ASTRO 3D

ANNUAL REPORT 2018

ARC CENTRE OF EXCELLENCE
FOR ALL SKY ASTROPHYSICS IN 3D

Australian Government
Australian Research Council

ACKNOWLEDGEMENT

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

OUR COLLABORATING UNIVERSITIES

Australian National University

Curtin University

The University of Western Australia

Swinburne University of Technology

The University of Melbourne

The University of Sydney

OUR PARTNER INSTITUTIONS

CSIRO

California Institute of Technology 1891

Chinese Academy of Sciences

University of Washington

University of Toronto

NCI

University of Oxford

AAO

ASTRON

Heidelberg Institute for Theoretical Studies

HITS

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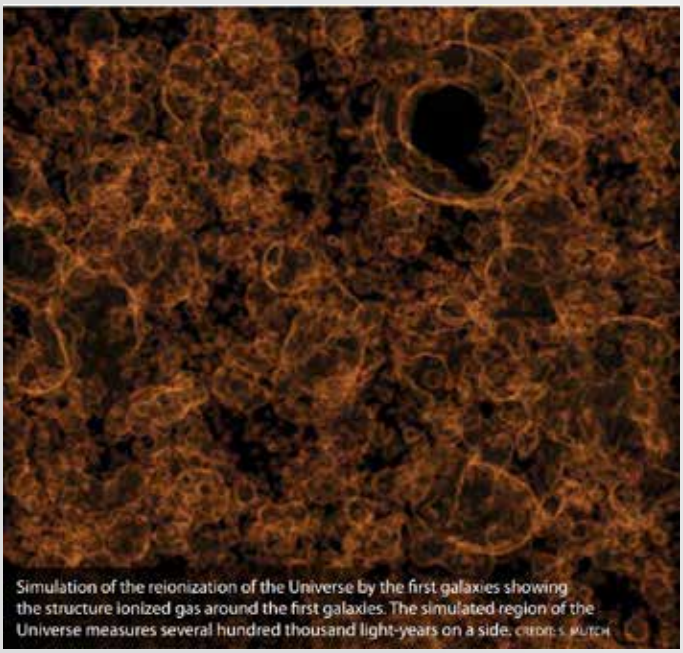
ACRONYMS AND ABBREVIATIONS

AAO	Australian Astronomical Observatory
AAL	Astronomy Australia Ltd
AAT	Anglo Australian Telescope
ACFR	Australian Centre for Field Robotics
ADACS	Astronomy Data and Computing Services
AGN	Active Galactic Nuclei
ALMA	Atacama Large Millimeter Array
ANU	The Australian National University
APOGEE	APO Galactic Evolution Experiment
ARC	Australian Research Council
ASA	Astronomical Association of Australia
ASKAP	Australian Square Kilometre Array Pathfinder
ASTRO 3D	Centre of Excellence for All Sky Astrophysics in 3 Dimensions
ASTRON	Netherlands Institute for Radio Astronomy
ASVO	All-Sky Virtual Observatory
ATNF	Australia Telescope National Facility
BoRG	The Brightest of Reionising Galaxies
BPT	Baldwin, Phillips & Terlevich
CAASTRO	Centre of Excellence for All Sky Astrophysics
CAS	Chinese Academy of Sciences
CASS	CSIRO Astronomy and Space Science
COO	Chief Operating Officer
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DIAP	Data Intensive Astronomy Program
DIG	Diffuse Ionised Gas
DINGO	Deep Investigation of Neutral Gas Origins
DSTG	Defence Science and Technology Group
ECR	Early Career Researcher
EDI	Equity Diversity and Inclusion
EoR	Epoch of Reionisation
ESO	European Southern Observatory
ESPRESSO	Echelle SPectrograph for Rocky Exoplanets and Stable Spectroscopic Observations
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)
HITS	Heidelburg Institute for Theoretical Studies
HPC	High-Performance Computing
IAB	International Advisory Board
ICRAR	International Centre for Radio Astronomy Research
IFU	Integral Field Units
IGM	InterGalactic Medium
IR	Infra-red
ITTC	Industrial Transformation Training Centres
JWST	James Webb Space Telescope
KiDS	Kilo-Degree Survey
KMOS	K-band Object Spectrograph
KPI	Key Performance Indicator
LIEF	Linkage Infrastructure Equipment and Facilities
LIGO	Laser Interforometer Gravitational-Wave Observatory
LSQR	Least Squares with QR Factorisation
MIGHTEE	MeerKAT International GHz Tiered Extragalactic Exploration
MOSFIRE	Multi-Object Spectrograph For Infra-Red Exploration
MPI	Message Passing Interface
MPIA	Max Planck Institute for Astronomy
MSTO	Main Sequence Turn-off

MUSE	Multi-Unit Spectroscopic Explorer
MWA	Murchison Widefield Array
NAB	National Advisory Board
NCI	National Computational Infrastructure
NCSA	National Centre for Supercomputing Applications
NIR	Near Infra-Red
PAF	Phased Array Feed
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PHISCC	SKA Pathfind HI Science Coordination Committee
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
SHARKS	Southern H-ATLAS Regions Ks-band Survey
SKA	Square Kilometre Array
SMC	Science Management Committee
SOFIA	Stratospheric Observatory for Infrared Astronomy
SQL	Structured Query Language
STEM	Science Technology Engineering Mathematics
SVD	Singular Value Decomposition
TAO	Theoretical Astrophysical Observatory
TESS	Transiting Exoplanet Survey Satellite
UCSD	University of California San Diego
UNSW	University of New South Wales
UAV	Unmanned Aerial Vehicle
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
WALLABY	Widefield ASKAP L-Band Legacy Allsky Blind Big Survey
WiFeS	WideField Spectrograph
WISE	Women in STEM and Entrepreneurship
ZFOURGE	FourStar Galaxy Evolution Survey



Simulation of the reionization of the Universe by the first galaxies showing the structure ionized gas around the first galaxies. The simulated region of the Universe measures several hundred thousand light-years on a side. CREDIT: S. MUTCH

DIRECTOR'S WELCOME AND REPORT

"How Did We Get Here?"

This question has puzzled and inspired humanity to search for our origins for thousands of years. The question covers vast ground; from the Big Bang and the first stars that illuminated the universe, to the diverse galaxies that surround us today. ASTRO 3D brings together world-class optical, radio, and theoretical astrophysicists to answer fundamental questions about our origins: What is the Origin of Matter and the Periodic Table? What is the Origin of the Ionising Radiation in Universe? No one wavelength or telescope can answer these questions. We need radio astronomy to trace the cold gas, optical astronomy to trace the hot gas and the stars, and theory to weave our observations together into a comprehensive picture of the formation and evolution of the universe that we see today, including the effects of dark matter. ASTRO 3D is achieving these goals with an incredible team from diverse backgrounds.

REACHING CRITICAL MASS

In 2018, ASTRO 3D continued hiring postdoctoral researchers and attracting PhD students to achieve critical mass to answer our science goals. As of 13 February 2019, we now have 192 highly talented people including 13 Chief Investigators, 14 Partner Investigators, 71 Associate and Affiliate Investigators, 6 Research Fellows, 20 Postdoctoral Researchers, 54 PhD, Masters and Honours students, and 14 Professional Staff. Our young and enthusiastic team comes from across the globe, bringing in fresh ideas and talent. Every month, we receive new membership requests from both within and outside the ASTRO 3D nodes and partner institutions. The large number of new membership requests as well as interest from external institutions in joining the Centre is testament to the exciting science and collaborative team environment that we are building together.

A large and successful Centre requires communication and meaningful collaboration across many institutions around Australia. These collaborations are now well established in ASTRO 3D through our Centre-wide strategic planning retreats, our annual science meeting, project busy weeks, cross institution meetings, all-Centre video meetings, and regular email updates. I am so excited to be leading such an excellent and engaged team of researchers, management, and administrative staff.

"ASTRO 3D brings together world-class optical, radio and theoretical astrophysicists to answer fundamental questions about our origins."

EXCITING RESEARCH AND MAJOR DISCOVERIES

Our surveys and projects hit the ground running in 2018, achieving major milestones and making exciting discoveries. Here are just some of the highlights from 2018:

- The MWA EoR Survey aims to detect neutral hydrogen in the universe at the Epoch of Reionisation. In 2018, the MWA EoR team used reflected light from the moon to measure the average brightness of the Milky Way!

- The First Stars team is searching for the first stars that illuminated the universe by finding the most chemically pristine stars in our Milky Way. In 2018, they discovered a smoking gun for a past interaction or collision between our Milky Way and a dwarf galaxy by showing that the chemical composition of two outlying groups of stars, 14,000 light years above and below the Milky Way, closely matches the stars in our galaxy.

- The First Galaxies team is using the deepest images obtained on Space Telescopes to reveal the first galaxies that formed in the universe. In 2018, they showed that an ultra-bright galaxy thought to be 13 billion years old is actually a "young whippersnapper interloper".

- The Galaxy Evolution program bridges the first galaxies to galaxies that surround us today by conducting large 3D spectroscopic surveys of thousands of galaxies across cosmic time. Galaxy evolution researchers discovered the most distant spiral galaxy! This discovery provides important tests for our models of disk galaxy formation.

- The ASKAP survey projects, WALLABY, DINGO, and FLASH, received their Early Science Data in 2018. This data is being used to refine analysis pipelines and to help plan the full surveys to detect and image the neutral hydrogen in galaxies in 3D

- The SAMI survey completed observations on the Anglo-Australian Telescope in 2018, achieving its goal of 3D images of 3000 galaxies, and the next generation instrument, HECTOR, is progressing rapidly. Exciting discoveries are already being made, including a 2018 Nature paper and press release showing how the intricate motions and ages of stars explain how galaxies evolve from "a pancake to a soccer ball shape".

- The GALAH survey reached its half-way mark, obtaining high resolution spectroscopy of 500,000 stars in the Milky Way. In 2018, the GALAH team also released data for 350,000 stars to the public, a significant impact on the field of galactic archaeology.

- The Genesis Theory team is now a large and impressive group of theorists from around Australia and overseas. The team is using supercomputing time provided to the Centre by the National Computational Infrastructure in Canberra to simulate galaxy formation and evolution and to produce 3D data cubes for direct comparison with the Centre's survey data.

Check out the survey/project summaries, research highlights and interviews throughout this Annual Report for more about our fantastic science!

FOCUSING ON DIVERSITY AND INCLUSION

One of the goals of ASTRO 3D is to achieve 50% female representation at all levels of the Centre by 2021. New hires bring our female representation from 38% in February 2018, to 40% in February 2019, ahead of the KPI set for year 2 (35%). Our equity policies include family friendly meeting times, all positions available as part time, child care at all Centre run and Centre sponsored events, and 50% female speakers at all Centre sponsored meetings and conferences.

Diversity in astrophysics has, to date, focused predominantly on achieving gender diversity to close the gap that has impacted the field. True diversity not only includes gender, but different ages, races, religions, socio economic backgrounds, physical ability, and sexual orientation. In 2018, our Diversity and Inclusion Working Group developed of goals, strategies and a set of activities to promote broader diversity and inclusion. These activities will reflect our ASTRO 3D values of honesty, trust, transparency, respect, diversity, fairness, and inclusion. These discussions culminated in a Diversity and Inclusion Action Plan, which we will begin implementing in 2019 through our newly formed Diversity and Inclusion Committee. I am looking forward to the many important advances that we will make in this space!

ENGAGING OUR PARTNERS

We strengthened our collborations with national and international partner institutions in 2018, through our Visitor Programs, key investigators in each Project/Survey directly engaging partners and also student exchange programs.

Our Centre includes seven international partners and we welcomed visitors from four of them in 2018. We explored collaborations in the DINGO, FLASH and MIGHTEE surveys as part of ASKAP, Galaxy Evolution and MWA projects. Each of the visits is listed on the table on page 78.

A range of ASTRO 3D members also visited several of our partner institutions in 2018. I had the pleasure of visiting Oxford University to meet with our new co-lead of ASKAP James Allison and had discussions with Roger Davies, Andy Bunker and the galaxy evolution and SAMI groups there. I also visited Partner Investigator Volker Springel at the Heidelburg Institute for Advanced Studies to discuss future projects and collaborations.

We also continue to work CSIRO Astronomy and Space Science (CASS), the National Computational Infrastructure (NCI) and the Australian Astronomical Observatory (AAO). Our collaborations with these organisations are producing deep and high impact science.

EDUCATION AND OUTREACH PROGRAMS

In 2018, ASTRO 3D continued working with the Voyages Indigenous Tourism Group on the Uluru Astronomy programs, originally part of the CAASTRO Centre of Excellence. These programs support the Indigenous community in the Uluru region. ASTRO 3D has an astronomer at Uluru full-time for 9 months of the year, on a fortnightly roster. The astronomers engage the public in astronomy through lectures, Q&A sessions, and public viewing nights. In 2018, we continued the Uluru Astronomy Weekend where our astronomers engaged in discussions about the structure and history of the

Universe as well as leading fun family activities. The highlight for me was the starlight dinner where astronomers mingled with the public over dinner and viewing of the beautiful desert night sky.

ASTRO 3D continued the work of CAASTRO with the ASTRO 3D in the Classroom program in New South Wales, which includes live streaming interactive videos where our astronomers discuss topics with school students, and STEM and entrepreneurship workshops.

In 2018, we began planning for our Telescopes in Schools rural program, to be led by ASTRO 3D Associate Investigator Brad Tucker with our Education, Outreach and Communications Manager Ingrid McCarthy. The Telescopes in Schools rural program will begin in 2019 in the rural towns that showed the highest engagement in Stargazing Live. Stargazing Live broke the world record of the most people simultaneously observing the night sky, with >40,000 people across Australia observing the moon simultaneously. I can't wait to bring the Telescopes in Schools program to rural schools and increase engagement in STEM across Australia!

THE NEXT GENERATION

In 2019, we will be focusing on inspiring, training and retaining the next generation of young scientists. We will be expanding our education and outreach programs, and offering new training programs for young astronomers. This cohort of young astronomers is critical for maintaining research capacity and expertise in Australia, and we need to train the future leaders for the mega-scale facilities; the Square Kilometre Array and the Giant Magellan Telescope; that will come to fruition at the end of this Centre. A culture that is welcoming and engaging to a diverse range of young scientists is critical, as is encouraging a diverse range of ideas and helping those ideas come to fruition, whether the ideas will further our understanding of the universe, or within the broader community. I invite you to join me on this exciting and rewarding journey!

The entire arc of the Milky Way, full of gas, dust, star clusters and emission nebulae, makes a luminous background for the ESO-operated Very Large Telescope (VLT). The VLT is based at the Cerro Paranal site in the Atacama Desert of northern Chile, and it houses four 8.2-metre Unit Telescopes, known as Antu, Kueyen, Melipal and Yepun, shown here lined up in front of a stunning starry backdrop.
IMAGE CREDIT: Miguel Claro/ESO

ABOUT THE CENTRE

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

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

The Centre has been funded over seven years with a $30.3m grant from the Australian Research Council (ARC), $8.4m in cash from the six Australian universities and $144m 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.

"The ASTRO 3D Centre of Excellence is demonstrating excellent progress in understanding the Universe and how it evolved. But in addition to the scientific discoveries, the Centre is also building up its people – developing future leaders and providing transferable skills for employees in a modern workforce. The leadership being shown in engaging and developing people involved in the Centre is a critical element for success and will leave an important legacy for the future."

Sue Weston, Deputy Secretary, Department of Industry, Innovation and Science

OUR STRATEGIC GOALS

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

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

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

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

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

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

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

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

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

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

SCIENCE HIGHLIGHT

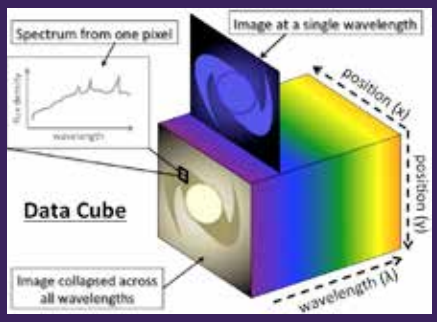
PUTTING THE '3D' IN ASTRO 3D

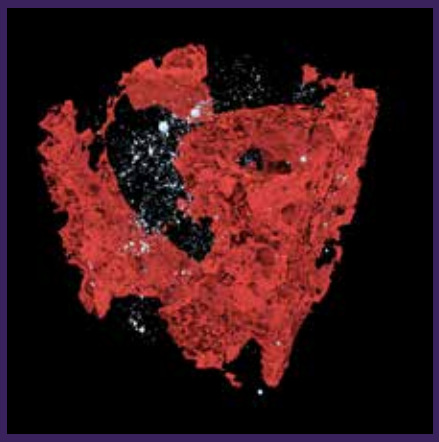
The flagship telescopes employed by ASTRO 3D (AAT, ASKAP, MWA and Skymapper) are collecting unprecedented volumes of multi-dimensional datasets.

For each pixel received by the telescopes — whether it is visible light from the Optical Telescopes (AAT and Skymapper) or radio frequencies from ASKAP and MWA — we are also collecting detailed spectra, using instruments such as SAMI, to compile a "datacube". For the first time, ASTRO 3D astronomers will have a 3D understanding of the shape and composition of stars and galaxies in the Universe and how they have changed since the Big Bang.

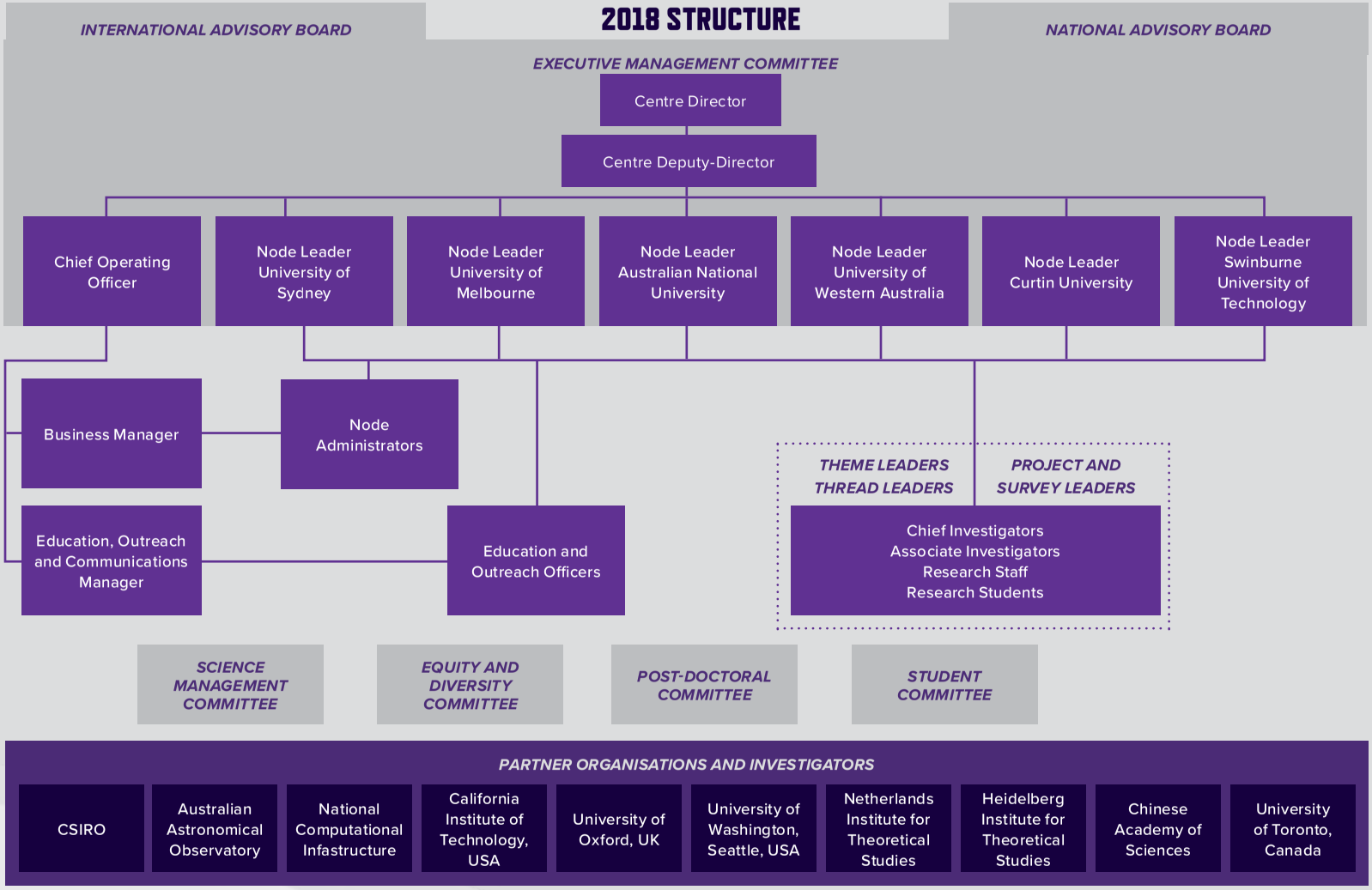
These petabyte-scale volumes of observational data being collected from current cutting-edge telescopes (and future next-generation telescopes like SKA and JWST) are also being fed into computer simulations. Using the super-computing facilities at NCI and the Pawsey centre, our theoretical astronomers are developing data management systems and visualisation tools that produce models of the evolution of the Universe, unlike anything we've been able to see before. The datacubes they produce show the three-dimensional structure of the Universe and how it evolves over time.

