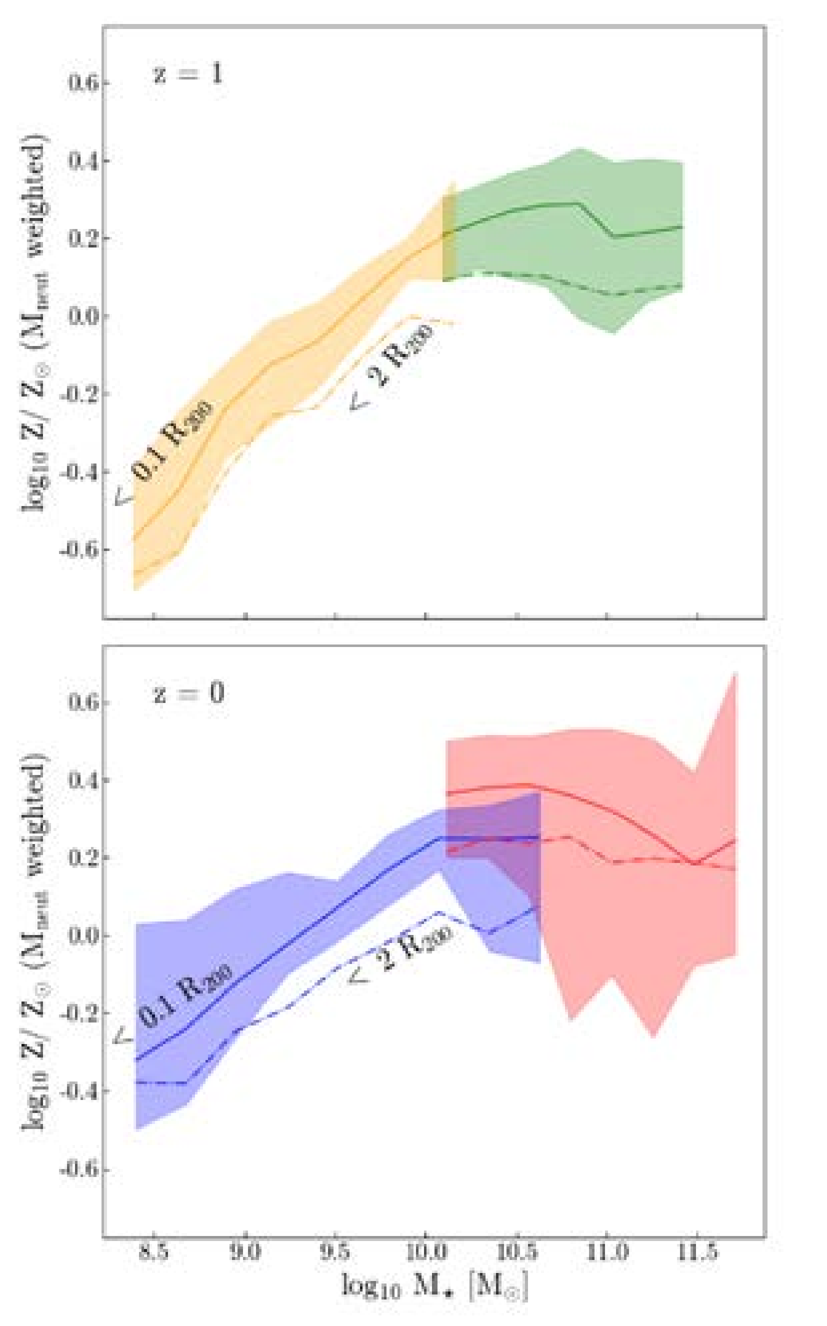

Figure 6: Publication no. 75 - The mean metallicity, weighted by the neutral gas mass M_{neut}, calculated for all gas below 2 radii; 0.1 R_{200c} (solid lines) and 2 R200c (dot- dashed lines) as a function of stellar mass, for galaxies in the RefL0100 (blue/ green) and RecalL0025 (red/ orange) EAGLE simulations at Z = 1 (upper plot) and Z = 0 (lower plot). The shaded areas show the 84th – 16th percentile range.

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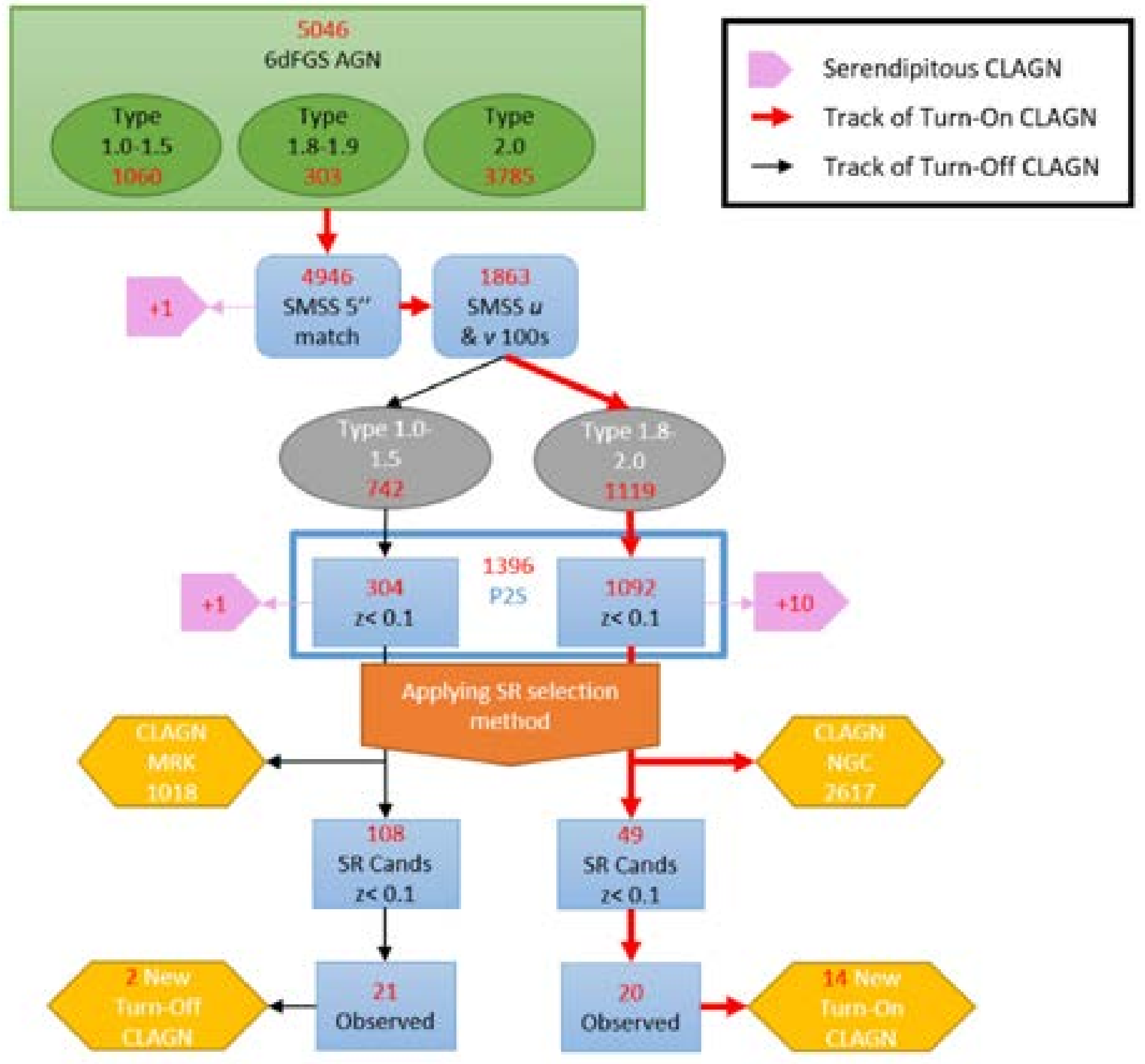

Figure 7: Publication no. 96 - Flowchart of the Paper II sample (P2S) sample, breaking down candidate selection, and observed targets. Starting with the green box as the breakdown of the 6dF AGN catalogue in terms of Seyfert types. The subsequent two blue boxes are the number of targets left after cross-matching with SkyMapper Southern Survey (SMSS), (refer to Section 2.6 of the publication).

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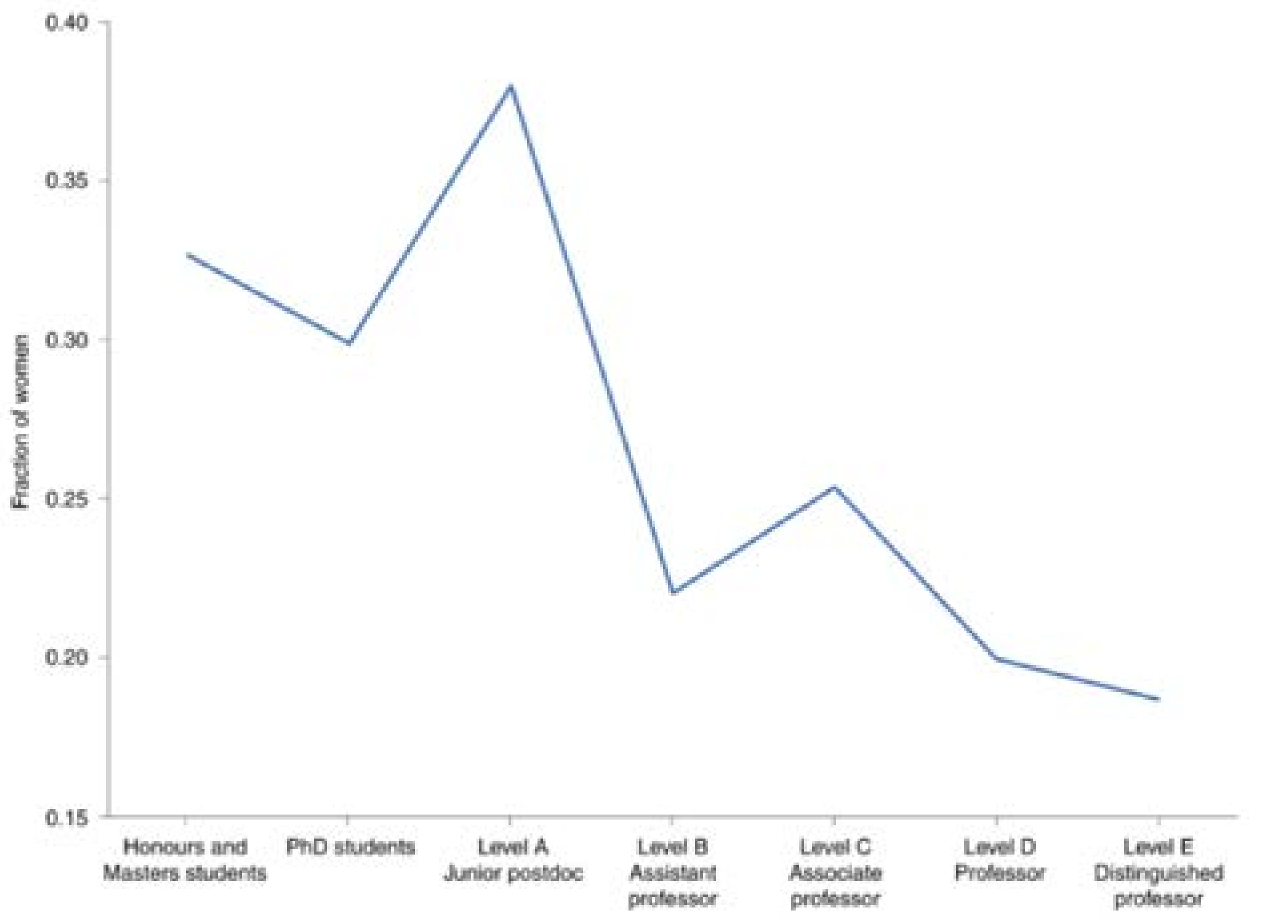