As a consequence of this cutting-edge 3D data and modelling, ASTRO 3D will be able to utilise tools such as Virtual Reality, Augmented 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.





2018 STRUCTURE



GOVERNANCE

We have established a collaborative and cohesive structure that will focus on the effective and efficient delivery of the Centre's Strategic Goals and meeting our Key Performance Indicators.

EXECUTIVE MANAGEMENT COMMITTEE

The Executive Management Committee works collaboratively to oversee day-to-day operations, including financial and risk management, the development of the strategic plan and monitoring performance against agreed outcomes. All collaborating universities are represented on the Committee, which is comprised of in 2018:

- Centre Director - CI Lisa Kewley (ANU)
- Centre Deputy Director - CI Stuart Wyithe (Melbourne)
- Node Leaders at each collaborating university - CI Scott Croom (Sydney), CI Karl Glazebrook (Swinburne), CI Lister Staveley-Smith (UWA), CI Cathryn Trott (Curtin)
- Chief Operating Officer - Ms Sheri Norton
- Collaboration Leader - CI Joss Bland-Hawthorn (Sydney)

In 2018, the ASTRO 3D Executive Committee met 11 times, including face-to-face meetings at ANU, Swinburne University of Technology and at the Annual Retreat in the Swan Valley, Western Australia.

ADVISORY BOARDS

Two proactive and engaged external Advisory Boards meet 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 education/outreach goals.

INTERNATIONAL ADVISORY BOARD

The Chair of the International Advisory Board is:

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

2018 IAB members:

Professor Meg Urry, Israel Munson Professor of Physics and Astronomy; Director, Yale Center for Astronomy & Astrophysics; President, American Astronomical Society

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

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

Professor Garth Illingworth, Professor, University of California, Santa Cruz

International Advisory Board Chair's Report

ASTRO 3D is carrying out an ambitious and exciting program of interrelated projects addressing the astrophysics of the young Universe. The main goals are to understand the nature of the ionised Universe, the formation of galaxies and the origin of the elements. The Director has put together a strongly-motivated, diverse set of researchers in various career stages, who work on the interrelated projects with multi-site teams. There is an excellent balance between observational expertise in optical and radio techniques, and theoretical work that is focused on numerical simulations.

The International Advisory Board (IAB) met at ANU in Canberra from 30 May to 1 June 2018. The IAB attended all science sessions and met separately with the directorate, project leaders, individual researchers, postdocs and students. It concluded that the ASTRO 3D partnership is doing very well. The scientific projects are exciting, and robustly underpin the Centre's scientific theme. The leadership is strong, and works together constructively, resulting in excellent progress in the specific scientific projects, as detailed in this report. Good internal communication is critical for the success of any project, in particular in a multi-site multi-project programme. The IAB supports the efforts in this direction, including increasing communication between junior researchers at different sites.

ASTRO 3D commitment to equity and inclusion is exemplary. The approach includes setting clear goals, articulating the connection to scientific excellence, and providing support and opportunities for professional development to ensure that all ASTRO 3D personnel operate at their full potential. The fraction of women is high across the partnership. The IAB supports the steps being taken to broaden the commitment to diversity beyond attention to gender and statistics.

The ten-year strategic partnership between Australia and ESO was signed a day before the formal launch of ASTRO 3D in July 2017. This development was not foreseen in the original ASTRO 3D proposal but provides an excellent opportunity for enrichment of the science program. The IAB recognised that the first initiatives in this direction had been taken and noted that it would be natural for the ASTRO 3D team to submit proposals for large observing programmes on the VLT and also to be actively engaged in the science planning of potential new instruments for the VLT with Australian leadership.

The first annual report (for 2017) covered the initial six months of the ASTRO 3D programme, and already demonstrated that the partnership was off to a good start. This second annual report covers a full year and records much progress in all areas of the partnership, also evident during the stimulating retreat in November in the Swan Valley. It is a pleasure to be associated with ASTRO 3D.

Tim de Zeeuw

NATIONAL ADVISORY BOARD

The National Advisory Board (NAB) focuses on the effectiveness of the Centre in training the next generation of scientists, implementing public outreach programs and the strategic management of the Centre. Its role is to provide advice on the Centre's progress towards achievement of the Government's National Science and Innovation Agenda, advise on the developments and delivery of education and outreach programs, and identify opportunities for further scientific collaboration and engagement with industry and government.

The Chair of the National Advisory Board is:

Dr Rob Vertessy, former Director of the Bureau of Metereology

2018 NAB members:

Dr Sue Barrel, Chief Scientist and Group Executive, Science and Innovation, Bureau of Meteorology

Sylvan Brown, Partner, FB Rice Law

Dr Bobby Cerini, Director of Science and Learning, Questacon

Dr Tanya Hill, Senior Curator, Astronomy, Melbourne Planetarium, Museums Victoria

Professor Joan Leach, Director, International Programs, Australian National Centre for the Public Awareness of Science

Sue Weston, Deputy Secretary, Department of Industry, Innovation and Science

National Advisory Board Chair's Report

The National Advisory Board held its first meeting at Mt Stromlo Observatory on 18-19 September 2018. Board members attending were Rob Vertessy (Chair), Sue Weston, Sue Barrell, Bobby Cerini and Tanya Hill. Joan leach and Sylvan Browne were apologies. Centre staff present include CI Lisa Kewley (Director), Sheri Norton (COO), CI Stu Wyithe (Science management), CI Joss Bland-Hawthorne (Partner engagement) and Ingrid McCarthy (Education and public outreach).

The Board received presentations and engaged in discussions on the following topics:

- Centre Director's Overview
- Science Management Committee Report
- Centre Science Highlights
- Centre Governance, Risks and Opportunities
- Centre Strategic Plan
- Equity and Diversity and developing Strategic Plan
- National and International Partner Engagement
- Student Training Programs and Internships
- National Stakeholder Relations
- Education and Outreach Programs Strategic Plan

The Board was impressed by the depth and quality of the presentations and supporting materials it received. The leadership of the Centre appears to be of a very high calibre. The DirectorP exhibits outstanding science vision and leadership and the COO demonstrates high quality organizational management. The senior staff in charge of science management and partner engagement were also impressive, providing compelling accounts of their respective portfolios of responsibility.

It was clear that very significant progress has been made in the short life of the Centre to date. There is a clear science vision, underpinned by cogent themes and coherent teams. The passion of the scientists involved and the exciting research being undertaken lend a vibrancy to the effort. Collectively, the leadership group exhibit a very positive leadership style and this appears to have engendered high levels of staff and student engagement and commitment to the aims of the Centre.

Rob Vertessy

SCIENCE MANAGEMENT COMMITTEE

The Science Management Committee (SMC), chaired by CI Stuart Wyithe, met twice during 2018 to assess the scientific progress against the Centre's goals, assess cross-node and cross-project collaborations, and set Key Performance Indicators (KPIs) and milestones for the coming year. This SMC concentrates the Centre's extensive science survey management expertise and is composed of two Theme Leaders, two Thread Leaders, a Collaboration leader, and key CIs and PIs who ensure that all scientific areas of the Centre are represented on the Committee.

2018 Membership:

Chair - CI Stuart Wyithe

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

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

Thread Leader (The Genesis Simulations) - CI Chris Power

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

Collaboration Leader - CI Joss Bland-Hawthorn

Key CIs and PIs - CI Martin Asplund, CI Karl Glazebrook, CI Cathryn Trott and PI Phil Edwards

The SMC is tasked with:

1. Ensuring that ASTRO 3D meets its science goals;
2. Driving the translation of ASTRO 3D science into maximum measurable outcomes; and
3. Maintaining focus on training and supporting early career researchers to lead Australia's future science programs on the next-generation telescopes.

The SMC is aided in its planning and assessment by work plans prepared by project leaders for the coming 12 months and reviews of progress against the previous year's plans.

In 2018 the success of the first year of ASTRO 3D science in each project was assessed by the SMC against a series of outcome-focused milestones (Activity Plans), identified areas of collaboration with international partners and identified areas of cross-project collaboration.

All ASTRO 3D projects were found to have achieved their key objectives. As part of the assessment process, the SMC identified areas of risk, competition and opportunities for collaboration. These outcomes fed into other areas of ASTRO 3D governance, including the risk register.

The SMC also approved a modification to the science plan with the First Galaxies project, allowing ASTRO 3D to take advantage of opportunities provided by the Hubble Space Telescope BoRG survey, in the face of unexpected delays to the James Webb Space Telescope.

In 2019 the SMC will increase its regularity of meetings to 4 times per year, reflecting the rapid pace of activity in the ASTRO 3D scientific program.

"I really liked to see the progress being made by each of the teams and the networking that's occurring - that's been really great."

EQUITY, DIVERSITY AND INCLUSION COMMITTEE

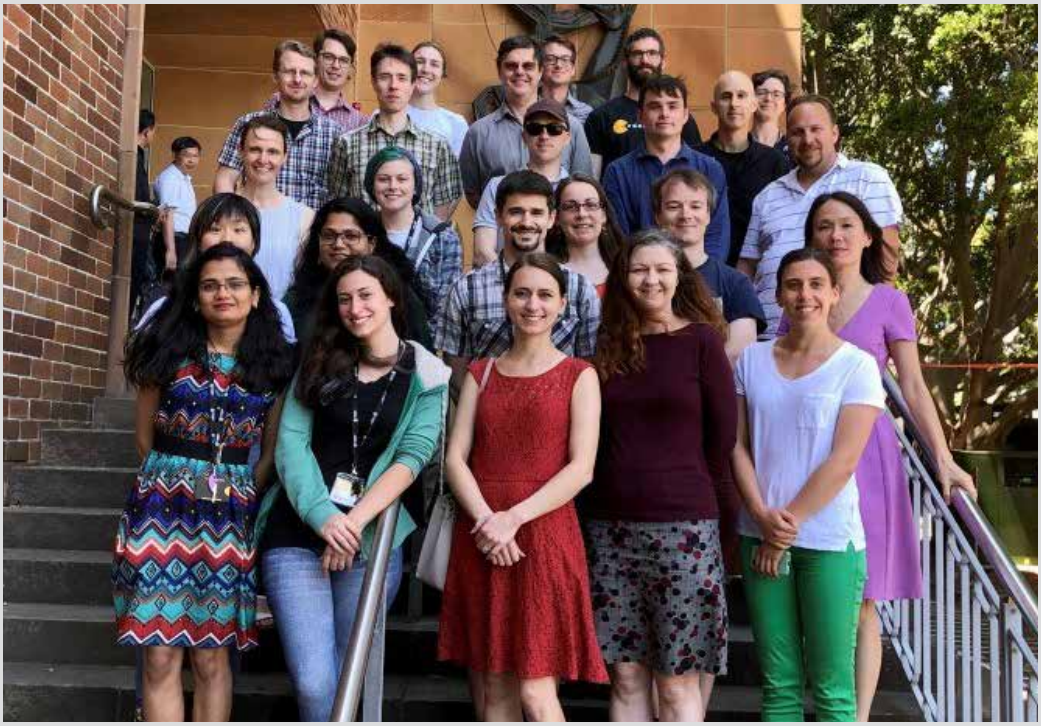
The Centre is committed to equality of opportunity and to a pro-active and inclusive approach to equality, which supports and encourages all under-represented groups, promotes an inclusive culture and values diversity.

The original Equity & Diversity Committee first met in December 2017 to begin the engaged and thoughtful process of promoting an inclusive culture that ensures people from all backgrounds have an opportunity to reach their full potential. Chaired by CI Rachel Webster with 12 members representing all of the ASTRO 3D nodes and Macquarie, the Committee collected information from existing Equity, Diversity and Inclusion (EDI) programs, e.g. CAASTRO and Swinburne, for guidance in developing an action plan tailored to ASTRO 3D.

Within the first half of 2018, the Committee drafted a Terms of Reference and Gender Equity Action plan that detailed the Committee's working structure and over-arching goals. The Gender Action plan provided objectives with strategies to apply and methods for assessing effectiveness over the proposed timeframes. After laying this critical foundation, ASTRO 3D Director Lisa Kewley identified a need to form a Working Group to further articulate the Centre's values, culture, and behaviour.

With the opportunity to now incorporate new knowledge and experiences from within ASTRO 3D, the EDI Working Group formed in August 2018. Chaired by CI Lisa Kewley, the new Working Group included a subset of the original Committee as well as new members and had representation spanning the range from students, early career researchers, faculty, and professional staff. The Working Group met five times between September and November to reflect on how to achieve a Centre that embodies the values of Honesty, Trust, Transparency, Respect, Diversity, Fairness, and Inclusion.

In parallel, the ASTRO 3D Executive Management



50/50 gender balance of speakers and discussion leaders at the Galaxies workshop at UNSW October 2018 ***IMAGE CREDIT:*** Kim-Vy Tran

Committee had multiple discussions on the ideal values, culture, and behaviours for the whole Centre. There were dedicated discussion sessions on Equity, Diversity, and Inclusion at the ASTRO 3D Barossa Valley meeting and the ASTRO 3D Strategic Planning retreat in Perth which were both held in November 2018. There was also an ASTRO 3D Climate Survey in November to better understand through anonymous feedback how the EDI environment differs across nodes and professional levels.

Notable EDI highlights from 2018 include :

- 50/50 gender balance of speakers and discussion leaders at the ASTRO 3D meetings, e.g. Galaxies workshop (October 2018; see picture), Barossa Valley workshop (November 2018), and Perth Strategic Planning retreat (November 2018).
- The now standard policy of family-friendly practices at ASTRO 3D meetings
- Showing and celebrating diversity through the "We are People" section of the Director's regular update

2019 Plans

As well-expressed by the original EDI committee, the Centre is committed to 1) celebrating and valuing diversity; 2) creating a fair and respectful workplace culture; and 3) building and retaining diverse capabilities and experiences. After the final Working Group meeting in November 2018, CI Lisa Kewley integrated input from across the Working Group, the Executive Committee and the Centre members to expand on the original Gender Equity Action plan. The new EDI Action Plan is in the process of being finalised and CI Lisa Kewley has appointed Working Group member AI Kim-Vy Tran to Chair the EDI Committee going forward.

The most immediate task is to assemble the new EDI Committee and Chair Tran has issued the call for expressions of interest from ASTRO 3D members to be received by 08 February. Once the new EDI Committee is formed, they will be tasked with implementing the multi-leveled action plan across all the nodes and including at large members to continue building a culture that is collegial, supportive, nurturing, professional, engaging, empowering, and inclusive.

POST-DOCTORAL COMMITTEE

The role of the ASTRO 3D postdoc committee is to assist the ASTRO 3D Executive team with developing strategies to promote postdoc engagement and to resolve issues affecting the postdoc community at large. This includes making recommendations on ways in which ASTRO 3D can increase postdoc participation and representation, as well as boost opportunities for postdocs, and monitor progress.

The ASTRO 3D postdoc committee was established midway through 2018 and convened its first meeting at Swinburne during the ASA general meeting. The postdoc committee have identified the need for a smoother “on boarding” process for new ASTRO 3D postdocs and requested a postdoc presence at meetings of the ASTRO 3D executive. We have also defined the scope and goals of a proposed ASTRO 3D postdoc retreat to coincide with the annual ASTRO 3D science meeting and have now begun detailed event planning.

STUDENT COMMITTEE

The ASTRO 3D Student Committee will be formally organised in 2019, but is building out of the momentum of the Student Retreat Organising Committee. In 2018, the Student Retreat Organising Committee coordinated a breakout session for PhD, Masters and Honours students during the Annual Retreat. They trialled a session designed to build student-student collaborations where groups of students from different institutions discussed collaborative opportunities.

The Committee will put a call out for representatives at the 2019 Science Meeting and a Student representative will attend Executive Meetings to represent the interests of ASTRO 3D students.

OUR PEOPLE

CHIEF INVESTIGATORS

PROF MARTIN ASPLUND

Institution: Australian National Univeristy

Project Lead: The First Stars

Survey Lead: GALAH

Node Leader: Australian National University

Professor Martin Asplund is an international leading authority in stellar/solar astrophysics, the Milky Way and the origin of the elements.

Martin and his First Stars team are using the ANU SkyMapper Telescope to discover the oldest stars in the Universe. A few of these stars have survived to the present day and can be found in and around the Milky Way Galaxy. Their chemical compositions reveal the nature of the first stars and the conditions in the early Universe.

Martin is also a leader of the GALAH survey, the largest stellar spectroscopic inventory of the Milky Way. By determining the chemical make-up of up to a million stars with the Anglo-Australian Telescope, the history of our own Galaxy can be unraveled.

He is also an active mentor for young researchers both in observations with the largest telescopes and advanced supercomputer simulations.

PROF JOSS BLAND-HAWTHORN

Institution: University of Sydney

Collaboration Leader

Survey Lead: GALAH

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

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

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









DR BARBARA CATINELLA

Institution: University of Western Australia

Project Lead: ASKAP

Senior Research Associate 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.

PROF MATTHEW COLLESS

Institution: ANU

Survey Lead: SAMI/HECTOR

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.

PROF SCOTT CROOM

Institution: University of Sydney

Survey Lead: SAMI/HECTOR

Node Leader: University of Sydney

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

Scott leads the SAMI and HECTOR surveys. SAMI results include new insights into galaxy scaling relations, the discovery of outflows in star-forming galaxies, and greater understanding of the formation mechanism behind dispersion-dominated galaxies.

SAMI will be replaced by the HECTOR spectrograph in 2019. HECTOR will survey 100,000 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 with observations.

PROF LISA KEWLEY

Institution: Australian National University

Centre Director

Theme Leader: Origin of the Ionised Universe

Centre Director Lisa Kewley is an established world leader in the theoretical modelling and observation of star-forming and active galaxies. Her recent research combines stellar evolution and photoionisation models with cosmological hydrodynamic simulations to predict how the ionising radiation in galaxies changes over time. Her work has shown that there have been dramatic changes in ionising radiation in galaxies over the past 6 billion years.

Lisa's expertise covers both optical and radio astronomy, observation and theory, as well as understanding local and distant galaxies. She will bring this expertise into her Theme leader role that connects the MWA Epoch of Reionisation project with simulations of the ionising radiation seen in the first galaxies and examines how the ionising radiation evolved over cosmic time to the point where is observed in nearby galaxies with SAMI.

PROF KARL GLAZEBROOK

Institution: Swinburne University of Technology

Project Lead: Galaxy Evolution

Professor Karl Glazebrook is the Director of the Centre for Astrophysics and Supercomputing at Swinburne University of Technology. He brings extensive expertise in the galaxy formation and evolution field, as well as substantial scientific and leadership experience to ASTRO 3D.

Karl is leading the Galaxy Evolution project, coordinating Keck observations, analysis and outputs for both the Origin of the Ionised Universe theme and the Origin of Matter and the Periodic Table theme.

He is also leading senior academics in large inter-University research collaborations, matching resources to skills and expertise across ASTRO 3D programs.

PROF DARREN CROTON

Institution: Swinburne University of Technology

Project Lead: Genesis Simulations

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

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

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

A/PROF CHRISTOPHER POWER

Institution: University of Western Australia

Project Lead: Genesis Simulations

Associate Professor Chris Power is a leading computational astronomer who is having a major impact in his field.

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

A/PROF EMMA RYAN-WEBER

Institution: Swinburne University of Technology

Project Lead: Galaxy Evolution

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.

Within the Galaxy Evolution Project Emma is overseeing work on ionisation: directly measuring the ionising radiation from galaxies at z~3–4 and developing calibration for escaping flux.

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

PROF ELAINE SADLER

Institution: University of Sydney

Theme Leader: Origin of Matter and the Periodic Table

Survey Lead: ASKAP

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

Elaine's research expertise covers both optical and radio astronomy, and she brings extensive science management experience, including the leadership of major galaxy surveys with significant international impact.

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

PROF LISTER STAVELEY-SMITH

Institution: University of Western Australia

Thread Leader: Data Intensive Astronomy

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

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

A/PROF MICHELE TRENTI

Institution: University of Melbourne

Project Lead: First Galaxies

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

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

He 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.

A/PROF CATHRYN TROTT

Institution: Curtin University

Project Lead: MWA EoR

Node Leader: Curtin University

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

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

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

PROF RACHEL WEBSTER

Institution: University of Melbourne

Project Lead: MWA EoR

Professor Rachel Webster is a world expert in the field of reionisation and is currently the chair of the Board of Directors for Australian Astronomy Limited (AAL). She brings extensive leadership expertise to ASTRO 3D.