Figure 8: Publication no. 116 - The fractions encompass all contract and permanent staff in Australian astronomy in December 2019. Levels A–E correspond to postdoc, assistant professor, associate professor, professor and distinguished professor in the US system. Source data

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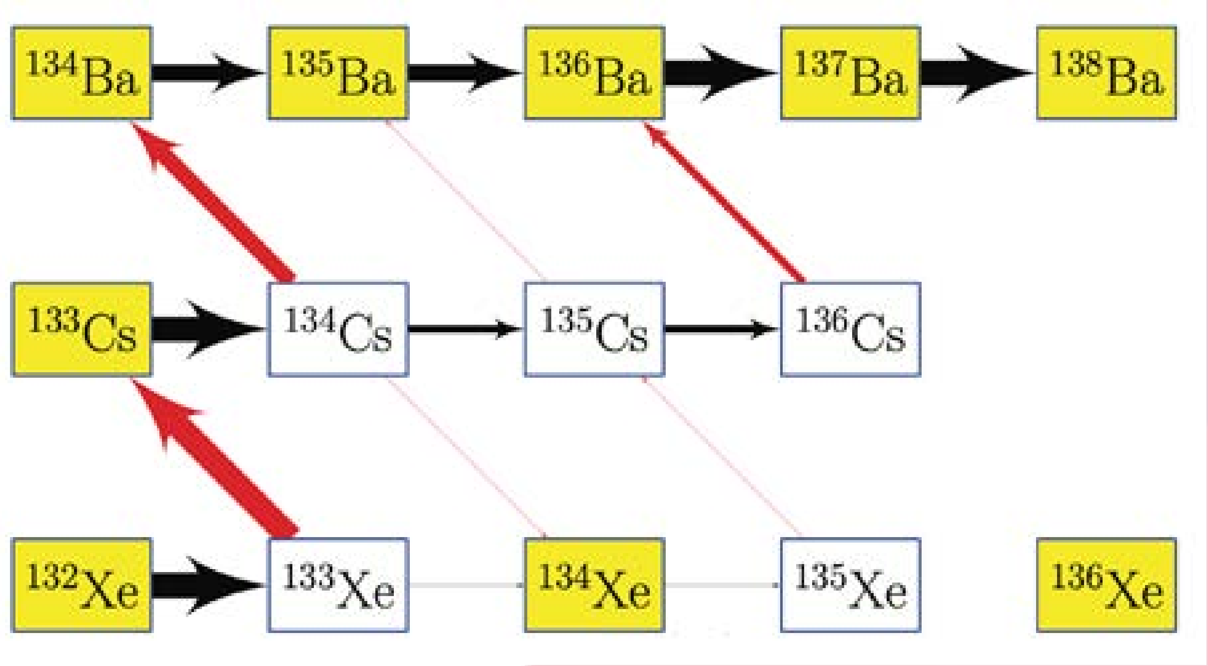

Figure 9: Publication no. 125 - The s-process path at the vicinity of ^{134}Cs at T = 0.35 GK (kT = 30 keV) generated by the NUCNET code (Bojazi & Meyer 2014). The red lines present β-decay, while the black lines present the neutron capture. Line width indicates the flow current in linear scale. The stable nuclei are marked with yellow color.

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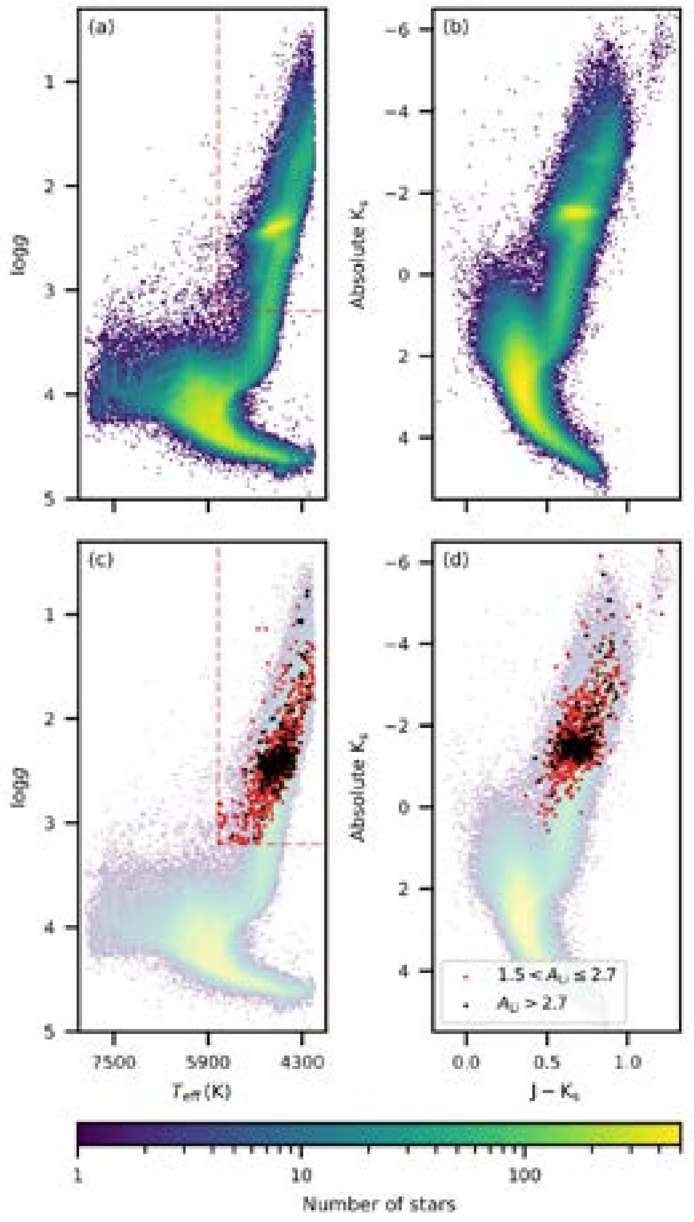