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

PROF STUART WYITHE

Institution: University of Melbourne

Centre Deputy Director

Thread Leader: Genesis Simulations

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.

Stuart's theoretical expertise spans the Epoch of Reionisation to first star and galaxy formation and evolution, and he also brings important strategic planning experience to ASTRO 3D.

Stuart is working closely with Lister Stavely-Smith to ensure the Genesis Simulations are incorporated into the Data Intensive Astronomy infrastructure, an mock data are produced for the Centre's surveys.

PARTNER INVESTIGATORS

NAME	ORGANISATION	PROJECT/S
Roberto Abraham	University of Toronto	Galaxy Evolution
Douglas Bock	CSIRO	First Stars
Andrew Bunker	University of Oxford	First Galaxies, Galaxy Evolution
Warrick Couch	AAO	SAMI
Julianne Dalcanton	University of Washington	ASKAP, Galaxy Evolution
Roger Davies	University of Oxford	SAMI
Bryan Gaensler	University of Toronto	MWA EoR, ASKAP
Andrew Hopkins	AAO	SAMI, HECTOR
Evan Kirby	California Institute of Technology	First Stars, GALAH
Bärbel Koribalski	CSIRO	ASKAP
Di Li	Chinese Academy of Sciences	ASKAP
Christopher Martin	California Institute of Technology	Galaxy Evolution
Miguel Morales	University of Washington	MWA EoR
Raffaella Morganti	ASTRON	ASKAP
Volker Springel	Heidelberg Institute for Theoretical Studies	Genesis
Michael Wise	ASTRON	Data Intensive Astronomy

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Andrew Connolly	University of Washington	MWA EoR, ASKAP
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Continued

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Continued

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Continued

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Di Wang	University of Sydney	SAMI, HECTOR
Haobing (Adeline) Wang	University of Sydney	SAMI, HECTOR
Adam Watts	University of Western Australia	ASKAP
Ruby Wright	University of Western Australia	Genesis

OTHER STUDENTS

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Dominic Mendoca	University of Melbourne	MWA EoR
Murray Riding	University of Sydney	SAMI/HECTOR
Diane Salim	Australian National University	SAMI/HECTOR
Erica Thyygesen	Curtin University	Galaxy Evolution

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Debra Gooley	University of Sydney	Node Administration
Emily Johnson	Curtin University	Node Administration
Susan Lester	Swinburne University of Technology	Node Administration
Tash Marshall	University of Sydney	Education Officer
Ingrid McCarthy	Australian National University	Education, Outreach & Communications Manager
Sheri Norton	Australian National University	Chief Operating Officer
Marie Partridge	University of Sydney	Node Administration
Clare Peter	University of Western Australia	Node Administration
Tina Salisbury	Curtin University	Node Administration
Teresa Slaven-Blair	Curtin University	Outreach Officer
Kirsty Waring	University of Melbourne	Node Adminstration

COLLABORATION HIGHLIGHT

2018 SCIENCE MEETING

In May 2018, ANU's University House hosted the inaugural ASTRO 3D Science Meeting, where the breadth and depth of our latest discoveries were shared by over 40 researchers from PhD students to Chief Investigators and everyone in between.

ASTRO 3D researchers from around the country had a chance to update their colleagues on their latest results from all the Projects and Surveys. Some of the highlights included:

- MWA Epoch of Reionisation project, including an overview from CI Cath Trott from Curtin University, and updates on limits, analysis, callibration and use of models in understanding this part of the Universe's evolution.
- ASKAP HI surveys with an overview from CI Elaine Sadler from the University of Sydney/CSIRO, highlights from the FLASH, DINGO and WALLABY surveys and an update from CI Barbara Catinella from UWA explaining the synergy between HI observations and integral field spectscopic surveys.
- Genesis Theoretical Simulations were outlined by CI Chris Power of UWA, CI Darren Croton from Swinburne explained how easy it was to build your own simulated universe and updates from TAO, PRISM, and using semi-numerical models for understanding the intergalactic medium and the indirect influence of quasars on reionisation.
- First Galaxies were outlined by CI Michele Trenti from University of Melbourne in tandem with CI Karl Glazebrook from Swinburne on the Galaxy Evolution project. Talks followed on high-redshift galaxy formation constraints, MOSFIRE emission-line survey targets, gravitationally-lensed galaxies, UV spectral diagnostics for high-z galaxies, KMOS3D survey data and star formation in young stellar clusters.
- SAMI was outlined by CI Scott Croom from Sydney University, followed by updates on embedded discs and radial trends, kinematic bulge/disc decomposition, galaxy shapes and ages, the effect of DIG on metallicity gradients, Fornax 3D and a HECTOR overview.
- GALAH was headed up by CI Martin Asplund from the ANU, with updates from Skymapper, GALAH and HERMES.

"I really enjoyed making connections with the other nodes." (feedback from Science Meeting)

SPOTLIGHT ON PROF ELAINE SADLER

CHIEF INVESTIGATOR FROM THE UNIVERSITY OF SYDNEY AND OUR PARTNER INSTITUTION, CSIRO

"I've been interested in astronomy since I was quite a small child. I think I was one of those irritating children who was always asking difficult questions and I think I was always excited by the unknown; the things we didn't understand about the Universe; the big questions. When I was 10 I got a book on astronomy for my birthday and then I decided I wanted to become an astronomer and I've been very lucky to able to do this."

"Not everybody knows that stars are born and die; they have very long lives, compared to human life, but they don't live forever. So we can think of a galaxy, like our own Milky Way galaxy, as kind of an ecosystem in which stars live, can be born and die. We also know that as we look back over cosmic time, that these galaxies were very different in the past, compared to how they are now. So I'm interested in how galaxies have changed over cosmic time (galaxy evolution)."

"But I'm also interested in black holes, because we have really massive black holes that live in the centres of most galaxies, and we now know there's a kind of symbiotic relationship between the black hole and the galaxy in which it lives and they actually influence each other. So I work quite a lot now with radio telescopes because that's one of the best ways of detecting the effects of a black hole and using radio telescopes to understand the complexities of the life cycles of galaxies as we look back over time."

"We've just started using a new telescope, called ASKAP – the Australian SKA Pathfinder – it's located in a really remote part of Western Australia, away from civilisation and the kind of radio noise that drowns out the cosmic signals that you get if you are close to a big city. So this allows us to pick up really faint traces of hydrogen gas over a time span of several billion years. So we can look back 5, 6, 7 billion years in time and just see how much of this gas, which is the raw material that forms new stars, was in galaxies at different stages of the history of the Universe. This helps us understand the rate at which stars are born and what happens to galaxies over time."

"In ASTRO 3D, I think the challenge is that you want to deliver something in 7 years of time; you want to do an ambitious project that's world-leading and so you need plan carefully so that at the end of the seven years of the time of the Centre, you've done something that's really worthwhile and you can go back to the Australian taxpayer and say 'look what we found out about the Universe – we've done what we've said we would do.'"

"The biggest opportunity is to have the resources to do a really long-term project - where you can say 'right, we're going to build up our expertise, we're going to tackle a really difficult problem, we're going to make Australian scientists really able to advance the field. To be able to do something really worthwhile, that takes a long time. To build up the technical expertise and then to go from there to apply that to the problem and make the discoveries. Bringing people together is also a great opportunity of the Centre. We are trying to do something that no single university group or even people in a single city could do – it's really about connecting people across the country and across the world to work on these really difficult problems and to have the resources to do a really good job and to get to where we want to go."

RESEARCH

RESEARCH THREADS

1. GENESIS THEORETICAL SIMULATIONS

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

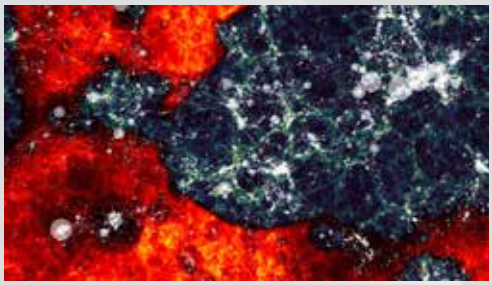
- Simulating the birth of the first stars and their impact on early universe chemical enrichment, proto-galaxy formation, reionisation and the evolution of the Intergalactic Medium (IGM).
- Tracking galaxy growth through star formation and mergers, and the build-up of angular momentum at all galactic scales, leading to the emergence and evolution of large-scale structure and the epoch of quasars.
- 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 initial phase of the Genesis Simulations thread has focused on generating a suite of large N-body simulations that will be coupled to semi-analytical models to produce synthetic galaxy populations across cosmic time.

The first set of runs consist of volumes of between 35 Mpc/h (distance units) and 500 Mpc/h on a side, with approximately 10 billion particles, allowing us to reliably resolve low-mass dark matter halos of approximately 10^9 solar masses.

Simulation run from Meraxes
IMAGE CREDIT: Simon Mutch and Paul Geil)



In parallel to the N-body programme, the Genesis team has been preparing hydrodynamical zoom simulations of individual systems, ranging in mass from dwarf galaxies to galaxy clusters. The initial phase has focused on identifying interesting candidates and running dark matter only versions of approximately 10 systems spanning a range of masses.

The runs have been designed to cater for a range of projects, from the Epoch of Reionisation to galaxy evolution with the HI and optical 3D surveys in the present-day Universe. An example of the ionisation structure of a 4-Mpc-thick slab during reionisation produced by MERAXES is shown in the figure. Red indicates regions of the volume which are neutral, whilst the green structure shows the underlying matter distribution inside the ionised bubbles surrounding the densest structures. A random 1/50th of the ionising galaxy population is overlaid as points scaled by instantaneous star formation rate.

A key component of the initial phase has been to ensure that we have robust dark matter halo catalogues and assembly histories and that these couple properly to semi-analytical models. In particular, Genesis postdocs Dr Pascal Elahi and Dr Simon Mutch have worked closely together to ensure that results from Dr Elahi's 6D phase space structure finder, VELOCIraptor, properly integrate into Dr Mutch's semi-analytical model (SAM), MERAXES. MERAXES has been developed to predict self-consistently the structure of the neutral and ionised hydrogen density field produced by the sources of reionisation. Meraxes is now being used to predict the properties of the first galaxies and their association with the distribution of HI during

the Epoch of Reionisation. The outputs from these simulations are being used to interpret surveys from the First Galaxies project and to make predictions and help develop analysis tools for the MWA EoR project.

During 2019, two new SAMs developed by Genesis team members – Shark, led by ASTRO 3D Fellow Dr Claudia Lagos, and Dark SAGE, led by ASTRO 3D Affiliate Dr Adam Stevens – will be run on the Genesis N-body trees to obtain predictions for the present day galaxy population, with particular emphasis on applications to ASKAP and SAMI/HECTOR IFU surveys. These will be used in parallel with Meraxes, which itself is being used together with new N-body simulations to understand the relationship between the earliest sources of reionisation and the spatial distribution of their descendants in the present-day.

Complementing the SAMs is a programme of hydrodynamical models, focusing on high mass and force resolution simulations of individual high redshift galaxies and small cosmological volumes, comparable to the highest resolution studies in the literature. The emphasis here is on studying chemical enrichment of the circumgalactic medium and the potential variation in the escape fraction of ionising photons, both of which have implications for measurements of quasar absorption line systems and the build up of the ionising background during cosmological reionisation.

SPOTLIGHT ON DR SIMON MUTCH

POST-DOCTORAL RESEARCHER FROM THE UNIVERSITY OF MELBOURNE

"I'm from Scotland originally, but moved to Australia about 10 years ago. I've always been interested in space and space travel and from a very young age, I was really interested in the Moon landings and things like that. As I got older, I got more interested in the question of how we went from just an empty universe filled with cold gas to this huge complexity of everything we see around us - even our brains came out of that."

"I'm focussed on the first galaxies that came into existence in the very early Universe, not long after the Big Bang. These are important, not just because they are the ancestors of all galaxies in the Universe, like our Milky Way, but also because they changed the Universe in a really fundamental way when they were formed. This area of research is one of the last frontiers in modern astronomy, you could say. There's lots of effort happening here in Australia and across the world to try and understand this early part of the Universe."

"My research is using simulations to try and study these first galaxies. I use some of Australia's biggest supercomputers to run simulations of early galaxy formation and then compare these to observations taken from big, powerful space telescopes, like Hubble. I also try to make predictions for radio telescopes, like the Square Kilometre Array that's being built out in Western Australia."

"From a personal point of view, my most exciting discovery was realising through doing astronomy research, that I really enjoy programming! From a science point of view, studying these first galaxies, and using a myriad of observations, not just of the galaxies themselves but also of their surroundings, in lots of different ways. Studying that has been really interesting and exciting."

"In a Centre of Excellence like ASTRO 3D, having such a big diverse group of people working on such a broad range of sciences is really challenging, but at the same time, one of the best opportunities of working on something like ASTRO 3D is the opportunity to speak with such a broad range of people and bouncing ideas off all of them and having the opportunity to collaborate with them."

2. DATA INTENSIVE ASTRONOMY (DIA) PROGRAM

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

The DIAP is managing two key projects:

- **Data Flow and Process Management**

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

- **Virtual Observatory (VO) and Theoretical Astrophysical Observatory (TAO)**

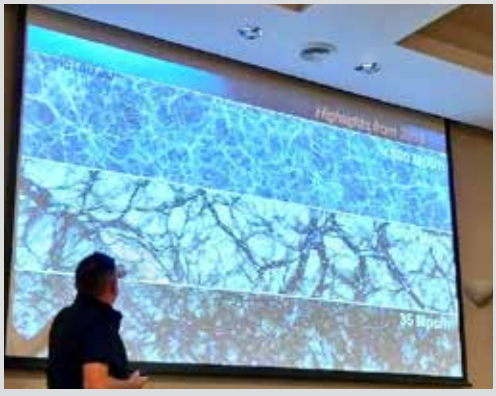
  The VO project aims to promote interoperability between the ASTRO 3D data sets that will exist on All-Sky Virtual Observtory (ASVO) nodes, especially those of most interest to ASTRO 3D - ADC, CASDA, MWA and TAO. The latter is an online eResearch laboratory that allows ASTRO 3D researchers to construct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

Highlights during 2018 include the addition of a new matrix iterative algorithm (Least Squares with QR-factorisation - LSQR) solver for the CSIRO/ASKAP data reduction pipeline ASKAPsoft by the ASTRO 3D Data Scientist Dr Vitaliy Ogarko, based at ICRAR/UWA. The new solver is more robust than current Singular Value Decompostion (SVD) solvers and is around an order of magnitude faster than the previously implemented ASKAPsoft solver, thus removing one of several bottlenecks preventing the real-time reduction of full ASKAP spectral-line data. Vitaliy has also modified the software package EAGLE which provides a graphical interface for distributed graphs for high-performance software pipelines, and has examined self-optimised methods for scheduling data-intensive workflows.

Developments in TAO have included a study of translating the GENESIS database into a format more suitable for TAO by postdoc Dr Manodeep Sinha, based at Swinburne. This will allow TAO to more easily ingest data products from GENESIS and other platforms (MERAXES, SHARK, SAGE, Dark SAGE etc). Dr Sinha has also integrated Lyman-alpha absorption into TAO, which allows realistic spectral energy distributions to be calculated for pre-reionisation galaxies.

ASTRO 3D has also assisted the Astronomy Data and Compute Services (ADACS) in delivering technical training in Python to ASTRO 3D nodes around the country, and assisted with the ICRAR/CASS radio interferometry school in Geraldton.

In 2019, the DIAP team will work with Astronomy Australia Ltd and other national infrastructure providers to help achieve a common national vision of requirements for future optical, radio and theory data centres around Australia to ensure that ASTRO 3D surveys and simulations have appropriate access to data and resources. We will pursue a pilot project based on cross-matching and querying data across the different data centres, will work towards implementation of a DINGO data reduction pipeline, and will implement a pilot SQL-queryable database in TAO.



SCIENCE HIGHLIGHT

MOON HELPS REVEAL SECRETS OF THE UNIVERSE

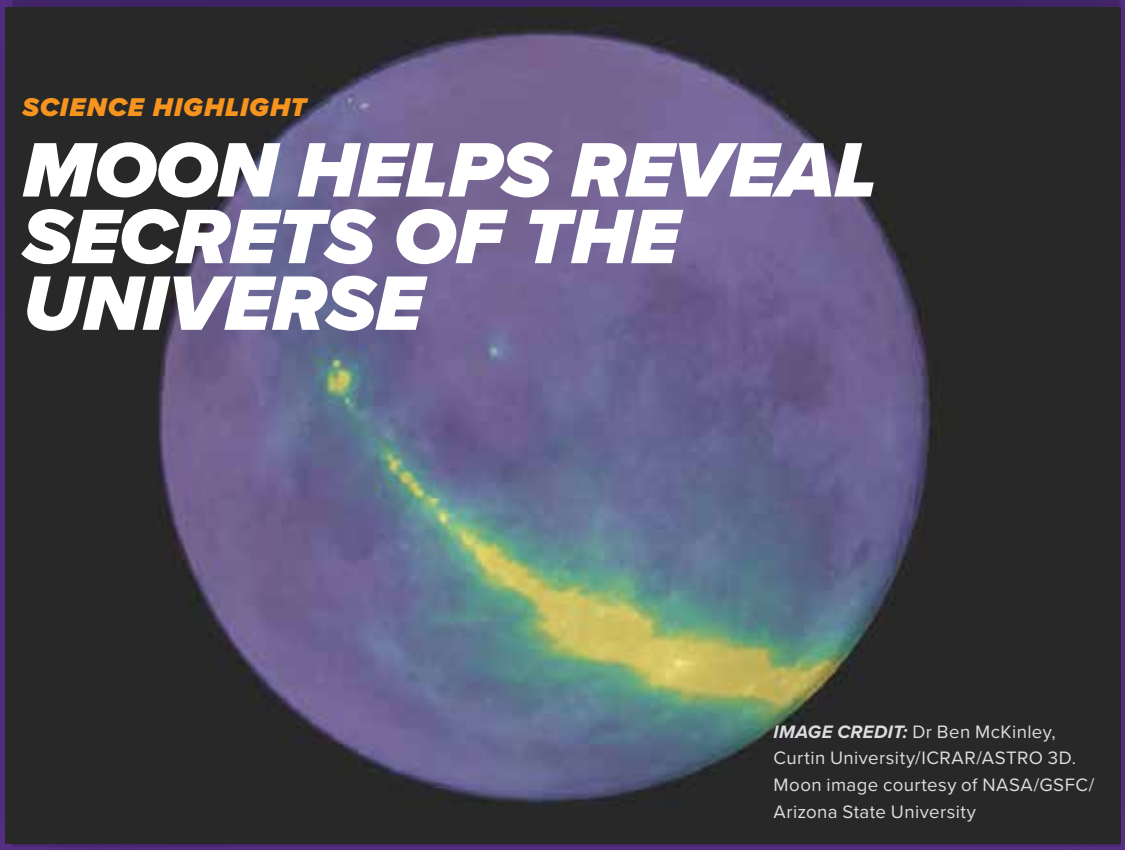


IMAGE CREDIT: Dr Ben McKinley, Curtin University/ICRAR/ASTRO 3D. Moon image courtesy of NASA/GSFC/ Arizona State University

A team of astronomers led by Dr Benjamin McKinley at Curtin University node observed the Moon with a radio telescope to help search for the faint signal from hydrogen atoms in the infant Universe.

“Before there were stars and galaxies, the Universe was pretty much just hydrogen, floating around in space,” Dr McKinley said. “Since there are no sources of the optical light visible to our eyes, this early stage of the Universe is known as the ‘cosmic dark ages’.

In research published in the Oxford University Press Monthly Notices of the Royal Astronomical Society, the astronomers describe how they have used the MWA radio telescope to help search for radio signals given off by the hydrogen atoms.

“This radio signal from the early Universe is very weak compared to the extremely bright objects in the foreground, which include accreting black holes in other galaxies and electrons in our own Milky Way. The key to solving this problem is being able to precisely measure the average brightness of the sky.

However, built-in effects from the instruments and radio frequency interference make it difficult to get accurate observations of this very faint radio signal. In this work, the astronomers used the Moon as a reference point of known brightness and shape. This allowed the team to measure the brightness of the Milky Way at the position of the occulting Moon.

The astronomers also took into account ‘earthshine’—radio waves from Earth that reflect off the Moon and back onto the telescope.

Earthshine corrupts the signal from the Moon and the team had to remove this contamination from their analysis.

With more observations, ASTRO 3D astronomers hope to uncover the hydrogen signal and put theoretical models of the Universe to the test.