Figure 10: Publication no. 138 - Kiel diagrams (left column) and absolute colour-magnitude diagrams (right column) for the “good” sample (i.e., no flagged problems) of stars considered in this work.

The dashed red rectangle in (a) and (c) shows the T_{eff}, log g selection used to identify giant stars. In the bottom row (c, d) we highlight giant stars with ALi > [1.5, 2.7], using red and black points respectively. This shows that Li-rich giants are found at all parts of the giant branch, but the very Li-enhanced stars (ALi > 2.7) tend to be found in the red clump region.

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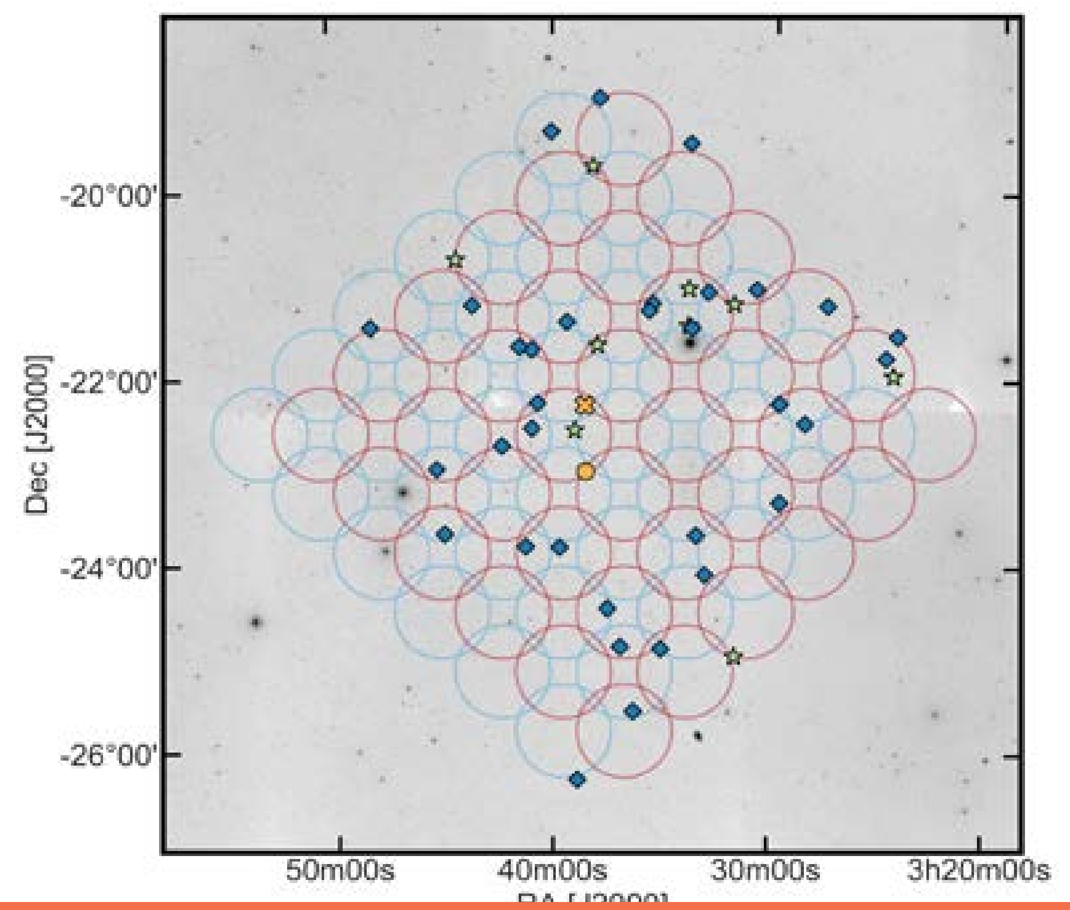

Figure 11: Publication no. 157 - Footprints A (light blue) and B (red), overlaid on DSS image of the Eridanus field. The blue diamond points denote the Eridanus galaxies, while the background galaxies are represented by the green stars. The yellow circle represents the central large elliptical NGC 1395 of the Eridanus sub-group, while the yellow cross marks the centroid of the Eridanus sub-group derived by Brough et al. (2006), using a friends-of-friends group-finding algorithm.