RESEARCH PROJECTS AND SURVEYS

1. THE MWA EOR

The Murchison Widefield Array (MWA) is a low-frequency radio telescope in the Western Australian desert. Operating between 80 and 300 MHz, it explores many scientific questions. Principal among these is the search for signals from neutral hydrogen that resides between galaxies in the first billion years of the Universe. During this crucial evolutionary period, entitled the Epoch of Reionisation (EoR), the first stars and galaxies in our Universe were born, completing our understanding of the full history of the Universe. The hydrogen signal encodes key information about the spatial location and evolution of these first astrophysical objects, but its detection remains elusive due to the weakness of the signal compared with the foreground radio sky, and the complexity of the instrumental measurement.

The ASTRO 3D EoR program provides new measurements of this period of the Universe. During 2018, the team processed all of the highest-quality data observed over four years to create a database of data quality metrics. Utilising this database, they were able to choose the cleanest data with which to pursue this weak cosmological signal.

To achieve an EoR signal detection, the team have also further refined their understanding of the telescope, improving their knowledge of its response to the sky and its behavior over different observing frequencies. They have developed new tools to understand how to treat the data, including improving their ability to calibrate the telescope and remove the foreground sky. In addition, the extra sensitivity and capabilities of the upgraded MWA have afforded improved models for the bright, extended radio galaxies that contaminate their data. These advances have led to improvements in the limits That can be placed on the magnitude of the signal. Beyond the main science program, ASTRO 3D has enabled exploration of new techniques to tackle this difficult problem, broadening the impact of the project internationally.

Finally, ASTRO 3D creates key connections between the EoR theorists at the University of Melbourne, observers at Melbourne and Curtin University, and the Genesis Simulation Thread members at Melbourne, the University of Western Australia and Swinburne University. With joint student projects, we will use the sophisticated Genesis simulations to guide our observational program, simulating targeted experiments that allow more science to be achieved.

MWA antennas as part of a tile
IMAGE CREDIT: **mwatelescope.org**

2. THE FIRST STARS

The First Stars team are searching for the oldest stars in the Universe, which formed within a few hundred million years after the Big Bang. Some of these stars have survived to the present day and are currently located in and around the Milky Way galaxy. These stars contain crucial clues to the very earliest cosmic epochs. By measuring their chemical composition one can infer the nature of the very first generations of stars, the conditions during the formation of the first galaxies, how the cosmic dark ages ended, and even learn about the Big Bang itself. Studying relic stars in our Galactic neighbourhood thus complements observations of the most distant galaxies to probe the early Universe.

The properties of the First Stars uncovered by this project are crucial input to other ASTRO 3D projects, in particular, the Genesis simulations of the formation of the first stars and to the First Galaxies simulations.

To find these exceptionally rare ancient stars, the First Stars team make use of ANU's SkyMapper telescope located at Siding Spring Observatory near Coonabarabran. The SkyMapper telescope is surveying the whole southern sky with multiple colour filters, including observing very faint and distant stars. The very oldest stars in the Milky Way have extremely low content of elements heavier than helium – somewhat confusingly referred to by astronomers as "metals". This metal deficiency results in very characteristic colours in the SkyMapper data, which can be used to identify candidates for the oldest stars. From the many millions of stars in the SkyMapper catalogue, the First Stars team reduce it down to some 20,000 interesting objects.

With the SkyMapper filters, the photometric selection is working very well with the majority of the spectroscopic targets having extremely low metallicities (stars with an iron abundance that is less than 100th of the value in the Sun). Indeed, the team has demonstrated that the SkyMapper selection is not improved noticeably by inclusion of additional publicly-available observations, such as data from the Gaia satellite.

Skymapper Telescope at Siding Spring Observatory
IMAGE CREDIT: James Gilbert

The First Stars team are specifically targeting metal-poor stars in the halo and bulge of the Milky Way, regions where the oldest surviving stars are expected to reside today. In order to confirm their metal-poor star nature, medium-resolution spectra are being obtained of thousands of the SkyMapper candidates with the WiFeS spectrograph on the ANU 2.3m telescope, a time-consuming process requiring some 80 nights per year. Finally, the most interesting, metal-poor stars are then observed with 6–10m telescopes such as the VLT, Magellan (both located in Chile) and Keck (Hawaii) telescopes to determine their detailed chemical composition based on high-resolution spectroscopy. The team continues to be very successful in being awarded time on these highly competitive telescopes, including six nights on VLT for the first half of 2019.

In 2018, ASTRO 3D postdoc Dr Thomas Nordlander (ANU) discovered an extraordinary star, SMSS1605-1443. Remarkably, this happened during the very first night ever at a telescope for Thomas, who normally is a theoretician rather than an observer. This lucky find turned out to have the lowest ever measured iron and magnesium content of any star, implying it contains the nuclear ashes of

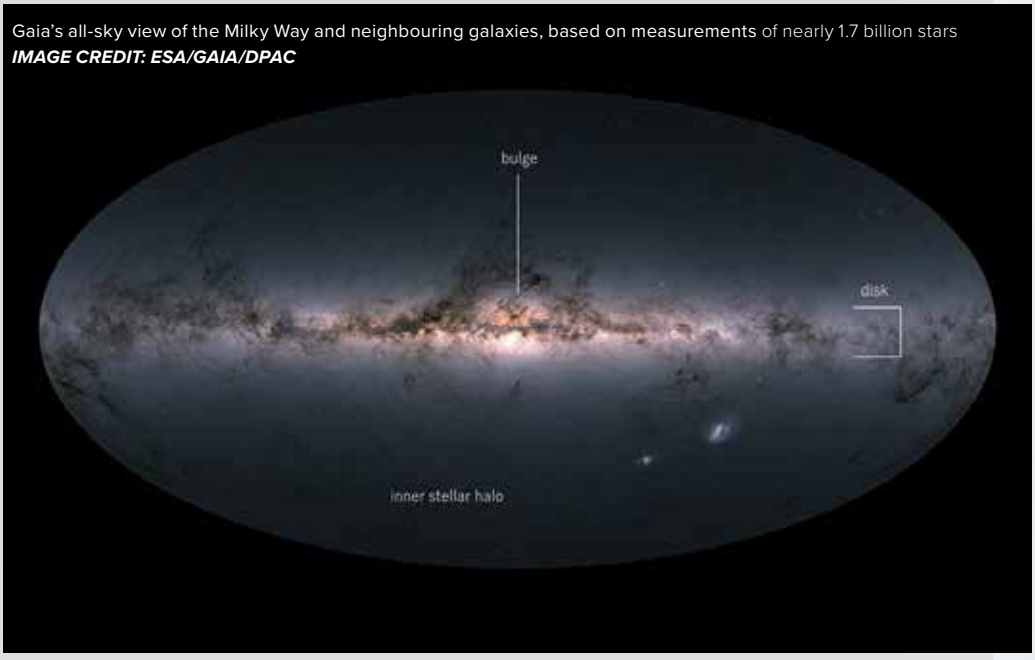
just a single supernova. The obtained Magellan spectrum allowed also the elemental abundances of carbon, calcium and titanium to be determined, which suggests that the supernova progenitor was relatively low mass; less than 20 times that of the Sun. A much improved VLT spectrum will be acquired in 2019, which will enable additional elements to be measured to set tighter constraints on the nature of the progenitor.

Team members AI David Yong (ANU) and Dr Anna Marino (Padova, Italy) chemically analysed some of the oldest stars observed by the team over the past few years with Magellan and Keck, respectively. These studies boost the number of extremely metal-poor stars the team has carefully determined the chemical compositions for to almost 300, the largest such sample ever analysed and providing a gold-mine for understanding the elusive nature of the first stars. Many stars show a wide diversity in their elemental abundance patterns as a result of stochastic enrichment of individual supernovae in the very first generation of stars.

PhD student Abdu Abohalima (ANU) has measured the abundances of elements heavier than iron in a large sample of extremely metal-poor stars in the Milky Way bulge. Such bulge stars are particularly interesting since they may in fact be the very oldest known stars, being on average even older than halo stars of the same metallicity. The heaviest elements are produced in either low mass red giants, exploding massive stars (core-collapse supernovae), or in the mergers of two neutron stars (which also generates gravitational waves which have recently been discovered by the LIGO collaboration).

Undergraduate student Ella Wang (ANU) has performed the most accurate spectroscopic calculations for lithium (Li) in order to address the long-standing cosmological lithium problem: why the observed Li abundance in the oldest stars is a factor of three lower than predicted by Big Bang nucleosynthesis models. Her new sophisticated computations imply that either the stars must have destroyed some of the lithium or our physical understanding of the Big Bang is incomplete. She has been awarded observing time with the new ESPRESSO spectrograph on VLT to test this in 2019.

Gaia's all-sky view of the Milky Way and neighbouring galaxies, based on measurements of nearly 1.7 billion stars
IMAGE CREDIT: ESA/GAIA/DPAC



SPOTLIGHT ON DR TIANTIAN YUAN

ASTRO 3D FELLOW

FROM SWINBURNE UNIVERISTY OF TECHNOLOGY

"I grew up in the countryside in China, and I remember when I was 6 or 7 or 8, I could see the Milky Way, because the light pollution in my little hometown is not that much. I could see the white band of the Milky Way span across the whole sky. My grandparents told me that in Chinese it was called the "Silver River" with milk and silver splashed across the whole sky. And that just triggered my raw curiosity, because I really wanted to know if there was really river, water or silver on the sky – that cannot be! Later on in Primary school, I learnt if you have a big telescope, you can resolve those white milky patches into individual, sparkling stars. I was really amazed – you mean those white fluffy things are actually individual stars?"

"Even to today, I think I have that raw curiosity in order to figure out where we are, what kind of galaxies we live in, are the galaxies we live in typical, is our world the only world that we know of, and that's what drives me everywhere, from China, to the United States, and now to Australia – I've been following that raw curiosity."

"My research is figuring out how galaxies, like our Milky Way came into being. If you shrink the length of the Milky Way into the size of my hand, the thickness of our Milky Way disc is as thin as a music CD, so it's very thin. Whereas if you go back in time, 10 billion years ago, the galaxies were as thick and puffy as my fist – so about two times smaller and ten times thicker and also very irregular. So how do galaxies go from this to a very thin CD disc is what my research is about. I focus on observing the earliest or oldest galaxies that are puffy and irregular and trying to figure out when was the earliest onset of those beautiful structures we see today, like our spiral arm."

"I love to push the observational boundaries – I love to observe things that we don't have a complete theory for yet."

"In order to look back to 10 billion years ago, I really need the largest optical and near-infrared telescope, so I've mostly been using the Keck Telescope on Mauna Kea in Hawaii, and sometimes I use Gemini. So it's mostly those 8-10 metre telescopes on top of Mt Mauna Kea. Recently I've been thinking of using some of the large telescopes at the VLT in the ESO, the European Observatory."

"I love to push the observational boundaries – I love to observe things that we don't have a complete theory for yet. My most recent exciting discovery is that I discovered and confirmed the most ancient spiral galaxy. I found a galaxy that has the most beautiful spiral arms as our own Milky Way 11 billion years ago. So that was amazing, because we thought that the Milky Way spiral structure doesn't appear until half the age of the Universe, which is about 6 billion years ago. But we can trace all the way back to 11 billion years ago and find galaxies that already exhibit spiral arms and structures like our own Milky Way – it just triggers your imagination – maybe it has planets and life all the way back then, 11 billion years ago!".

3. THE FIRST GALAXIES

The First Galaxies project is focused on discovering galaxies during the first billion years after the Big Bang and characterising their properties. 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 of the expected properties of these galaxies.

A large inflow of data taken with the Hubble Space Telescope kept the First Galaxies team busy throughout the year. The team analysed primarily infrared images taken by Hubble's Wide Field Camera 3 as part of the 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. Overall, they collected data worth about two weeks of Hubble time (about 300 orbits) over the last year, and more observations are being planned for 2019.

Searching for such galaxies means looking for sources so distant that their light has traveled for more than 13 billion years before it has reached us. This means that although they might appear as tiny reddish dots in the Hubble images, those galaxies are more luminous than our own galaxy, the Milky Way, each likely already having formed billions of stars. Spotting them is not always easy, and sometimes relatively nearby objects (only 7-9 billion light years away) masquerade as "impostors" with similar appearance and color. However, the team's optimsied observational strategy that involves following-up sources to measure their colors more accurately purifies the sample efficiently, as ASTRO 3D DECRA Fellow Dr Rachael Livermore demonstrated in a paper published in the Astrophysical Journal in July (see image below). In addition to Dr. Livermore's high-impact publication and press release, the First Galaxies team published 15 other peer-reviewed articles on a wide range of topics related to formation and evolution of stars and galaxies across cosmic time.

In 2018 the First Galaxies team also welcomed a new ASTRO 3D Fellow based at the Melbourne node, Dr Maryam Arabsalmani. Maryam is an expert on multi-wavelength observations of galaxies that host some of the most energetic explosions in the Universe, Gamma Ray Bursts (GRB) and Super-Luminous Supernovae. Maryam's strengthens the team's research focus on data from ground-based telescopes to complement space-based observatories, and we are planning to combine information from GRB host galaxies with data from Hubble surveys such as BoRG to investigate how stars form, evolve (and explode) at cosmic dawn.

Hubble Image of galaxy cluster Abell S1063, 4 billion light years away from Earth. The cluster's massive gravity allows Hubble to see even further back into the Universe, by warping and magnifying the light of galaxies behind it, called gravitational lensing. IMAGE CREDIT: NASA/ESA/J. Lotz (STScI)

SCIENCE HIGHLIGHT

A GALAXY (NOT SO) FAR, FAR AWAY

The Brightest of Reionising Galaxies (BoRG) survey team used the Hubble Space Telescope to observe two galaxies (BoRG 0116+1425 747 and BoRG 0116+1425 630). They originally thought they were more than 13.2 billion years old when the Universe was about 5% of its current age.

The effect known as redshift gives distant galaxies distinct colours that can indicate how far away they are. But some relatively nearby galaxies have deceptively similar colours, lending uncertainty to their estimated distance.

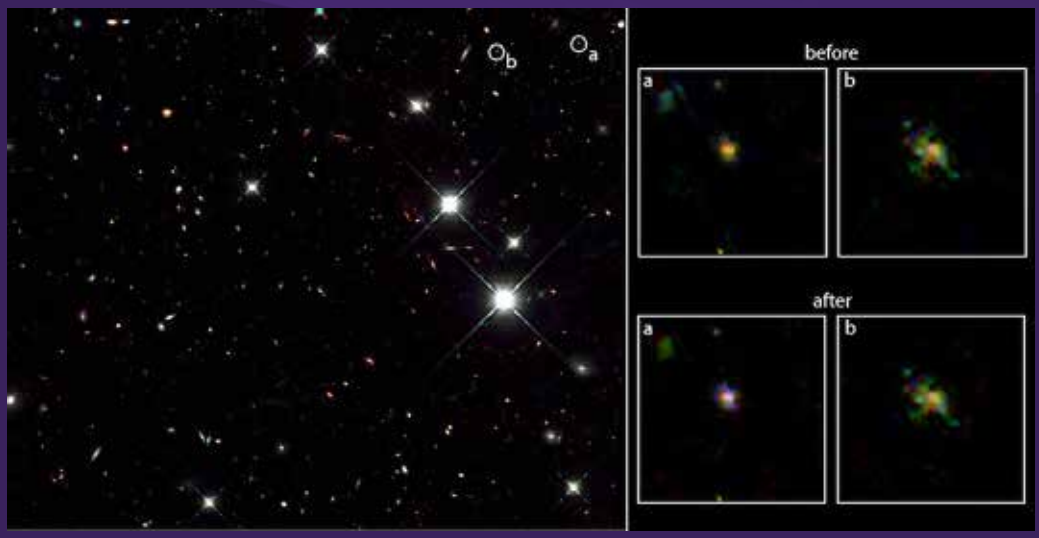
The redshift observed for these two galaxies indicated that the light had been emitted by them a very long time ago. In fact, BoRG 0116+1425 630 was estimated to be the oldest bright young galaxy ever detected.

Their results confirmed BoRG 0116+1425 747 as a highly-probable distant bright galaxy. However, they discovered that BoRG 0116+1425 630 is likely to be an "interloper", relatively nearby and much younger than previously thought.

Dr Rachael Livermore, who led the research, said "Now that we have a better measurement of the colours, it looks as though the brightest galaxy is actually relatively nearby – we see it only nine billion years back in time, whereas it was previously thought to be 13 billion."

This galaxy was incredibly bright compared to its peers. "This makes it a perfect target for further study, so that we can really understand what's going on inside galaxies way back in the early years of the Universe," Dr Livermore said.

The researchers say this discovery has profound implications for models of how galaxies formed when the Universe was in its infancy and that ultra-bright galaxies in the early Universe may be less common than scientists initially thought.



The colour composite image on the left is taken in near-infrared light and shows the location of the two candidate galaxies initially thought to be at a distance of more than 13.2 billion light-years from Earth. The close-up images on the right show a zoom-in of the two galaxies. The top row uses data from the initial discovery, while the bottom row shows the colours using additional, more precise observations. ***IMAGE CREDIT:*** **R Livermore, M Trenti, and the BoRG team via U. Melbourne)**

4. GALAXY EVOLUTION

The Galaxy Evolution program tracks mass assembly, chemical evolution and ionising radiation across 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. In 2018, many new postdoctoral staff started at ANU and Swinburne. There are now over 22 people contributing to the galaxy evolution workplan and around 40 people within this project overall.

The Swinburne team, led by CI Karl Glazebrook began applying advanced data mining techniques to large surveys such as the Dark Energy Survey) to discover rare gravitational lenses to provide an amplified view of the distant Universe. Using the deep learning technique of 'convolutional neural networks', they discovered dozens of new lens candidates, many of which were confirmed on the European Southern Observatory Very Large Telescope (VLT) and the Magellan Telescope in Sep-Oct 2018. This new sample will be used to test dark matter models of galaxies and provide magnified views of the high-z universe. ASTRO 3D Fellow Dr Trevor Mendel is helping to extend this work to the VISTA IR surveys to look for distant lensed elliptical galaxies. One of the main challenges when using lensing is how to reconstruct images when natural lenses have different magnifications in different images. Traditional codes use a fixed grid and handle this poorly. ASTRO 3D PhD student at the ANU Soniya Sharma has developed a new adaptive resolution forward modelling approach which accounts for local signal-to-noise ratio and magnification and in 2018 she applied this to a lensed arc at z=2.225 achieving an unprecedented resolution of 170 parsecs.

The ASTRO 3D Galaxy Evolution fellows were very productive in 2018. Fellow Dr Tiantian Yuan observed high redshift spiral galaxy candidates to determine when and how spiral-arm structures form in the universe. She discovered the earliest known spiral galaxy, while Fellow Dr Emily Wisnioski published a major paper analyzing 35 compact, massive distant star-forming galaxies. Emily's analysis showed that galaxies stop their star formation and become quiescent while they still have disks.

CI Emma Ryan-Weber and ASTRO 3D postdoc Rob Bassett are investigating calibration proxy for escaping Lyman continuum (ionising) flux using rest-frame optical emission lines. The measured optical emission lines will provide a critical measure of the ionization properties of these galaxies, whose more distant counterparts are responsible for reionising the Universe. With colour selection and spectroscopy of Lyman continuum (ionising) galaxies, we will measure the escape fractions of ionising radiation, a crucial parameter for the Genesis Simulations. The galaxies discovered will help understand the foregrounds in the MWA EoR data, and their history will be compared with the archaeological history of the Milky Way from the GALAH survey.

The ANU galaxy evolution team led by CI Lisa Kewley has completed their work on developing chemical abundance, ionisation and pressure diagnostics for galaxies across 12 billion years of cosmic time. ASTRO 3D postdoc Dr Nell Byler produced new UV diagnostics that will be important for measuring the chemistry of the most distant galaxies observed with the VLT and, in future, the James Webb Space Telescope. ASTRO 3D postdoc Dr Phil Taylor incorporated the effects of supermassive black hole feedback into his chemical evolution models of galaxy evolution and began large simulation runs on the NCI.

In November 2018, the Galaxy Evolution project held an important national planning meeting (kindly hosted by UNSW) to bring the different threads of the project together. The brainstorming at that meeting united the team together behind three large programs addressing ionization, chemical evolution, and mass assembly of galaxies. Swinburne will be hosting a proposal-writing busy week at Swinburne in February 2019 to write joint proposals to observe the distant universe from both hemispheres using VLT and Keck.

5. THE ASKAP SURVEYS

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

- The WALLABY survey (led by PI Bärbel Koribalski and CI Lister Staveley-Smith) will cover three-quarters of the sky and is expected to detect the 21cm HI emission-line from up to 600,000 galaxies, looking back 2 billion years in cosmic time.
- The DINGO survey (led by AI Martin Meyer) focuses on the evolution of galaxies and the gas-rich Universe out to 4 billion years ago and expects to detect up to 100,000 galaxies through deep ASKAP observations spanning 60 square degrees of sky.
- The FLASH survey (led by CI Elaine Sadler and AI James Allison) will search for the 21cm HI line in absorption against bright continuum sources across the whole southern sky, and will probe the neutral gas content of several hundred individual galaxies between 4 and 8 billion years ago, where the HI emission line is too weak to be detectable in even the deepest ASKAP surveys.