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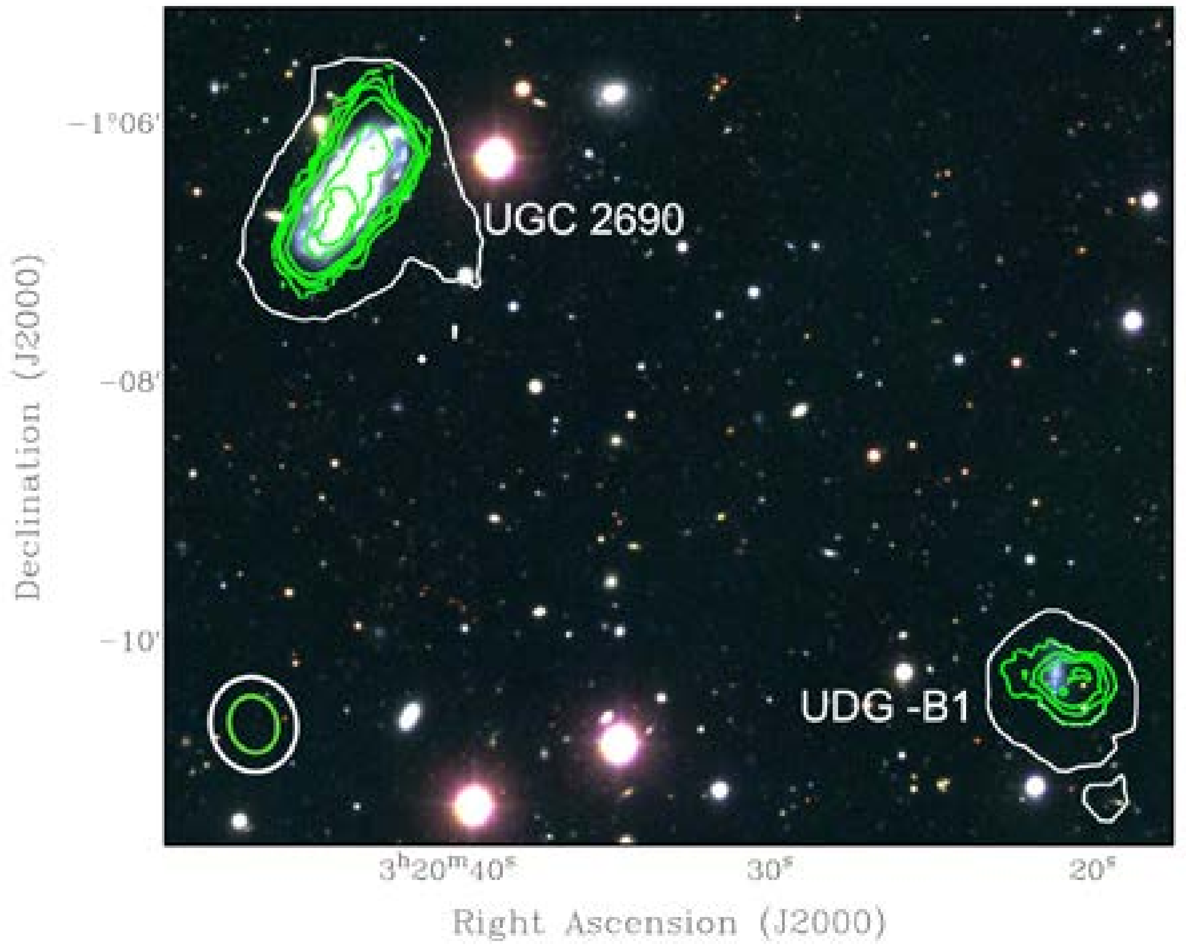

Figure 12: Publication no 204 - Wide–angle region SW of HCG 25 with the GMRT low resolution (44.82″ × 40.48″) H i contour (white) at 0.39 × 1020 atoms cm−2 and medium resolution (26.46″ × 22.65″) Hi contours (green) at 1.46, 2.73, 3.6, 5.5 11.0 and 13.8 × 1020 atoms cm−2. These contours are overlaid on an IAC stripe 82 composite g,r, i image showing H i detections in UGC 2690 and UDG –B1. The ellipses at the bottom left indicate the size and orientation of the GMRT synthesized beams.

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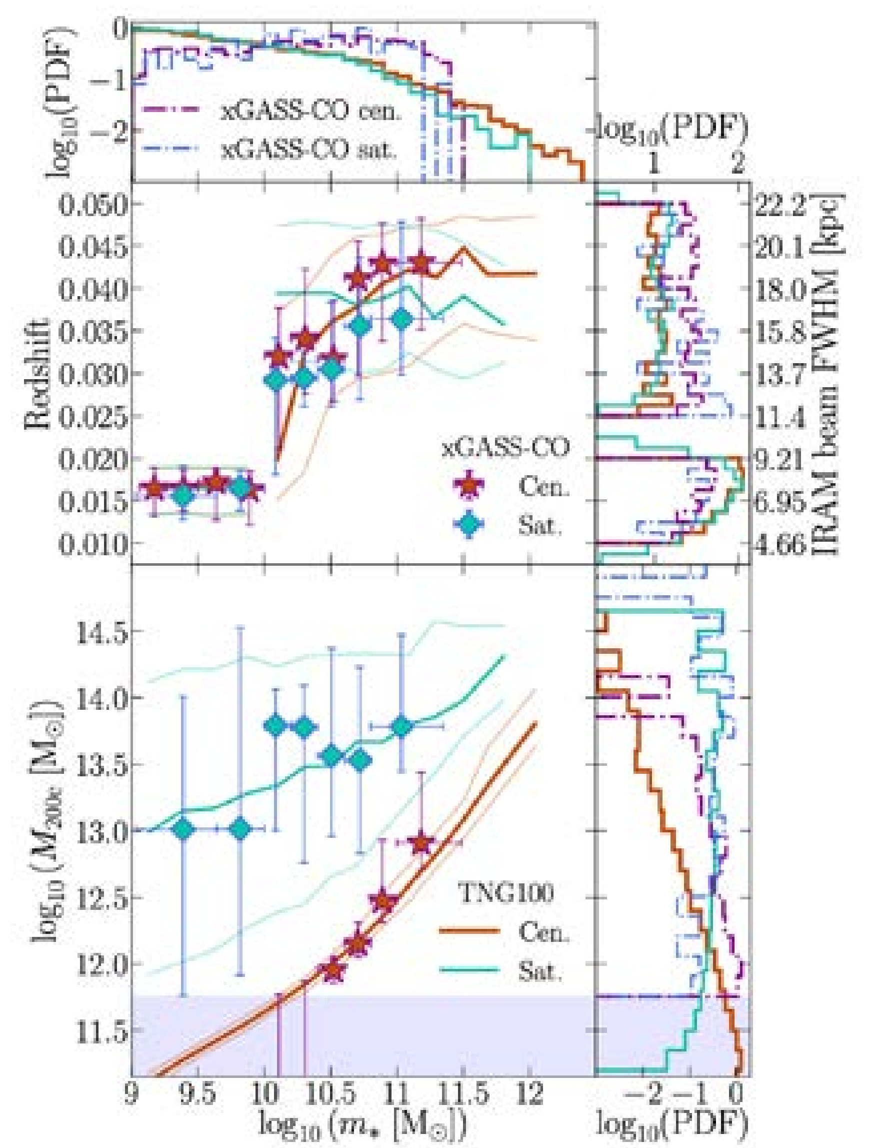