In 2018, the Wallaby and Dingo teams carried out Early Science observations with ASKAP arrays consisting of 16 to 28 Phased Array Feed-equipped antennas (out of 36). The FLASH project also transitioned from CAASTRO to ASTRO 3D.

WALLABY

In 2018 a series of WALLABY Early Science papers were submitted for publication, based on ASKAP-12 observations of four 30-square-degree

Phased Array Feed (PAF) receiver on an ASKAP radio telescope - each PAF is made up of 188 individual receivers, positioned in a chequerboard-like arrangement. Alongside the receivers are low-noise amplifiers, which greatly enhance the weak radio signals received. This new technology gives the telescopes a wide field-of-view and makes ASKAP the fastest radio telescope in the world for surveying the sky, taking panoramic snapshots over 100 times the size of the full Moon. **IMAGE CREDIT:** CSIRO

fields. Paper I was led by UWA PhD student Tristan Reynolds on the NGC 7162 galaxy group and contains a comprehensive kinematic analysis of six WALLABY galaxies. Paper II was led by CASS postdoc Dr Karen Lee-Waddell on the interacting NGC 7232 galaxy group, which features tidal HI streams and clouds. Paper III was led by UWA PhD student Ahmed Elagali on the spiral galaxy NGC 1566. Several other papers are in preparation including: (1) the nearby spiral galaxy IC 5201, led by Dane Kleiner, now part of Paolo Serra's team at INAF, Sardinia; (2) the wider NGC 1566/Dorado field, led by PhD student Ahmed Elagali and ASTRO 3D postdoc Dr Jonghwan Rhee; and (3) a census of gas-rich M83 background galaxies in the Hydra-Centaurus region led by ASTRO-3D Fellow Dr Bi-Qing For.

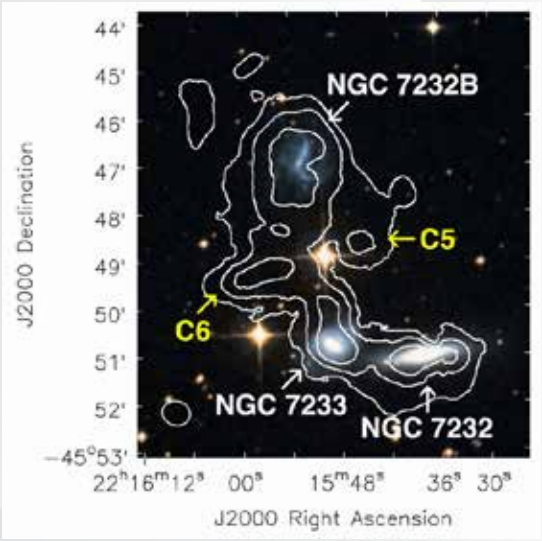
Testing of the ASKAP software pipeline continued, with most Pawsey data processing now in the hands of the dedicated ASKAP operations team. The WALLABY source-finding group, coordinated by UWA AI Tobias Westmeier, continued to improve the 3D Source Finding Application (SoFiA), and is exploring options for parallelization for fast processing on Pawsey supercomputers. SoFiA is employed to find and characterize WALLABY HI sources, and has been used for all Early Science studies.

WALLABY is a large team of over 100 Australian and international scientists, but the dedication of the core early-science data processing group, coordinated by Karen Lee-Waddell and Attila Popping, has been the key to the rapid progress achieved in 2018. The group has about 10-15 active members, and has been responsible for data processing and debugging the ASKAPsoft pipeline, and data validation and verification. Dr Bi-Qing For is leading the validation and data control effort. Swinburne PhD student Chandra Murugeshan has also started to work on WALLABY Early Science data.

Many WALLABY presentations were given during the year, including at the Barossa workshop (AI Koribalski and Mr Elagali), and the Annual Science Meeting. The broader membership was kept updated via the updated www pages and via two WALLABY Newsletters, edited by UWA's Dr Ivy Wong.

ASTRO-3D Distinguished Visitor Kristine Spekkens (Royal Military College in Canada) spent a productive period at UWA and the Annual Retreat. She is the coordinator of the WALLABY kinematics group which aims to ramp up activity in 2019, partly funded by the Canadian CIRADA grant.

Finally, towards the end of 2018, the WALLABY executive was joined by three at-large members, namely AI Virginia Kilborn, Jeremy Mould and Kristine Spekkens. These members bring invaluable high-level experience to the project and are expected to advise on future strategies and project implementation.



ASKAP HI intensity distribution of the NGC 7232 galaxy triplet (white contours) overlaid onto an optical DSS 2 colour image. Two HI clouds are marked as C5 and C6. **IMAGE CREDIT:** WALLABY Survey

SPOTLIGHT ON AYAN ACHARYYA

PHD STUDENT FROM AUSTRALIAN NATIONAL UNIVERSITY

"I was really able to get into astronomy because of the series of opportunities that presented themselves to me when I was at university. So through summer projects, short-term projects and working with other astronomers from other institutes, it paved the way for me to be able to do a PhD in astronomy, which I am doing right now."

"I am looking at galaxies in the very early, very distant Universe, about 10 billion years ago and trying to figure out what quantity of life-supporting elements were present. Carbon, oxygen, and nitrogen are essential to life on Earth and were not present at the beginning of the Universe. They all started at some point, and they've been growing ever since, to the point that they can support life, for at least one planet that we know of. I'm looking at these very, very distant galaxies with very powerful telescopes to try and determine which of these elements are present."

"I'm a student, who is just starting in my research career now, so it can sometimes get a bit overwhelming, to go to conferences and meetings, and interact with so many people who are working in so many different areas of astronomy. The most exciting opportunity is all these different interactions with different people, but I think it becomes easier when you're part of a team and around all these other people, who have been through the stage you are going through currently."

"The most exciting opportunity is all these different interactions with different people."

DINGO

The initial DINGO Early Science program was conducted between September 2017 and March 2018, with the project taking data over six nights (corresponding to ~70h of integration time in total) with the ASKAP-12 and ASKAP-16 arrays (192 MHz and 240 MHz bandwidth, respectively). These observations targeted an area on the sky known as the GAMA (Galaxy and Mass Assembly project) 23H that is well-studied in radio astronomy in two different frequency configurations, matching the redshift range planned for the full survey. These data are being used to develop and test the DINGO data reduction pipelines, characterise radio frequency interference, and to carry out early HI emission-line stacking experiments.

Complementing these ASKAP Early Science data, Ph.D. student Qingxiang Chen finished his processing of the DINGO Very Large Array data in the GAMA 09h field, and is now carrying out a $z < 0.1$ HI stacking analysis, investigating both spectral and cubelet stacking methods.

Another Ph.D. student, Kristóf Rozgonyi, carried out an initial analysis of uv-gridding and aligned-deep-imaging techniques. These methods aim to provide a new way to combine the multi-epoch DINGO data, and to provide a way for storing visibility data for the survey. Kristóf has tested these new techniques on simulated data with promising results, and he is now working on the ASKAP early science observations to apply his methods to real data.

Dr Jonghwan Rhee joined the DINGO team in June 2018 as an ASTRO 3D research scientist. Jonghwan's efforts have focussed on processing the DINGO early science data using ASKAPsoft on the Galaxy Supercomputer at Pawsey, including a 16 MHz datacube ($z < 0.0113$) with 144 PAF beams over the GAMA 23h field. This yielded a promising HI stacked spectrum from the 22 GAMA galaxies in the field. Jongwhan is now processing another 32MHz datacube ($0.039 < z < 0.064$) with the goal of yielding a higher signal-to-noise detection, this volume containing more the 1300 galaxies for stacking.

For phase 2 of ASKAP early science, the DINGO team has proposed 30-hr test observations for four GAMA fields (9h, 12h, 15h, and 23h) using the 28 antennas currently available before the ASKAP pilot surveys begin with the full 36-dish array in early 2019.

FLASH

The FLASH team began the year with a very successful Simulations Workshop held at UWA in February 2018. This was a joint meeting with members of the Genesis Simulations team (including CI Chris Power and AI Claudia Lagos), to plan a set of simulations that will allow us to use data from the ASKAP FLASH survey to test different theoretical predictions for the amount and distribution of HI gas in distant galaxies.

Much of the focus this year was on multi-wavelength follow-up observations of galaxies where the team's ASKAP commissioning observations detected HI in the redshift range $z = 0.4$ to 1. In particular, a paper by Allison et al. used the Atacama Large Millimetre Array (ALMA) to detect a rare example of redshifted 12CO (2-1) absorption in the $z=0.44$ radio galaxy PKS B1740-517, providing us with a detailed picture of the cold ISM within this recently-triggered young radio galaxy. From early 2019, the FLASH team will begin new a new program of radio observations with the full 36-antenna ASKAP array.

FLASH team members gave presentations at many conferences during the year, including the SKA Pathfinder HI Science Coordination Committee (PHISCC) meeting in China, the IAU General Assembly in Vienna, and the 'HI Absorption 2018' conference at ASTRON in the Netherlands (organized by PI Raffaella Morganti).

There were some changes to the structure of the FLASH project this year, with James Allison (previously an ASTRO 3D Fellow, and now at Oxford University) joining CI Elaine Sadler as co-PI of the FLASH survey. We also welcomed Frof Sara Ellison (University of Victoria, Canada) and PI Raffaella Morganti as international members of the FLASH executive.

IMAGE CREDIT: CSIRO

SPOTLIGHT ON DR BARBARA CATINELLA

CHIEF INVESTIGATOR FROM THE UNIVERSITY OF WESTERN AUSTRALIA

"I've been interested in astronomy since I was a kid, mostly thanks to my Dad who really loved science, so he would bring me some of his very nice magazines about astronomy research with pretty pictures, and I got really excited and really interested about that, then he bought me a telescope, so I started to do my little observations using it, and that was really fun."

"As a researcher, my goal is to understand the universe that we live in, and in particular I'm interested in knowing the story of galaxies. So objects like the Milky Way, which contains billions of stars and lots of other materials. In particular, gas, atomic hydrogen, which is the material out of which new stars are made. I want to understand how galaxies are formed, and evolve. And a very important piece of the puzzle is understanding how gas is used to make new stars. How stars live, and die, and how the gas is returned to the galaxy when the massive stars are exploded supernovae. So it's a very exciting field."

"I'm an observer, so I have colleagues that do numerical simulations, but I'm really more of an observer and I use radio telescopes. This is because emission from atomic hydrogen is detected with the telescopes, and I've been using some of the largest telescopes in the world like the Arecibo telescope which is located in Puerto Rico in the USA. People might be familiar with this because there were a couple of movies made like Contact, which was a very great sci-fi movie, and also one of the James Bond movies, and so I did a post-doc there, for four years, I learned how to use the telescope very well, and I did most of my recent work there. But I've also been using very large optical telescopes, at Mt Palomar in the states for my PhD research and Keck."

"My most exciting discovery was made when I was doing my post-doc in Arecibo. I was interested in measuring the gas content of galaxies, and detecting atomic hydrogen is very difficult because emissions are very, very faint, so you need very big telescopes, and Arecibo was the largest in the world until very recently, until about a year ago, when China built an even bigger one. And that was by far the best instrument to use to try and do this work. So I really pushed this telescope to its limit, trying to find the gas emissions from the farthest galaxies which was physically possible to do. So I had the record for the most distant atomic hydrogen detected for about a decade."

"ASTRO 3D is a fantastic Centre of Excellence, and I think the most exciting thing is to have the possibility and opportunity to interact with so many bright scientists in my area. So getting together people, very bright students, and researchers at a level and really putting our minds together to try to solve some of the most longstanding issues that are still open in our field."

"I really pushed this telescope to its limit, trying to find the gas emissions from the farthest galaxies which was physically possible to do."

6. SAMI/HECTOR SURVEYS

In 2018, the SAMI survey completed its observational program of obtaining 3D data cubes for over 3000 galaxies in the nearby Universe. Integral-field spectroscopy with SAMI allows the measurement of a huge range of galaxy properties that are impossible to obtain from single-fibre surveys and allows direct tests of the latest galaxy-formation simulations. SAMI observables include gas and stellar internal and bulk kinematics, the spatial distribution of star formation, stellar metal content and age gradients, gas oxygen abundance distributions, resolved ionisation diagnostics and many others. This is the first 3D sample that is sufficiently large to disentangle the competing roles of galaxy mass and environment. As a result, the SAMI team can address the following three key questions:

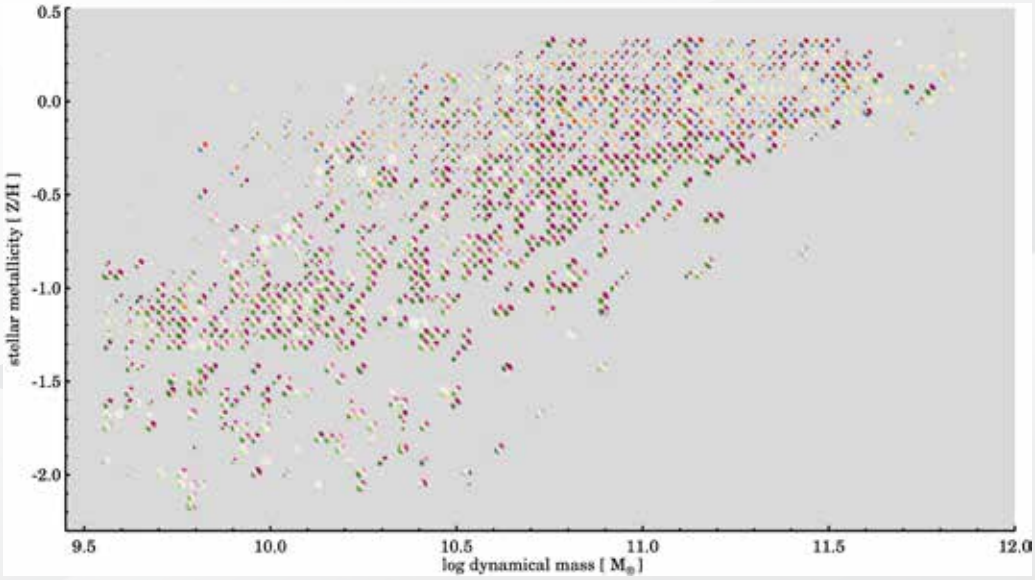
1. What is the physical role of environment in galaxy evolution?

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

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

As well as completing the observational program for SAMI (May 2018), this year the team also made its second major data release. This included cubes and value-added products for 1559 galaxies. Data release two was the first sample to include stellar kinematics and population measurements as well as the emission line measurements also provided in earlier releases. Over the last year the team have published key science papers for a number of fields. These include ASTRO 3D PhD student Henry Poetrodjojo, who led work measuring the distribution of gas phase metallicity and ionisation parameter across SAMI galaxies. AI's Jesse van de Sande and Nic Scott published a Nature Astronomy paper demonstrating the link between stellar population ages and galaxy shapes. ASTRO 3D Fellow Dr Caroline Foster used the stellar kinematics in the outer parts of SAMI galaxies to look for embedded disks and signatures of two-phase galaxy growth.

Work on SAMI in 2019 will focus on final analysis of the complete sample, with studies of star-formation quenching, the correlation of galaxy spin to large-



Data Release 2 galaxies - stellar metallicity within one effective radius versus dynamical mass. We show stellar velocity maps for all early-type galaxies (blue-red) and gas velocity maps for the late-type galaxies (green-purple). For each galaxy we show its velocity map aligned to 45° using the stellar or gas kinematic position angle, with the velocity range set by the stellar mass Tully-Fisher relation. A regularisation algorithm is applied to avoid overlap of the velocity maps; dynamical masses and metallicities are indicative, not exact. IMAGE CREDIT: Jesse van de Sande, Andy Green, Scott Croom

scale-structure, gas kinematic misalignment, stellar population gradients, decomposition of galaxies into bulge and disk and much more. The treatment of complete stellar kinematics will be developed through international collaboration and a workshop on dynamical modelling.

In parallel, effort is focused on the replacement for SAMI, the HECTOR instrument. HECTOR will increase the power of SAMI in terms of spectral resolution, spatial sampling and galaxy number. HECTOR will be commissioned on the Anglo-Australian Telescope at the end of 2019.

There is a substantial effort currently committed to instrument development. Procurement of spectrograph components is currently underway, along with manufacture of fibre bundles and development of the robotic positioner for fibre placement. At the same time, the HECTOR Galaxy Survey team is finalisng the input catalogue for the survey and developing an upgrade to the data-processing pipeline in time for the start of observations.

SPOTLIGHT ON PROF JOSS BLAND-HAWTHORN

CHIEF INVESTIGATOR FROM THE UNIVERSITY OF SYDNEY

"My awareness of space, I think, started with the lunar landings when I was a young child. That blew me away – the idea of actually walking on the moon's surface. At the age of 12, somebody pointed out the Milky Way to me and said "do you know why we have a Milky Way?" and I said "no idea" and they said "because we live in a flat galaxy" and I just couldn't believe that you could learn something about an entire galaxy from Earth, looking up at the stars."

"My primary interest is in the understanding of the Galaxy – where the Milky Way Galaxy came from - for the simple reason that the Galaxy is so different in terms of what we can learn from any other galaxy, even nearby galaxies. We can learn about stars, from brown dwarfs all the way up to super-giants and we can learn about things that you can never hope to learn at the highest redshifts and distances. I don't think that even 100 years from now, we'll do things at high redshift that you can do in the Galaxy."

"The telescopes I tend to concentrate on are the infrared and the optical telescopes and at the moment, we are more concerned with what Australia is doing for this work. Australia has been building instruments that can look at 400 stars at once. In the olden days, you looked star by star – literally, the telescope would go over here, over there, one star at a time. Today, it's 400 fibres – optical fibres – and we use robots to position them on 400 stars because each star pattern is different."

The light from those fibres goes down a path of 50 metres to a giant spectrograph on the floor at the bottom of the telescope. And then the light arrives at the spectrograph and gets dispersed into a rainbow of colours and if you magnify those rainbows, there's a lot of detail, due to the presence of elements. So we learn all through space, up to the highest redshifts, we can learn about the metals, the elements that make up the light of a star. Those spectra tell us about how the elements have been evolving over cosmic time.

Nowadays, astronomy is very collaborative. We have all these new telescopes – optical, satellites, and extremely large telescopes coming online. I think ASTRO 3D really allows us to organise, in an effective way, to make use of these opportunities, because Centres of Excellence are funded to allow for those collaborations and connections to happen.

SCIENCE HIGHLIGHT

GALAXIES GROW BIGGER AND PUFFIER AS THEY AGE

Scientists from ASTRO 3D have found that galaxies grow bigger and puffier as they age.

"Galaxy shape and age are not obviously linked so the connection is surprising and may point to a deep underlying relationship," lead author Dr Jesse van de Sande from the University of Sydney said.

Co-researcher Professor Matthew Colless from ANU said that stars in a young galaxy moved in an orderly way around the galaxy's disk, much like cars around a racetrack. "All galaxies look like squashed spheres, but as they grow older they become puffier with stars going around in all directions," said Professor Colless from the ANU Research School of Astronomy and Astrophysics, and Chief Investigator of ASTRO 3D. "Our Milky Way is more than 13 billion years old, so it is not young anymore, but the galaxy still has both a central bulge of old stars and spiral arms of young stars."

To work out a galaxy's shape, the research team measured the movement of stars with an instrument called SAMI on the Anglo-Australian Telescope at the ANU Siding Spring Observatory. They studied 843 galaxies of all kinds and with a hundred-fold range in mass. The study, which is published in Nature Astronomy, was funded by the ARC Centre of Excellence for All Sky Astrophysics in 3 Dimensions (ASTRO 3D) and the ARC Centre of Excellence for All Sky Astrophysics (CAASTRO) at Sydney and ANU.

"As a galaxy ages, internal changes take place and the galaxy may collide with others," Dr van de Sande said. "These events disorder the stars' movements."

Co-author Dr Nicholas Scott from the University of Sydney, and a researcher in ASTRO 3D, said scientists measured a galaxy's age through colour. "Young, blue stars grow old and turn red. When we plotted how ordered the galaxies were against how squashed they were, the relationship with age leapt out. Galaxies that have the same squashed spherical shape, have stars of the same age as well."

Dr van de Sande said scientists had known for a long time that shape and age were linked in very extreme galaxies, that is very flat ones and very round ones. "This is the first time we've shown shape and age are related for all kinds of galaxies, not just the extremes – all shapes, all ages, all masses."

LEFT IMAGE: Hubble image of NCG 3501 galaxy – a flattened young galaxy ***IMAGE CREDIT:*** Dane Kleiner (CSIRO — CASS)

RIGHT IMAGE: Virgo cluster galaxy NGC 4660, an elliptical located about 50 million light-years from Earth ***IMAGE CREDIT:*** ESA, NASA and E. Peng (Peking University, Beijing)

7. GALAH SURVEY

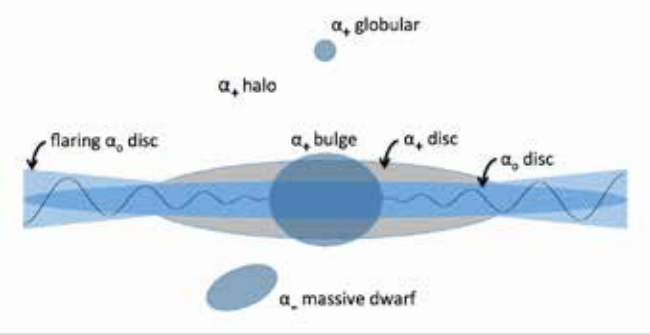
The GALactic Archaeology with HERMES (GALAH) survey is aiming to unravel the assembly, star formation, dynamical and chemical history of the Milky Way through the nucleosynthetic fingerprints encoded into the chemical compositions of up to a million stars. The survey uses the AAT and the HERMES spectrograph, with which 400 stars can be observed simultaneously at high spectral resolution. To date, half a million stars have been observed, already the largest spectroscopic survey at high-resolution ever undertaken.

The GALAH observations and data reduction are led out of Sydney (CI Joss Bland-Hawthorn, Dr Janez Kos, AI Sanjib Sharma, University of Sydney, AI Sarah Martell, UNSW, AI Gayandhi De Silva, AAO, among others) while the spectrum analysis pipeline to determine stellar parameters and elemental abundances was developed at ANU (CI Martin Asplund, Ly Duong, PhD student Jane Lin) and MPIA, Germany (Sven Buder, Karin Lind). These data are complemented by more than 100,000 stars observed by NASA's K2 (extended Kepler mission) and TESS, two major satellites used for exoplanetary science and asteroseismology (programs led by AI Sanjib Sharma, and Dennis Stello, UNSW). Many of these stars will thus have asteroseismic information on stellar masses and ages. There are also complementary programs on open clusters (AI Gayandhi De Silva) and the Galactic bulge (Ly Duong, CI Martin Asplund).

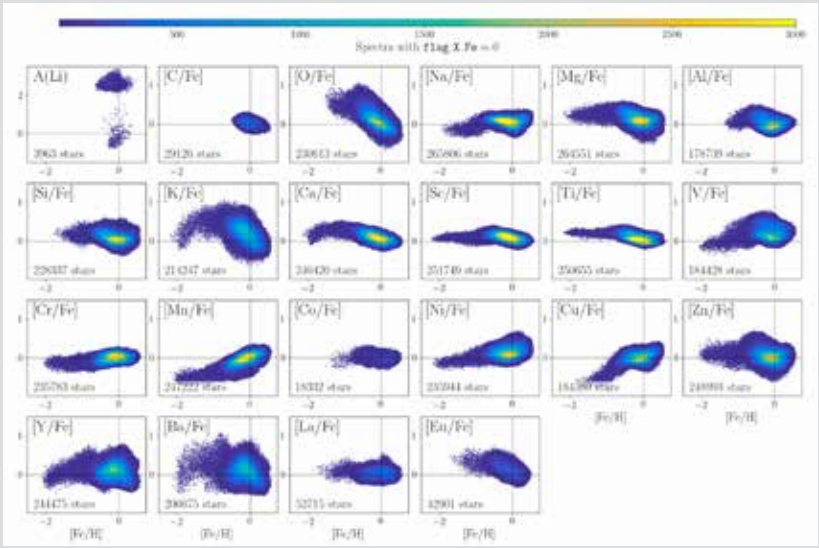
2018 was a massive year for the GALAH survey, which saw enormous progress towards achieving its very ambitious goals. In April, the GALAH team published the second public data release (DR2), containing accurate stellar parameters and detailed abundances for more than 20 elements for almost 350,000 stars, an unprecedented dataset. Accompanying the scientific data was the publication of ten scientific articles discussing some of the most interesting results published by the GALAH team. GALAH DR2 was timed to coincide with the second Gaia data release, which included parallaxes and thus distances to all GALAH stars. The combination of the two datasets is thus a phenomenal gold-mine for Galactic archaeology and has already been extensively used by a large number of research groups around the world – the GALAH survey will undoubtedly be the premier spectroscopic survey of the Milky Way for many years. The GALAH DR2 was reported extensively in Australian and overseas media.

University of Sydney postdoc Dr Janez Kos discovered new members of the Pleiades star cluster through 3D kinematics from Gaia DR2 and high-dimensional chemical tagging. He used the same technique to show that some famous open star clusters first catalogued in 1888 are in fact random projections and not real entities. Jeffrey Simpson (AAO and UNSW) demonstrated that some co-moving stellar pairs in the Galaxy emanate from the same birth site, but some do not, which has important implications for using chemical tagging to identify stars born together.

PhD student Sven Buder (MPIA, Germany) led a detailed study of the chemo-dynamical history of the solar neighbourhood using overlapping stars



A schematic of the Milky Way galaxy showing the inner stellar bulge, the thin disc (carrying most of the stars) and the faint thick disc. The Gaia satellite has discovered an undulating wave within the thin disc, now confirmed by the GALAH survey which also showed that the amplitude gets larger with increasing radius. The alpha notation refers to [alpha/Fe], i.e. the enhancements of alpha-elements relative to iron, which are either high (+), solar (o) or low (-) depending on where you are looking in the Galaxy. The high values are associated with the oldest stars in the Galaxy.



The GALAH survey recently released velocities and elemental abundances for hundreds of thousands of stars. Each box shows the enhancement of an element relative to iron, as a function of the abundance of iron: note the different distributions in each case. From these remarkable data, we are trying to learn how the Galaxy formed and evolved over billions of years.

with Gaia, finding a clear distinction between the Milky Way thin and thick disks in terms of age, metallicity and the abundances of alpha elements such as oxygen and magnesium. ANU PhD student Ly Duong found more evidence for the distinct formation history and separation of the thin and thick disks using stellar abundances. She also carried out a detailed comparison with the chemistry of bulge stars. This was extended further by ASTRO 3D Fellow Michael Hayden (University of Sydney) who showed complex kinematic trends in the thick vs. thin disks, and also found evidence for stellar migration throughout the disks.

CI Joss Bland-Hawthorn (University of Sydney) managed to dissect the local disk in terms of age, action, chemistry and location. This work confirms a remarkable discovery of a “phase spiral”, a signature of phase mixing after the disk has been violently disturbed by a colliding dwarf galaxy. The stellar disk is found to be corrugated with the strongest signature confined to the younger thin disk. Detailed simulations by Affliiate Dr Thorsten Tepper-Garcia (University of Sydney) were used to put constraints on the mass of the perturbing dwarf galaxy and the timescale for the last disk-crossing collision less than 400 Myr ago. PhD student Shourya Khanna (University of Sydney) revisited the distribution of non-rotational motions in the Galaxy and found that the streaming motions (departures from circular motion) were on average very small (<4 km/s), contrary to recent claims by other Galactic surveys.

PhD student Jane Lin (ANU) has successfully determined ages and masses for almost 200,000 of the GALAH stars based on their luminosities and surface temperatures and state-of-the-art stellar evolutionary models. She concluded that the overall metal content in the thin disk has not increased noticeably over the past 10 billion years but that there is substantial scatter at all ages, a distinct signature of the migration of stars through the Galaxy. Intriguingly she also finds evidence for a star formation burst coinciding with the thick disk 10-12 billion years ago.

The ANU and MPIA spectroscopic analysis team has worked hard to improve the stellar parameters and abundances using the new and accurate Gaia distances. The new GALAH dataset will be released to the community in 2019 but early results are extremely encouraging, demonstrating the excellent complementarity between GALAH and Gaia. The ANU team was joined in November by ASTRO 3D postdoc Govind Nandakumar.

The GALAH survey is now embarking on its second phase for observations during 2019-2020. By preselecting stars based on Gaia distances, GALAH is now specifically targeting stars for which reliable ages can the determined, the biggest uncertainty in Galactic archaeology at present time. Phase 2 will result in some 650,000 stars with accurate ages and abundances.

SCIENCE HIGHLIGHT

MILKY WAY STARS KICKED OUT BY AN INVADING GALAXY

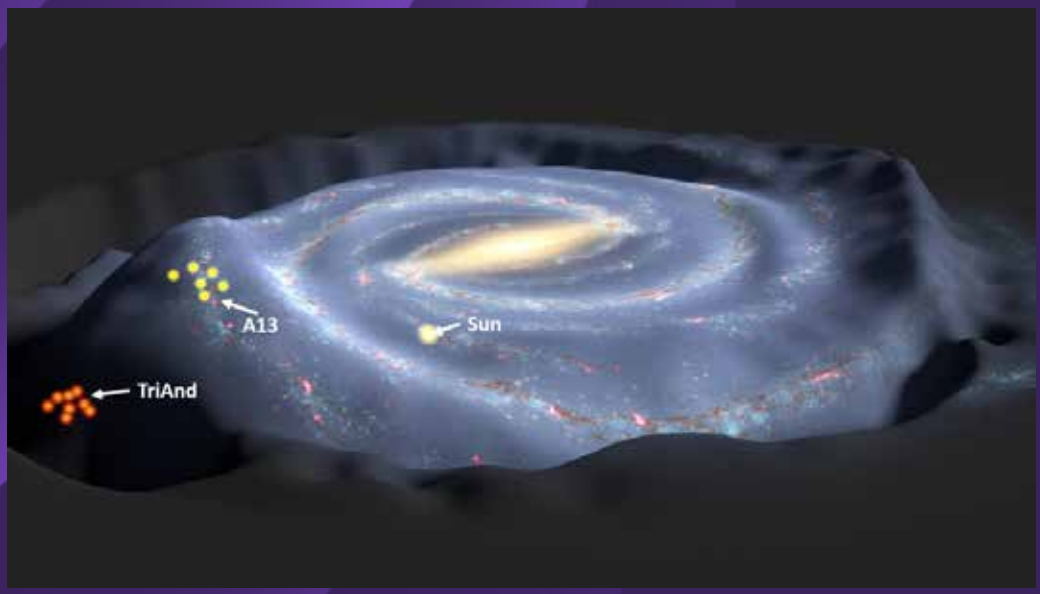
The outer "halo" region of the Milky Way contains the vast majority of the mass of the Galaxy. Unlike the Galaxy's spiral arms, which contain bright stars, the halo is mostly dark, but they do contain some globular clusters of stars, some of the oldest stars in the Milky Way.

These stars are generally thought to be ghosts of dwarf galaxies past, long ago torn into shreds after encounters with our more massive galaxy. Now, new research involving ASTRO 3D researcher Dr Luca Casagrande, shows that some of these stars might not be dwarf remnants at all – they might have come from the Milky Way's own disk. The question then becomes: how did they travel all the way from the disk out into the stellar halo?

The researchers found the chemical composition of two outlying groups of stars, A13 and Triangulum-Andromeda, which are about 14,000 light years above and below the plane of the Milky Way, closely matched the stars in our galaxy.

"We think these stars were evicted through a tidal interaction of the Milky Way and a dwarf galaxy," said Dr Casagrande, an ARC Future Fellow at the ANU Research School of Astronomy and Astrophysics. Tidal interactions between galaxies involve the gravitational field of each galaxy distorting the other –such interactions can change, sometimes dramatically, the form and structure of the galaxies involved.

"These findings are very exciting, as they indicate that the Milky Way Galaxy's disk as a whole can oscillate because of tidal interaction and its dynamics are significantly more complex than previously thought."



3D artist's impression of the Milky Way, A13 and Triangulum-Andromeda ***IMAGE CREDIT:*** T. Mueller/NASA/JPL-Caltech

ACTIVITY PLAN 2019

ACTIVITY		ACTION
RESEARCH PROJECTS AND SURVEYS	**Genesis**	• Ensure that merger trees and additional derived data products from large N-body simulations are compatible with SAMS • Build sample of 30 gas-rich galaxy mass systems in a range of environments to look at HI and IFU properties • Modeling of AGN feedback on small scales • Compare HI properties in large-scale cosmological simulations with ASKAP FLASH observations • Create mock absorption datacubes as a function of intervening absorber properties (eg: structure, column density, star formation history) • Incorporate Genesis data into TAO • Apply Prospect, ViperFish, Stingray data to galaxy formation predictions and mock observables • Cosmic web classification of simulations • Get feedback from the astronomy community about the datasets they want
	Data Intensive Astronomy (DIA)	• Identification of processing bottlenecks in ASKAPsoft and implementation of optimisations and/or new algorithms • Pilot implementation of a SQL-queryable database for the astronomical simulation data (galaxies, halos, etc) • Pilot implementation of DINGO and WALLABY pipelines using DALiuGE • Pilot cross-matching and querying of heterogeneous ASTRO 3D data sets across ASTRO 3D data centres • Design visualisation tools for scientifically meaningful interpretation of the ADC-CASDA cross-matched data based on user requirements
	MWA EoR Survey	• Develop an end-to-end simulation to explore instrumental parameters • Process EoR2-field data through independent pipeline to test systematics introduced by RTS • Process LOBeS data for improved EoR foreground model • Process MWA Moon data for EoR global signal detection or limit • An improved MWA limit on the 21cm power spectrum at z=12-17 • An improved limit from MWA EoR1 highband data • Explore new statistics for extracting the EoR signal and discriminating foregrounds • Measure the MWA beam at each tile

Continued

ACTIVITY	ACTION
RESEARCH PROJECTS AND SURVEYS	
First Stars Project	• Analyse AAO spectra of bulge extremely metal-poor star candidates • Perform 3D spectral line formation calculations for each element, such as H, Li, C, Na, Mg, and Al • Determine new stellar parameters for all known ultra-metal-poor stars based on 3D modelling and new Gaia parallaxes • Initiate theoretical/numerical program on the formation of the first stars
First Galaxies Project	• Analysis of Hubble Space Telescope BoRG cycle 24 data; pipeline and data reduction for BoRG cycle 25 survey • Analysis of Spitzer BoRG data • Modelling of the bright-end of the galaxy luminosity function • Analysis of environment around the most distant galaxies and quasars • Planning of survey of characterising chemical enrichment of the most distant dwarf galaxies • Derive the chemical abundances of the most distant galaxies using gravitationally-lensed galaxies and Keck data
Galaxy Evolution Project	• Reduce XSHOOTER and PISCO data on lenses • Explore geometry-sensitive emmission lines, especially UV emission lines • Apply metallicity diagnostics to full lensed sample • Using TOSCA stellar data, run models to compare with observations to identify how well model results fit data • Predict chemical evolution of galaxies using COCKATOO suite simulations • Initial application of machine learning lens identification to KiDS/VIKING data and spectroscopic confirmation
ASKAP FLASH Survey	• Delivery and verification of FLASH end-to-end data processing pipeline • Analysis of 36-antenna ASKAP Pilot Survey data • Collaborate with WALLABY to search for HI absorption in galaxies at $z<0.26$ • Apply Genesis simulations to FLASH data
ASKAP DINGO Survey	• Carry out alternative pipeline tests (cloud, non-Pawsey HPC) for data processing • Initial processing of DINGO ASKAP-36 Pilot survey data

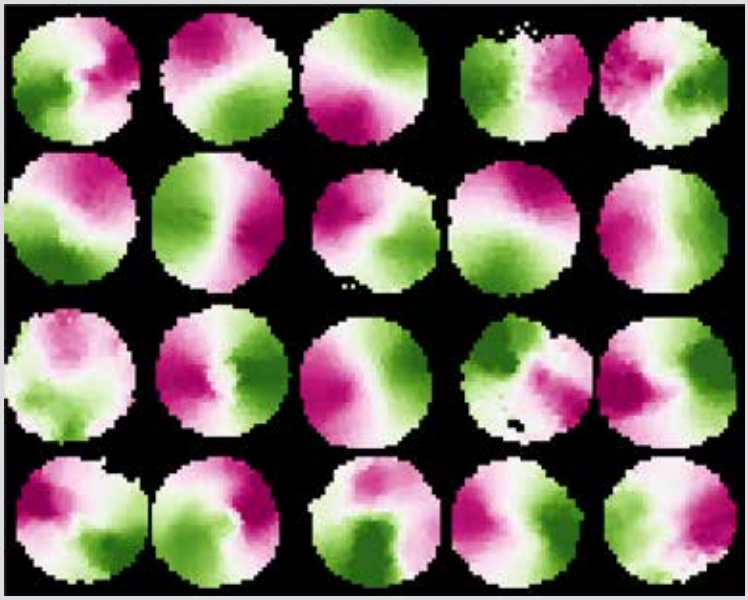
Continued

	ACTIVITY	ACTION
RESEARCH PROJECTS AND SURVEYS	**ASKAP WALLABY Survey**	• Submit review documentation • Present early science results at 2019 PHISCC workshop in Perth • Investigate processing options for data outside of the Pawsey Centre • Analysis of pilot survey data
	SAMI/HECTOR Survey	• Final SAMI internal data release using updated pipeline • Identify link between instrinsic shape of visible and dark matter by combining simulations and observations • Apply stellar population analysis to the decomposed bulges and disks from the SAMI sample • HECTOR input catalogue and pilot survey design • HECTOR data reduction pipeline phase 1 complete and end-to-end processing operational • Continue manufacture HECTOR fibre cable and hexabundles • HECTOR positioning system creation and development • HECTOR commissioning and survey operations begin
	GALAH	• Complete GALAH internal data release 3 • Complete high-resolution Galaxy simulation study • Develop new tools in preparation for new GALAH “MSTO” sample • Identify stellar twins in GALAH survey • Investigate the chemical enrichment history of the solar neighbourhood using GALAH abundances and stellar ages • Determine the efficiency of stellar radial migration using the most metal-rich stars
EDUCATION	**ASTRO 3D in the Classroom**	• Complete the WISE program workshops • Develop lesson plans on spectroscopes, EoR and 3D printing that can be downloaded by teachers
	Telescopes in Schools	• Provide funding to buy Dobsonian telescopes for schools in regional Victoria, NSW, WA and Tasmania • Provide online resources to existing schools on how to use their telescopes
	Space Squad	• Continue to provide spectroscope activity and astronomer talk for the YMCA Canberra Space Squad in January, April, July and October

Continued

	ACTIVITY	ACTION
OUTREACH AND COMMUNICATIONS	**Uluru Programs**	• In partnership with Voyages Indigenous Tourism, coordinate and deliver the Uluru Astronomer in Residence program from April to September in 2019
	Public Outreach	• Participate in science events and develop public outreach activities for National Science Week in August 2019 • Participate in major astronomy festivals around Australia where there is a strategic benefit to the Centre • Deliver public talks on the research work of the Centre and astronomy in general as well as ASTRO 3D gender equity programs
	Public Relations and Media	• Ensure that the research outcomes of the Centre are communicated through the media to reach the broadest possible audience • Share discoveries and promote discussion and comment on the activities of the Centre and astronomy in general via social media platforms such as Facebook, Twitter, Instagram, YouTube • Continue to create video resources that highlight the Centre's achievements
	Innovation	• Develop the concept and production plan for 3D Virtual Reality education resources
	Website	• Update the ASTRO 3D website and intranet

Continued



The SAMI Survey can detect how gas orbits around a galaxy's centre; green shows gas moving towards us, pink moving away. Sometimes the motion of the gas is very different to the stars, indicating outflows of gas driven by supernovae, or the accretion of new gas onto the galaxy.

	ACTIVITY	ACTION
RESEARCH AND LEADERSHIP TRAINING	**Professional Development**	Deliver the following professional development training: • Professional Astronomical Skills Training Workshop • Diversity Training Workshops at every node • Early Career Researcher Training Day • Science Communication Workshop • Transferable Skills Workshop • Writing Workshops and Project Busy Weeks Develop and implement the following ongoing programs: • Centre-wide Mentoring Program • Emerging Leaders Program • Women's Career Advancement Program
	Workshops and Conferences	Deliver a workshop and conference program that includes: • 2 international conferences • 2 national conferences/workshops • At least 40 professional conferences and workshops
	Visitor Program	• Deliver a Visitor Program promoting effective collaboration and development
GOVERNANCE	**Advisory Boards**	• Organise meetings, as per the terms of reference, of the International Advisory Board and National Advisory Board
	Committees	• Ensure the Executive Management, Science Management and Equity and Diversity Committees contribute effectively to the work of the Centre • Develop Terms of Reference and form the following new Committees — Intellectual Property Committee, Post-Doctoral Committee and Student Committee
	Equity and Diversity	• Implement the ASTRO 3D Diversity and Inclusion Action Plan
	Financial Management	• Revise the ASTRO 3D budget and ensure that proper controls are implemented to ensure sound financial management practices
	Reporting	• Ensure that ASTRO 3D meets all its financial and KPI reporting obligations

COLLABORATION HIGHLIGHT

INTERNATIONAL ASTRONOMICAL UNION XXXTH GENERAL ASSEMBLY

ASTRO 3D PRESENCE SHINES

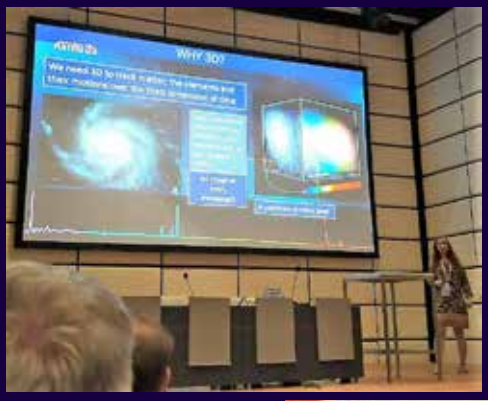
ASTRO 3D had excellent coverage at the IAU science meetings, particularly at the Focus Meeting on Galactic Angular Momentum, which was organised and chaired by AI Danail Obreschkow, with support from CI Karl Glazebrook on the SOC. Papers were presented by Charlotte Welker, CI Matthew Colless, Fellows Caroline Foster and Claudi Lagos, and postdoc Dr Sarah Sweet.