Figure 13: Publication no. 221 - Distributions of stellar masses, parent halo masses, and redshifts of galaxies used in this work, split into centrals and satel- lites. Points and thick lines in the main panels are respective medians for xGASS-CO and the ‘mock observed’ TNG100 galaxies. Thin lines and vertical error bars give the correspond- ing 16th and 84th percentiles. Horizontal error bars for xGASS- CO points cover the full bin width. For each marked redshift, the equivalent physical scale on which H2 masses are measured is given on the right-hand side (FWHM = full width at half-maximum). Smaller panels give the one-dimensional projected probability dis- tribution functions (PDFs) along each axis. The shaded region in the bottom panels is where halo masses are not explicitly com- puted for xGASS-CO galaxies. For this reason, points for xGASS- CO centrals drop off at low stellar masses; there do exist galaxies at those masses, but they cannot meaningfully be shown on these axes.

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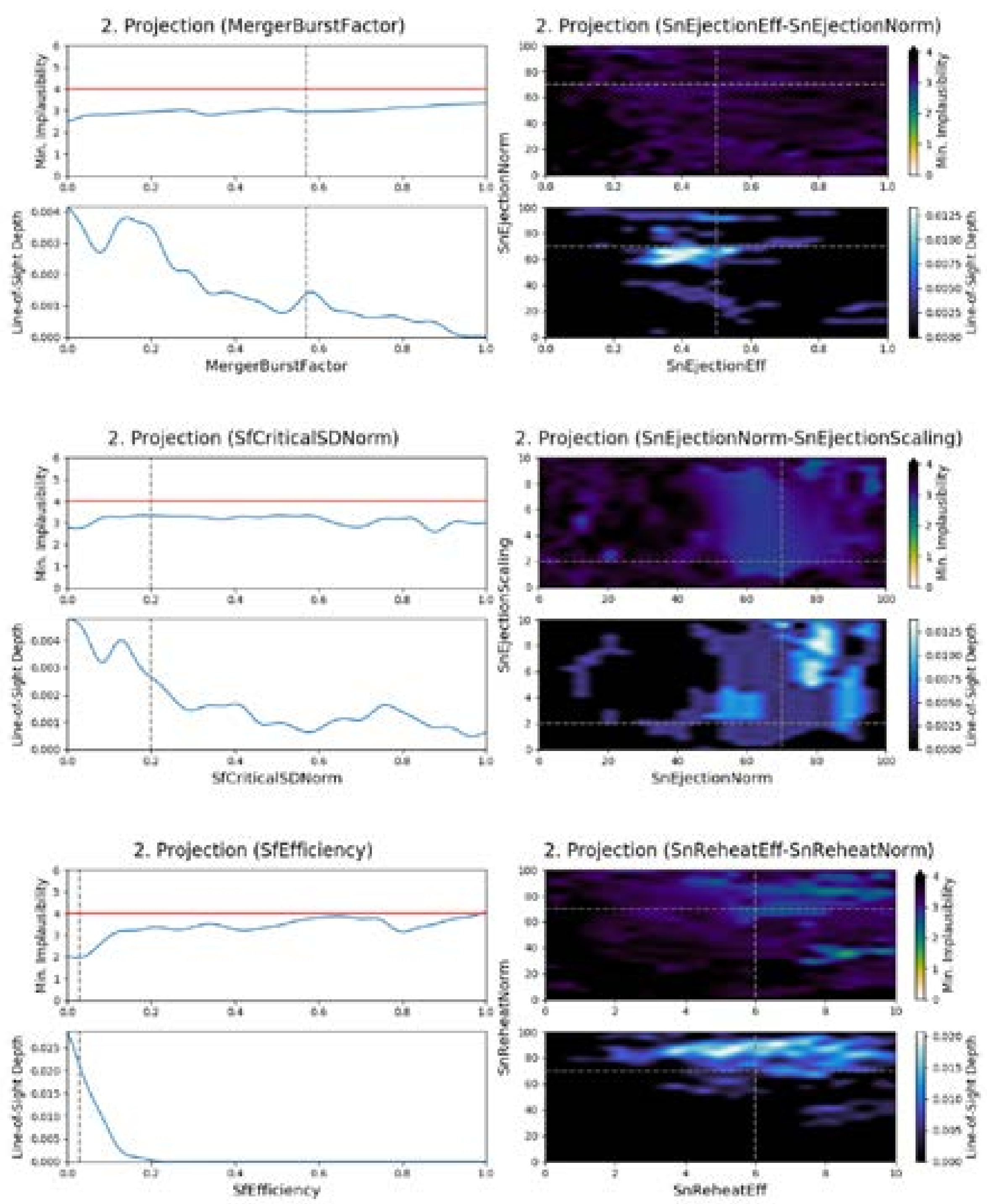

Figure 14: Publication no. 237 - Projection figures of the Meraxes emulator using SMF data at iteration i_{emul} = 2. The dashed lines show the estimated value of the corresponding parameter as given in Tab. 1. Left: Three 2D projection figures showing the behavior of the parameters related to the star formation. Right: Three 3D projection figures showing the behavior of and correlations between the parameters related to the supernova feedback.

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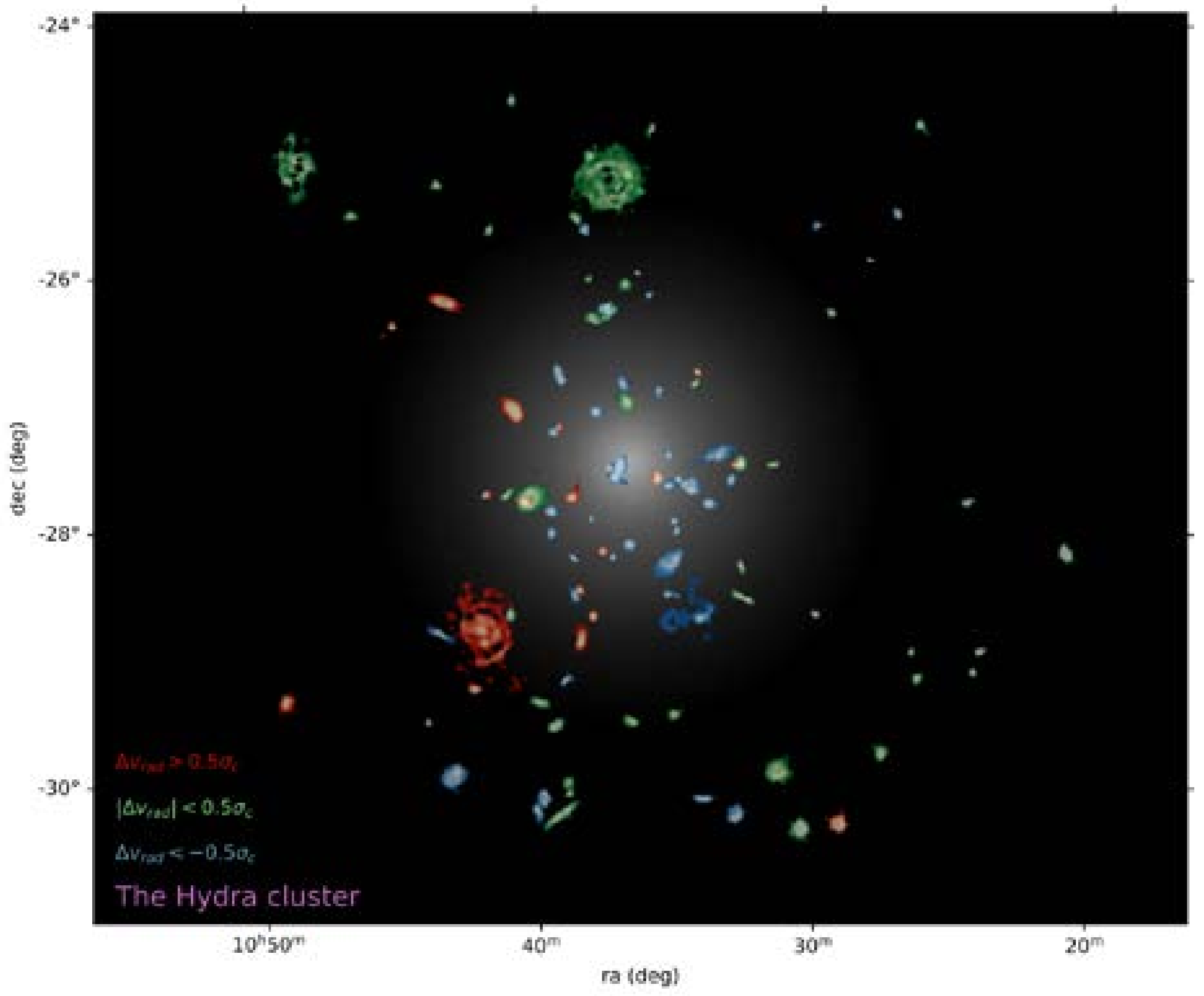

Figure 15: Publication no. 241 - WALLABY detected galaxies in the Hydra cluster. The frame is $5.5r_{200}$ in width and $4.5r_{200}$ in height, where r_{200} is the cluster centric radius where the enclosed averaged density is 200 times the cosmological critical density. The Hi column density images are shown in different slices of velocity offset from the cluster center (Δv_{rad}) around the X-ray halo of Hydra (grey scale, based on the ICM model described in Sec.2.2). The column density images are enlarged by a factor of 5 for clarity. A similar image has been shown for the Virgo Cluster by (Chung et al. 2009) using targeted HI observations.