ASTRO 3D results (from the ASKAP HI surveys) were also presented at the Focus Meeting "Radio Galaxies: Resolving the AGN Phenomenon" with a paper presented by CI Elaine Sadler.

Papers were also presented by AIs Naomi McClure-Griffiths, Christoph Federath and Luca Casagrande, and CI Stuart Wyithe.

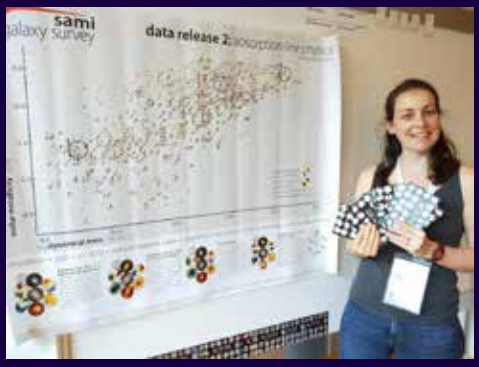
Our Director, Lisa Kewley gave a prestigious Invited Discourse on Galaxy Evolution in 3D. Additionally, she gave two invited talks on metallicity gradients at the Focus Meeting and also at the IAU Symposium on Extremely Large Telescopes. She was also invited to speak at the Women in Astronomy Meeting.

ASTRO 3D was also a partner in the Australian Astronomy stand in the conference hall (along with CSIRO, AAO, ICRAR and AAL). Here we were able to showcase the highlights of our research so far (and learn a lot of about what works in these big professional conference stands for the next IAU General Assembly in Busan, Korea in 2021).



Above left: Prof. Lisa Kewley explains the significance of 3D in her Invited Discourse.

Above right: Education, Outreach & Communications Manager, Ingrid McCarthy with International Advisory Board Chair Tim de Zeeuw at the Australian Astronomy stand.



Left: Dr Carolyn Foster from the University of Sydney at the SAMI poster session.

PRESENTATIONS IN 2018

INVITED AND CONTRIBUTED TALKS

(includes conferences, workshops, colloquia, collaborations)

EVENT	SPEAKER	LOCATION	WHEN
Chemical and dynamical evolution of galaxies conference	Martin Asplund	Sexten, Italy	Jan 18
22nd International Microlensing Conference	Sanjib Sharma	Auckland, New Zealand	Jan 18
MPA colloquium	Adam Stevens	Garching, Germany	Jan 18
MPA/HITS theory retreat	Adam Stevens	Fischen, Germany	Jan 18
Cosmological Signals from Cosmic Dawn to the Present: 2018 Aspen Winter Conference on Astrophysics	Ben McKinley	Aspen, USA	Feb 18
ANITA Workshop	Christopher Jordan	Perth, Australia	Feb 18
ANITA Workshop	Ronniy Joseph	Perth, Australia	Feb 18
ANITA Workshop	Madeline Marshall	Perth, Australia	Feb 18
ANITA Workshop	Simon Mutch	Perth, Australia	Feb 18
ANITA Workshop	Bella Nasirudin	Perth, Australia	Feb 18
Cosmological Signals from Cosmic Dawn to the Present: 2018 Aspen Winter Conference on Astrophysics	Stuart Wyithe	Aspen, USA	Feb 18
Nice Observatory, France	Luca Casagrande	Nice, France	Mar 18
Next-Generation Cosmology with Next-Generation Radio Telescopes Conference	Brad Greig	Sesto, Italy	Mar 18
Next-Generation Cosmology with Next-Generation Radio Telescopes Conference	Stuart Wyithe	Sesto, Italy	Mar 18
Colloquia ICRAR/UWA	Claudia Lagos	Perth, Australia	Mar 18

Continued

INVITED TALKS (includes conferences, workshops, colloquia, collaborations)

EVENT	SPEAKER	LOCATION	WHEN
MAVIS workshop	Luca Cortese	Sydney, Australia	Mar 18
European Week of Astronomy and Space Science	Martin Asplund	Liverpool, UK	Apr 18
Observational Techniques Workshop	Scott Croom	Sydney, Australia	Apr 18
Sextens Center for Astrophysics Conference	Lisa Kewley	Italy	Apr 18
"A Star Was Born" Conference	Lisa Kewley	Spineto, Italy	Apr 18
Mock Durham workshop	Claudia Lagos	Durham, UK	Apr 18
Mock Durham workshop	Simon Mutch	Durham, UK	Apr 18
Mock Durham workshop	Chris Power	Durham, UK	Apr 18
Colloquium	Chris Power	Dublin, Ireland	Apr 18
Observational Techniques Workshop	Gayandhi da Silva	Sydney, Australia	Apr 18
MPE	Lister Staveley-Smith	Garching, Germany	Apr 18
Mock Durham workshop	Adam Stevens	Durham, UK	Apr 18
Swinburne GEM talk	Adam Stevens	Melbourne, Australia	Apr 18
International Telescopes Support Office Observational Techniques Workshop,	Sarah Sweet	Sydney, Australia	Apr 18
Keck Observatory Seminar	Tiantian Yuan	Waimea, USA	Apr 18
Swinburne Colloquium	Nell Byler	Melbourne, Australia	May 18
MAVIS workshop	Luca Casagrande	Sydney, Australia	May 18
Tempo and Mode Seminar	Lisa Kewley	Canberra, Australia	May 18
Physics Director's Colloquium	Lisa Kewley	Canberra, Australia	May 18
Colloquia Lyon Observatory	Claudia Lagos	Lyon, France	May 18
MAVIS workshop	J. Trevor Mendel	Sydney, Australia	May 18
Python in Astronomy Meeting	Manodeep Sinha	New York, USA	May 18
The metal-poor Milky Way conference	Martin Asplund	Ringberg, Germany	Jun 18

Continued

INVITED TALKS (includes conferences, workshops, colloquia, collaborations)

EVENT	SPEAKER	LOCATION	WHEN
Astronomical Society of Australia, Annual Scientific Meeting	Tania Barone	Melbourne, Australia	Jun 18
MWA Project Meeting	Nichole Barry	Shanghai, China	Jun 18
Astrophysics Colloquium	Nichole Barry	Melbourne, Australia	Jun 18
AIP seminar	Luca Casagrande	Potsdam, Germany	Jun 18
FAST-SKA-Meerkat synergies workshop	Barbara Catinella	Guiyang, China	Jun 18
KIAA Forum on Gas in Galaxies	Barbara Catinella	Beijing, China	Jun 18
FAST-SKA-Meerkat synergies workshop	Luca Cortese	Pingtang, China	Jun 18
KIAA Forum on gas in galaxies	Luca Cortese	Beijing, China	Jun 18
USA Decadal Review Workshop	Simon Driver	Snowbird, USA	Jun 18
4MOST Science Team Meeting	Simon Driver	Geneva, Switzerland	Jun 18
KIAA Forum on Gas in Galaxies	Bi-Qing For	Beijing, China	Jun 18
ASA Annual Science Meeting	Ronniy Joseph	Melbourne, Australia	Jun 18
Black Hole Meeting	Lisa Kewley	Oxford, UK	Jun 18
Rise and Shine: galaxies in the epoch of reionization	Bella Nasirudin	Strasbourg, France	Jun 18
ACAMAR	Ben McKinley	Chengdu, China	Jun 18
Rise and Shine: galaxies in the epoch of reionization	Steven Murray	Strasbourg, France	Jun 18
Seminar presenter at The Scuola Normale Superiore di Pisa	Yuxiang Qin	Pisa, Italy	Jun 18
Rise and shine: galaxies in the epoch of reionization	Yuxiang Qin	Strasbourg, France	Jun 18
PHISSIC 2018	Elaine Sadler	Pingtang, China	Jun 18
ACAMAR 4	Elaine Sadler	Chengdu, China	Jun 18
34th IAP Conference	Elaine Sadler	Paris, France	Jun 18

Continued

INVITED TALKS (includes conferences, workshops, colloquia, collaborations)

EVENT	SPEAKER	LOCATION	WHEN
Radio Astronomy Forum 2018	Lister Staveley-Smith	Pingtang, China	Jun 18
KIAA Forum on Gas in Galaxies	Lister Staveley-Smith	Beijing, China	Jun 18
Glenfiddling galaxy clusters workshop	Adam Stevens	Edinburgh, UK	Jun 18
MPIA galaxy coffee	Adam Stevens	Heidelberg, Germany	Jun 18
MPA colloquium	Adam Stevens	Garching, Germany	Jun 18
Munich Observatory colloquium	Adam Stevens	Munich, Germany	Jun 18
ASA Annual Scientific Meeting	Cathryn Trott	Melbourne, Australia	Jun 18
ACAMAR	Cathryn Trott	Chengdu, China	Jun 18
PHISCC Workshop	Tobias Westmeier	Pingtang, China	Jun 18
Radio Astronomy Forum 2018	Tobias Westmeier	Pingtang, China	Jun 18
KIAA Forum on Gas in Galaxies	Tobias Westmeier	Beijing, PR China	Jun 18
ACAMAR4 conference	Ivy Wong	Chengdu, China	Jun 18
Kavli Gas in Galaxies conference	Ivy Wong	Beijing, China	Jun 18
232nd AAS meeting	David Yong	Denver, USA	Jun 18
The metal-poor Galaxy	Martin Asplund	Ringberg, Germany	Jul 18
HST workshop on M31, M33	Nell Byler	Ringberg, Germany	Jul 18
Physics of Galaxy Scaling Relations	Tania Barone	Kingston, Canada	Jul 18
Hector Busy Week - Macquarie Uni	Scott Croom	Sydney, Australia	Jul 18
Conference	Kathryn Grasha	Sexten, Italy	Jul 18
Heidelberg Joint Colloquium	Lisa Kewley	Heidelberg, Germany	Jul 18
"The early growth of supermassive black holes" workshop	Madeline Marshall	Sexten, Italy	Jul 18
The Metal-Poor Galaxy	Thomas Nordlander	Ringberg, Germany	Jul 18

Continued

INVITED TALKS (includes conferences, workshops, colloquia, collaborations)

EVENT	SPEAKER	LOCATION	WHEN
Galaxy & dark matter conference	Danail Obreschkow	Kingston, Canada	Jul 18
The Physics of Galaxy Scaling Relations & the Nature of Dark Matter	Sree Oh	Kingston, Canada	Jul 18
The Metal-Poor Galaxy	David Yong	Ringberg, Germany	Jul 18
Jim Gunn's 80th Birthday conference	Joss Bland-Hawthorn	Princeton, USA	Aug 18
IAU General Assembly	Joss Bland-Hawthorn	Vienna, Austria	Aug 18
Macquarie University Physics School Colloquium	Julia Byant	Sydney, Australia	Aug 18
UNSW Colloquium	Nell Byler	Sydney, Australia	Aug 18
IAU General Assembly	Bi-Qing For	Vienna, Austria	Aug 18
IAU General Assembly	Caroline Foster	Vienna, Austria	Aug 18
ASTRON HI absorption workshop	Lilian Garratt-Smithson	Dwingeloo, The Netherlands	Aug 18
IAU General Assembly	Kate Harborne	Vienna, Austria	Aug 18
Invited Discourse - Galaxy Evolution in 3D - IAU General Assembly	Lisa Kewley	Vienna, Austria	Aug 18
Emission-line diagnostics for galaxies - IAU General Assemby	Lisa Kewley	Vienna, Austria	Aug 18
ISM conditions in distant galaxies - IAU General Assembly	Lisa Kewley	Vienna, Austria	Aug 18
Colloquium	Lisa Kewley	Lyon, France	Aug 18
IAU General Assembly	Claudia Lagos	Vienna, Australia	Aug 18
The 4th SKA SummerSchool	Jack Line	Shanghai, China	Aug 18
"Are AGN special? The environmental dependence and global impact of AGN activity" conference	Madeline Marshall	Durham, UK	Aug 18
IAU General Assembly	Elaine Sadler	Vienna, Austria	Aug 18
HI absorption 2018	Lister Staveley-Smith	Dwingeloo, The Netherlands	Aug 18
ICRAR Astro Morning Tea	Adam Stevens	Perth, Australia	Aug 18

Continued

INVITED TALKS (includes conferences, workshops, colloquia, collaborations)

EVENT	SPEAKER	LOCATION	WHEN
Swinburne Univeristy colloquium	Adam Stevens	Melbourne, Australia	Aug 18
14th China-Australia Symposium 2018 “Light Changes our Lives”	Michele Trenti	Changchung, China	Aug 18
Astronomy Colloquium, Italian Astronomical Observatory	Michele Trenti	Trieste, Italy	Aug 18
IAU General Assembly	Stuart Wyithe	Vienna, Austria	Aug 18
Kavli Prize symposium	Martin Asplund	Oslo, Norway	Sep 18
West Coast Swings Conference	Joss Bland-Hawthorn	Perth, Australia	Sep 18
Emission Line Galaxies workshop	Nell Byler	Teruel, Spain	Sep 18
West Coast Swings workshop	Barbara Catinella	Perth, Australia	Sep 18
LORCA meeting	Luca Cortese	Marseille, France	Sep 18
SAMI data reduction busy week	Scott Croom	Sydney, Australia	Sep 18
Conference	Kathryn Grasha	Potsdam, Germany	Sep 18
Colloquium	Claudia Lagos	Melbourne, Australia	Sep 18
HI Absorption 2018 workshop	Elaine Sadler	Dwingeloo, Netherlands	Sep 18
Wallaby	Lister Staveley-Smith	Marseilles, France	Sep 18
SKA EoR/CD Science Working Group meeting	Cathryn Trott	London, UK	Sep 18
Swinburne Proposal Writing Workshop	Emily Wisnioski	Melbourne, Australia	Sep 18
Colloquium	Emily Wisnioski	Melbourne, Australia	Sep 18
Galaxy Evolution Meeting - UNSW	Scott Croom	Sydney, Australia	Oct 18
Colloquium	Claudia Lagos	Sydney, Australia	Oct 18
ICRAR/CASS Radio School	Christene Lynch	Geraldton, Australia	Oct 18
Colloquium	J. Trevor Mendel	Melbourne, Australia	Oct 18
Illustris TNG team meeting	Simon Mutch	Munich, Germany	Oct 18

Continued

INVITED TALKS (includes conferences, workshops, colloquia, collaborations)

EVENT	SPEAKER	LOCATION	WHEN
Korean Astronomical Society Fall Meeting 2018	Sree Oh	Chungsong, Korea	Oct 18
ICRAR Astro Morning Tea	Adam Stevens	Perth, Australia	Oct 18
ICRAR/CASS Radio School	Tobias Westmeier	Geraldton, Australia	Oct 18
Science at Low Frequencies V	Nichole Barry	Nagoya, Japan	Nov 18
Gas Fuelling of Galaxy Structures across Cosmic Time	Nell Byler	Barossa Valley, Australia	Nov 18
Gas Fuelling of Galaxy Structures across Cosmic Time	Barbara Catinella	Barossa Valley, Australia	Nov 18
Gas Fuelling of Galaxy Structure across Cosmic Time	Luca Cortese	Barossa Valley, Australia	Nov 18
MANIFEST workshop	Luca Cortese	Sydney, Australia	Nov 18
Gas Fuelling of Galaxy Structures across Cosmic Time	Ahmed Elagali	Adelaide, Australia	Nov 18
Gas fueling of galaxy structures across cosmic time	Lilian Garratt-Smithson	Barossa Valley, Australia	Nov 18
Gas Fuelling of Galaxy Structures: across Cosmic Time	J. Trevor Mendel	Barossa Valley, Australia	Nov 18
USyd Physics HDR Symposium	Bruce Murray Riding	Sydney, Australia	Nov 18
Science at Low Frequencies V	Bart Pindor	Nagoya, Japan	Nov 18
90th Anniversary Symposium, Academia Sinica	Elaine Sadler	Taipei, Taiwan	Nov 18
SAMI-GAMA Meeting	Jesse van de Sande	Perth Australia	Nov 18
Galactic Fidelity Workschool	Tobias Westmeier	Cape Town, South Africa	Nov 18
``Gas Fuelling of Galaxy Structures Across Cosmic Time”	Emily Wisnioski	Barossa Valley, Australia	Nov 18
Australian Institute of Physics congress	Barbara Catinella	Perth, Australia	Dec 18

Continued

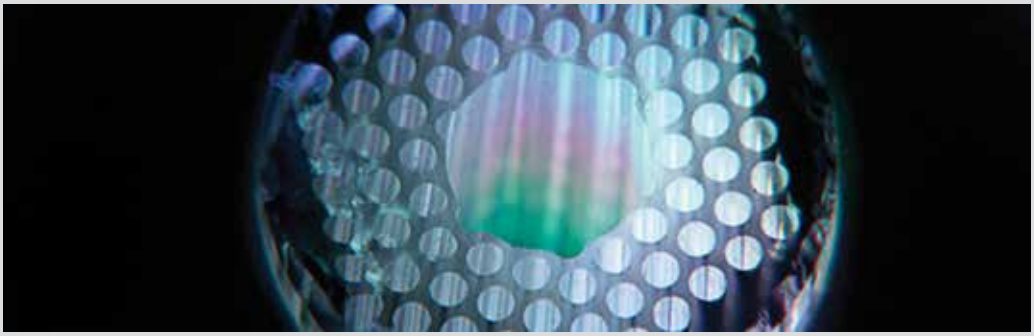
INVITED TALKS (includes conferences, workshops, colloquia, collaborations)

EVENT	SPEAKER	LOCATION	WHEN
Science at Low Frequencies V	Ronniy Joseph	Nagoya, Japan	Dec 18
Lorentz Workshop	Claudia Lagos	Leiden, The Netherlands	Dec 18
Science at Low Frequencies V	Christopher Jordan	Nagoya, Japan	Dec 18
Science at Low Frequencies V	Jack Line	Nagoya, Japan	Dec 18
Science at Low Frequencies	Christene Lynch	Nagoya, Japan	Dec 18
Australian Institute of Physics Congress	Ben McKinley	Perth, Australia	Dec 18
KMOS@5: Star and Galaxy Formation in 3D workshop	J. Trevor Mendel	Garching, Germany	Dec 18
AIP congress	Simon Mutch	Perth, Australia	Dec 18
Australian Institute of Physics congress	Elaine Sadler	Perth, Australia	Dec 18
Science at Low Frequencies V	Randall Wayth	Perth, Australia	Dec 18
AIP	Randall Wayth	Perth, Australia	Dec 18

OTHER PRESENTATIONS

SUBJECT	SPEAKER	LOCATION	WHEN
Women in Astronomy - ESO Delegate Workshop Panel	Lisa Kewley	Canberra, Australia	Mar-18
ASTRO 3D and MUSE - MUSE instrument for ESO discussion	Lisa Kewley	Canberra, Australia	Mar-18
ASTRO 3D Update - DVC-R Briefing	Lisa Kewley	Canberra, Australia	Jun-18
ASTRO 3D Update - National Committee for Astronomy Meeting	Lisa Kewley	Melbourne, Australia	Jun-18
ASTRO 3D Merger Tree workshop	Pascal Elahi	Melbourne, Australia	Jul 18
ASTRO 3D: Gender Equity Policies - IAU Women in Astronomy Meeting	Lisa Kewley	Vienna, Austria	Aug-18
ASTRO 3D Update - National Committee for Astronomy Meeting	Lisa Kewley	Canberra, Australia	Dec-18

COMMERCIAL TRANSLATION



The Sydney Astrophontonic Instrumentation Laboratory (SAIL) is a group led by Collaboration Leader CI Joss Bland-Hawthorn and is based at the University of Sydney. The group collaborates with ASTRO 3D and other research groups around the world to develop new materials and devices for astronomical instrumentation.