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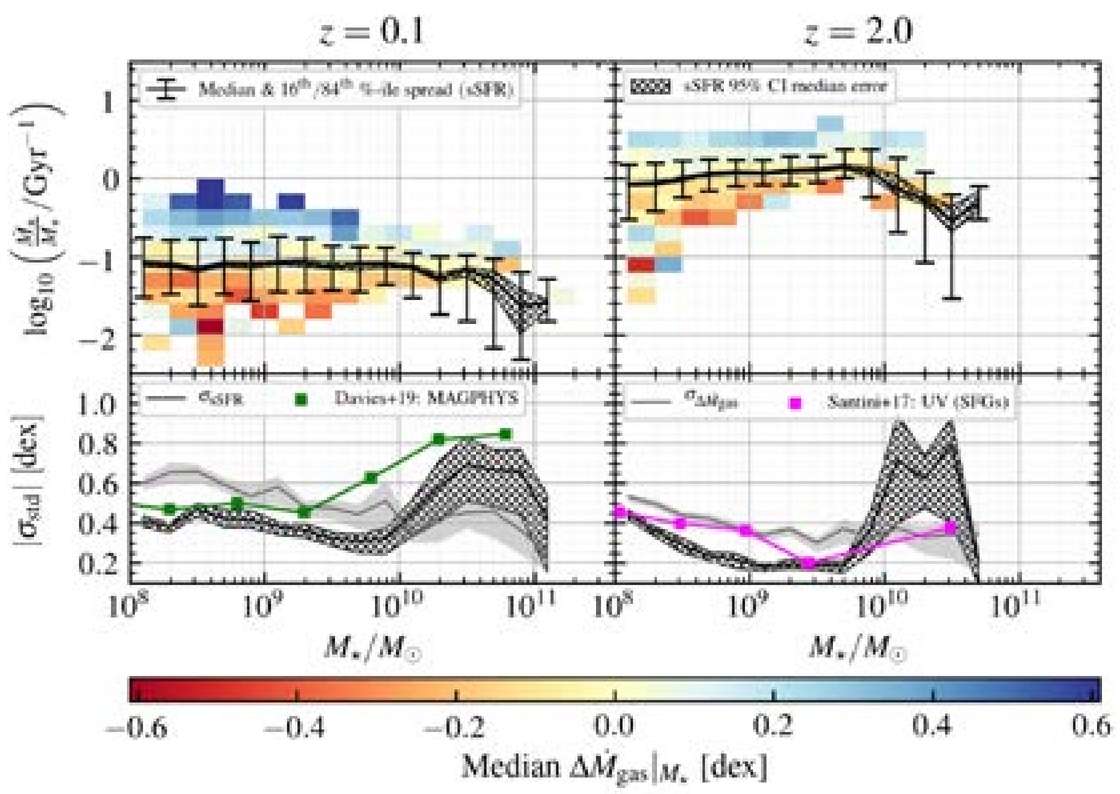

Figure 16: Publication no. 251 - Top panels: The specific star formation rate (sSFR; $M_\star/M_\star$) - stellar mass plane, coloured by excess gas accretion efficiency ($\Delta\dot{M}_{gas}$). The bins in sSFR are spaced in increments of 0.2 dex. Bottom panels: The standard deviation in sSFR as a function of stellar mass (black) together with observational constraints from Santini et al. (2017) at z ≈ 2 and Davies et al. (2019a) at z ≈ 0. In the bottom panels, we also include the standard deviation in excess gas accretion rate at fixed stellar mass (grey). Left panels correspond to a selection at z ≈ 0, while right panels correspond to a selection at z ≈ 2. Error bars show the 16th – 84th percentile range in sSFR. In the top panels, hatched regions show the bootstrap-generated 95% confidence interval error on the sSFR median, while in the bottom panels, the hatched regions show the bootstrap-generated 95% confidence interval error on the sSFR standard deviation (σ). Similarly, the grey shaded regions in the bottom panels show the bootstrap-generated 95% confidence interval error on $\sigma\Delta\dot{M}_{gas}$ as a function of stellar mass.

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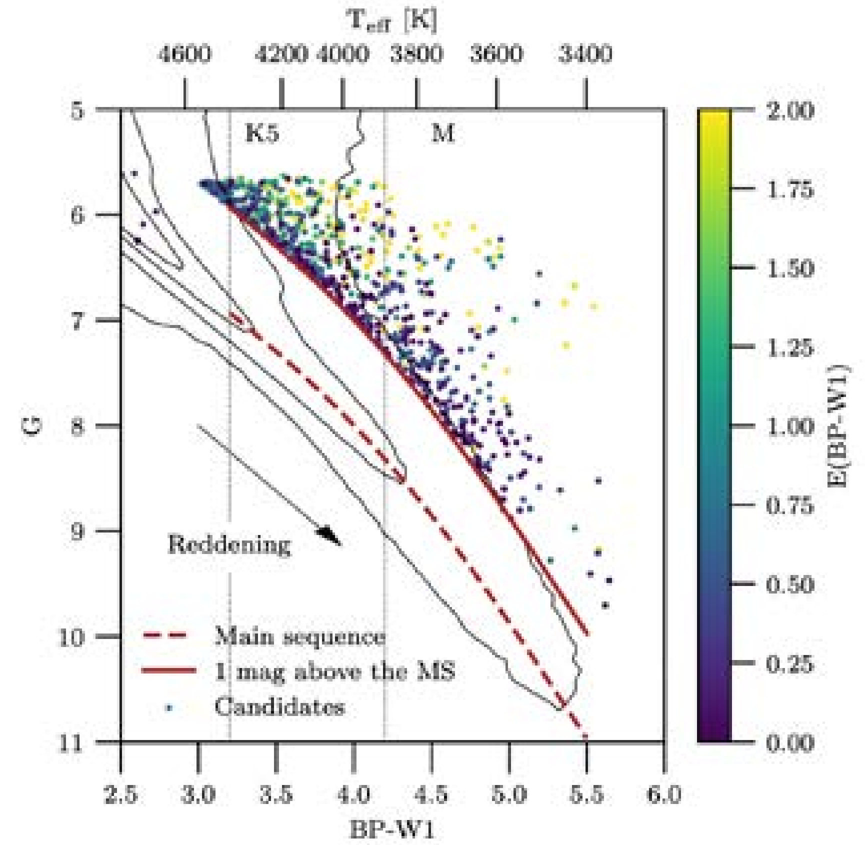

Figure 17: Publication no. 270 Colour-magnitude diagram with candidate young stars and their reddening estimated in this work. Details on the reddening estimation are described in Sec. 2.5. The most crowded region (~K5 dwarfs) is contaminated with reddened hotter stars while M dwarfs show less contamination due to their proximity. Red lines denote the main sequence (dashed line) and the selection function 1 magnitude above (solid line). Contours show the density of stars in the Gaia catalog.

PUBLICATIONS

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	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	Osmological 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 Space Industry Responsive Intelligent Thermal) nanosatellite
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