SAIL is part of the newly funded $4.6M ARC Training Centre for CubeSats, Unmanned Aerial Vehicles (UAV) and Their Applications. The centre, starting in January 2018, will train the next generation of workers in collaboration with industry partners in cutting-edge advanced manufacturing, entrepreneurship and commercial space and UAV applications. SAIL will lead the technological development, in collaboration with the Australian Astronomical Observatory, the Defence Science, Technology Group (DSTG) and HyVista (NSW based company) of 2 of the 4 advanced optical instrumentation projects in Aim 2 – Instruments, of the proposal. Specifically, Aim 2.1 Compact Imagers and Aim 2.2 Photonic Spectrometers and Hyperspectral Imagers. SAIL will be hosting two PhDs and 1 FTE Postdoc from the ITTC Training Centre.

SAIL is an emerging area of research at the University of Sydney in advanced photonics sensors for the farming industry using robotic platforms, in collaboration with Prof Salah Sukkarieh from the Australian Centre for Field Robotics (ACFR) and Prof Robyn McConchie, Director of the ARC ITTC for Food Safety in Fresh Food. Based on a previous collaboration, industry funded by Horticulture Australia Limited (Hort Innovation).

SAIL leads a newly funded ($150K) University of Sydney Strategic Research Excellence Initiative (SREI-2020). This project aims to bring together an interdisciplinary team from Industry and the Faculty of Science, Agriculture and Engineering to create new research capacity in a field with immediate opportunities for addressing real-world problems in Food Safety and the Farming Industry.

In 2017, SAIL completed two consultancy projects worth $200K with industry in the area of photonic technologies. One in greenhouse spectroscopy sensors with Melbourne Water and Draco Analytics, and the second one with Ocular Robotics. This industry exposure has led to several industry linkages -- SAIL is now in the process of drafting an ARC Linkage worth $1M grant with Melbourne Water to exploit photonic gas sensors in water utilities.

Recently completed contracts include the delivery of photonic lanterns to AT&T Bell Labs ($100K), and the delivery of hexabundles to the University

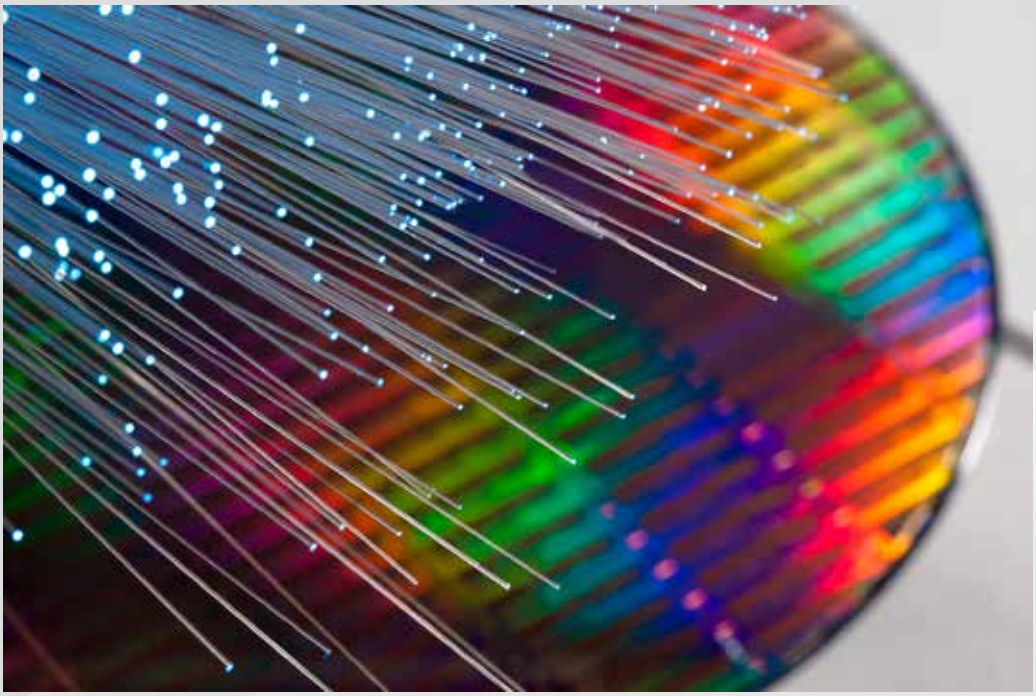
of North Carolina ($120K). Photonic Raman spectrograph for food safety for Horticulture Australia Limited (Hort Innovation) ($270K). SAIL is presently under contract to the University of Maryland and NASA Goddard ($400K).

In 2018, SAIL landed a $1.27 M grant over 2 years from the Grains Research & Development Corporation to develop a compact laser-weeding system that would be deployed on a farm robot. The idea here is to target and isolate weeds with solar-powered lasers thereby avoiding the need for harmful chemicals that are less able to isolate weeds. The first prototype has already been demonstrated. In recognition of ongoing success, Affilliate Assoc Prof Sergio Leon-Saval was awarded a further $150K by the University of Sydney in support of this work.

In 2018, CI Bland-Hawthorn and AI Julia Bryant were awarded a $650K ARC LIEF grant to complete the development of the Hector instrument for the AAT. In addition, AI Bryant was awarded $500K through an ARC Future Fellowship and the University of Sydney to ensure the SAIL labs have sufficient funds to complete the instrument development.

Since its foundation in 2015, the refurbished SAIL labs have attracted a total of $2M cash and $200K in equipment and research materials from external research and consultancy contracts to the University of Sydney. Industry and research organisation clients include national and international organisations: Horticulture Innovation Australia (Hort Innovation), Melbourne Water, Ocular Robotics, Draco Analytics, Nokia Bell Labs, the University of Maryland and the University of North Carolina. Furthermore, a $250K cash contribution from Melbourne Water has been committed in writing for a SAIL lead ARC Linkage Grant application for 2019.

Many of these projects have assisted SAIL's developments in astronomical instrumentation – the benefits go both ways. Moreover, the SAIL labs have emerged as an ideal training ground for students, post-docs and staff to pick up some experimental training, in particular, in prototyping R&D.



COLLABORATIONS

The Emu over the Anglo-Australian Telescope Dome. ***IMAGE CREDIT:*** Ángel López-Sánchez

One of our main aims in 2018 was to strengthen our collaborations with our national and international partner institutions. This was achieved through a combination of our Distinguished and Science visitor program, key investigators in each survey/ project directly engaging partners, and student exchange programs.

Our national partner institutions in 2018 were CSIRO Astronomy and Space Science (CASS), the National Computational Infrastructure (NCI), and the Australian Astronomical Observatory (AAO). We maintain our strong connection with CASS through the ASKAP surveys. In 2018, we welcomed the appointment of Chief Investigator Elaine Sadler as ATNF Chief Scientist, and we look forward to our Annual Science Meeting to be held at the CASS headquarters in Sydney in May 2019.

The ASTRO 3D nodes have been collaborating closely with researchers based at and affiliated with the Australian Astronomical Observatory, including PIs Andrew Hopkins and Warrick Couch, as well as AIs Angel Lopez-Sanchez, Richard McDermid, Gayandi de Silva, Lee Spitler, and Dan Zucker. These PIs and AIs are working within the SAMI, GALAH and the Galaxy Evolution projects in ASTRO 3D.

In June 2018, the Anglo Australian Telescope and staff transitioned to a new arrangement managed by the Astronomy Australia Limited, while the Australian Astronomical Observatory technical and research program transitioned from the Department of Industry, Innovation and Science to an independent national entity, with headquarters at Macquarie University. The new AAO entity, a collaboration between Macquarie University, the University of Sydney and the Australian National University, is already proving a success. The AAO Consortium has secured a $3.3M contract with the Turkish government to build an imager for their new 4m telescope in Eastern Anatolia, and a $2M grant from ESO for the development of software systems. ASTRO 3D welcomes the news that Dr. Mark Casali (ESO) is the incoming AAO Director and we look forward to a fruitful collaboration on the many shared projects.

Our collaborations with NCI are producing deep and high impact science. In 2018, CIs Chris Power,

Darren Croton, and Stu Wyithe engaged with NCI staff to optimize the Genesis simulations for NCI computers and continue the Genesis simulation runs. In December, Director Lisa Kewley met with new NCI Director Sean Smith to provide an overview of the ASTRO 3D science conducted with NCI in 2018. We also discussed exciting future Genesis simulations planned for the NCI facility.

Our Centre includes seven international partners University of Washington, Caltech, University of Toronto, the Heidelberg Institute of Advanced Studies, the ASTRON Institute in the Netherlands, Oxford University and the Chinese Academy of Sciences. In 2018, we welcomed Oxford Associate Investigator James Allison as co-lead of the ASKAP FLASH survey. Director Lisa Kewley visited Oxford in 2018 and enjoyed stimulating discussions with PIs Roger Davies, Andy Bunker, and the galaxy evolution and SAMI groups there. Oxford researcher Matt Jarvis visited the ASKAP team at UWA in 2018 to explore synergies between the DINGO and MIGHTEE surveys, and we are looking forward to Oxford PhD student Yiqing Liu's visit to collaborate on SAMI science in 2018.

In 2018, we continued our collaborations with astronomers at the University of Washington (UW). PI Julianne Dalcanton and AI Tom Quinn visited multiple Australian ASTRO 3D nodes to collaborate on the Galaxy Evolution and MWA Epoch of Reionisation programs, while UW students Ruby Byrne and Mike Wilensky visited the Curtin and Melbourne nodes to further the MWA Epoch of Reionization research. We welcomed UW PhD graduates Dr Nell Byler and Dr Nichole Barry at the ANU and Melbourne to begin ASTRO 3D postdoctoral research positions in Galaxy Evolution and the Epoch of Reionisation, and expect to further expand our collaboration with UW in 2019.

Our discussions with the Chinese Academy of Sciences on the synergies between the FAST telescope and ASKAP surveys are progressing well, and we are looking forward to the upcoming visit by PI Di Li in early 2019. The CAS-ASTRO 3D PhD student exchange program is strong, with several student exchanges with student-led papers now in preparation.

Harvard Illustris theorist Lars Hernquist visited the ANU and University of Sydney in May 2018 to discuss on-going and new collaborations. Lisa Kewley visited PI Volker Springel at the Heidelberg Institute for Advanced Studies in 2018 and they discussed future projects and collaborations. Melbourne ASTRO 3D postdoc Dr Simon Mutch represented ASTRO 3D at the Illustris TNG Workshop in late 2018.

ASTRON PI Rafaella Morganti and AI Vanessa Moss collaborated with the FLASH team, and we look forward to Vanessa's visit to UWA in 2019. University of Toronto PI Roberto Abraham visited Swinburne to further the Galaxy Evolution project and we look forward to continued engagement on this program in 2019.

INTERNATIONAL VISITORS AND VISITS

WHO	INSTITUTION/AFFILIATION	WHEN
VISITORS TO AUSTRALIAN NATIONAL UNIVERSITY		
Dr Guillermo Blanc	Observatories of the Carnegie Institution for Science	September
Sven Buder	Max Planck Institute for Astronomy	March-April
Dr Thomas Collett	Institute of Cosmology and Gravitation, Portsmouth	March-April
Professor Julianne Dalcanton	University of Washington	September
Professor Lars Hernquist	Harvard University	May
Professor Garth Illingworth	University of California Santa Cruz	May
Dr Stephanie Juneau	National Optical Astronomy Observatory	November-December
Assistant Professor Melissa Ness	Columbia University	June
Professor Tiziana Di Matteo	Carnegie Mellon University	June-July
Associate Professor Karin Sandstrom	University of California	August
Dr Alfred Tiley	Durham University	May
Professor Meg Urry	Yale Center for Astronomy & Astrophysics	May
Professor Tim de Zeeuw	Leiden University	May and November
Professor Tomaz Zwitter	University of Ljubljana	June
VISITORS TO UNIVERSITY OF MELBOURNE		
Ruby Byrne	University of Washington	November
Dr Thomas Collett	Institute of Cosmology and Gravitation, Portsmouth	March-April
Dr Andre Offringa	ASTRON	October
Associate Professor Karin Sandstrom	University of California	August
Michael Wilensky	University of Washington	
Professor Tim de Zeeuw		May and November
VISITORS TO UNIVERSITY OF SYDNEY		
Professor Julianne Dalcanton	University of Washington	September
Professor Roger Davies	Oxford University	March

Professor Lars Hernquist	Harvard University	May
Professor Mike Hudson	University of Waterloo	April-May
Professor Tiziana Di Matteo	Carnegie Mellon University	June-July
Associate Professor Karin Sandstrom	University of California	August
Dr Alfred Tiley	Durham University	May
VISITORS TO SWINBURNE UNIVERSITY OF TECHNOLOGY		
Professor Roberto Abraham	University of Toronto	
Dr Guillermo Blanc	Observatories of the Carnegie Institution for Science	September
Dr Thomas Collett	Institute of Cosmology and Gravitation, Portsmouth	March-April
Dr Stephanie Juneau	National Optical Astronomy Observatory	December
Dr Alfred Tiley	Durham University	May
Dr Fiorenzo Vincenzo	Oxford University	November-December
VISITORS TO UNIVERSITY OF WESTERN AUSTRALIA		
Dr Sandrine Codis	Institut d'Astrophysique de Paris	March-April
Professor Julianne Dalcanton	University of Washington	September
Matt Jarvis	Oxford University	
Dr Clothilde Laigle	Oxford University	March-April
Professor Tiziana Di Matteo	Carnegie Mellon University	June-July
Professor Christophe Pichon	Institut d'Astrophysique de Paris	March-April
Associate Professor Kristine Spekkens	Royal Military College of Canada/Queen's University	November
Dr Alfred Tiley	Durham University	May
Professor Tim de Zeeuw	Leiden University	May and November
VISITORS TO CURTIN UNIVERSITY		
Ruby Byrne	University of Washington	November
Dr Sandrine Codis	Institut d'Astrophysique de Paris	March-April
Professor Julianne Dalcanton	University of Washington	September
Dr Clothilde Laigle	Oxford University	March-April
Dr Andre Offringa	ASTRON	October
Michael Wilensky	University of Washington	

VISITS TO INTERNATIONAL INSTITUTIONS AND ASTRONOMY FACILITIES

WHO	WHERE	WHEN
Martin Asplund	Max Planck Institute for Astronomy, Germany	Jan 18
Joss Bland-Hawthorn	UC Berkeley, USA	Jan 18
Elaine Sadler	FAST radio telescope, Guizhou, China	Jan 18
Adam Stevens	Max Planck Institute for Astrophysics, Germany	Jan 18
Ayan Acharyya	NASA Space Flight Centre, USA	Jan 18
Ben McKinley	Aspen Winter Physics Conference, USA	Feb 18
David Yong	Magellan Telescope, Chile	Feb 18
James Esdaile	W.M. Keck Observatory, Hawaii, USA	Mar 18
Uros Mestric	W.M. Keck Observatory, Hawaii, USA	Mar 18
Brad Greig	Stockholm University, Sweden	Mar 18
Brad Greig	Scuola Normale Superiore, Pisa, Italy	Mar 18
James Allison	ASTRON, The Netherlands	Mar 18
Tiantian Yuan	W.M. Keck Observatory, Hawaii, USA	Mar 18
Dian Triani	W.M. Keck Observatory, Hawaii, USA	Apr 18
Manodeep Sinha	Vanderbilt University, Nashville, TN, USA	Apr 18
Darren Croton	Ogden Centre for fundamental physics, ICC & CEA, Durham University, UK,	Apr 18
Darren Croton	European Space Astronomy Center (ESAC), Villanueva de la Cañada, Spain	Apr 18
Simon Mutch	Durham University, UK	Apr 18
Simon Mutch	MIAPP, Germany	Apr 18
Carolinen Foster	ESO, Germany	Apr 18
Adam Stevens	Durham University, UK	Apr 18
Claudia Lagos	Lyon Observatory, France	Apr 18
Claudia Lagos	Durham University, UK	Apr 18
Ben McKinley	Tamachi Campus, Tokyo Institute of Technology, Japan	Apr 18
Ronniy Joseph	Tamachi Campus, Tokyo Institute of Technology, Japan	Apr 18
Lister Staveley-Smith	Nagoya University, Japan	Apr 18
Lister Staveley-Smith	MPE, Germany	Apr 18
Lister Staveley-Smith	ESO, Germany	Apr 18

Continued

Manodeep Sinha	Center for Computational Astrophysics, NYC, USA	Apr 18
Alex Cameron	Pennsylvania State University, USA	May 18
Joss Bland-Hawthorn	Oxford University, UK	May 18
Danail Obreschkow	Swiss Federal Institude of Technology, Switzerland	May 18
Martin Asplund	Max Planck Institute for Astronomy, Germany	May 18
Alex Cameron	University of California Davis, USA	Jun 18
Alex Cameron	W.M. Keck Observatory, Hawaii, USA	Jun 18
Yuxiang Qin	Scuola Normale Superiore di Pisa, Italy	Jun 18
Elaine Sadler	Institut d'Astrophysique de Paris, France	Jun 18
Adam Stevens	Max Planck Institute for Astronomy, Germany	Jun 18
Adam Stevens	University Observatory Munich, Germany	Jun 18
Ivy Wong	Yonsei University, South Korea	Jun 18
Simon Driver	Geneva Observatory, Switzerland	Jun 18
Simon Driver	University of Sussex, UK	Jun 18
Lister Staveley-Smith	FAST telescope, China	Jun 18
Thomas Nordlander	MPIA, Germany	Jun 18
Ben McKinley	ACAMAR, China	Jun 18
Ben McKinley	Shanghai Astronomical Observatory, China	Jun 18
Cathryn Trott	Shanghai Astronomical Observatory, China	Jun 18
Randall Wayth	Shanghai Astronomical Observatory, China	Jun 18
Bella Nasirudin	University of Sussex, UK	Jun 18
Christopher Jordan	Shanghai Astronomical Observatory, China	Jun 18
Lister Staveley-Smith	KIAA/PKU, China	Jun 18
Lisa Kewley	MPIA Heidelberg, Germany	Jun 18
Lisa Kewley	University of Heidelberg, Germany	Jun 18
Lisa Kewley	Heidelberg Institute of Astrophysics, Germany	Jun 18
Lisa Kewley	Oxford University, UK	Jun 18
Thomas Nordlander	MPIA, Germany	Jun 18
Madeline Marshall	Durham University, UK	Jun 18
Madeline Marshall	Sexten Center for Astrophysics, Italy	Jun 18
Colin Jacobs	Institute for Cosmology and Gravitation, University of Portsmouth, UK	Jun 18
Joss Bland-Hawthorn	Princeton University, USA	Aug 18

Continued

Sree Oh	Cerro Tololo Inter-American Observatory, Chile	Aug 18
Lister Staveley-Smith	ASTRON, The Netherlands	Aug 18
Elaine Sadler	ASTRON, The Netherlands	Aug 18
Lister Staveley-Smith	Shanghai Astronomical Observatory, China	Aug 18
Darren Croton	Caltech, USA	Sep 18
Colin Jacobs	ESO Paranal Observatory, Chile	Sep 18
Colin Jacobs	University of Milan, Italy	Sep 18
Sree Oh	Yonsei University, South Korea	Sep 18
Scott Croom	University of Heidelberg and MPIA, Germany	Sep 18
Cathryn Trott	Imperial College London, UK	Sep 18
Brad Greig	Imperial College London, UK	Sep 18
Brad Greig	Royal Astronomical Society, London, UK	Sep 18
Nichole Barry	Royal Astronomical Society, London, UK	Sep 18
Bart Pindor	Royal Astronomical Society, London, UK	Sep 18
Nichole Barry	ASTRON, The Netherlands	Sep 18
Bart Pindor	ASTRON, The Netherlands	Sep 18
Michele Trenti	INAF - Italian Astronomical Observatory, Trieste, Italy	Sep 18
Adam Thomas	California Institute of Technology, USA	Sep 18
Brad Greig	McGill Space Institute, Canada	Oct 18
Brad Greig	Scuola Normale Superiore, Italy	Oct 18
Simon Mutch	Max Planck Institute for Astrophysics, Germany	Oct 18
Emily Wisnioski	Max Planck Institute for Extraterrestrial Physics, Germany	Nov 18

EDUCATION PROGRAMS

ASTRO IN THE CLASSROOM

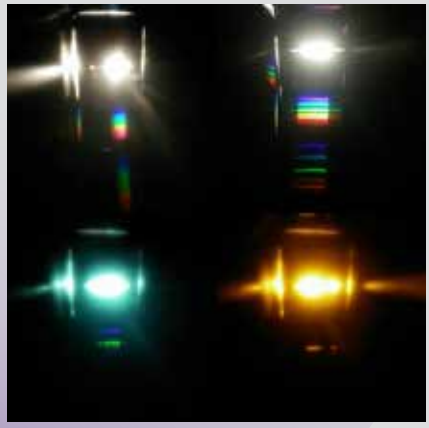
In 2018, ASTRO 3D took over the CAASTRO in the Classroom program funded by the Federal Government's Women in STEM and Entrepreneurship (WISE) funding.

Matt Dodds, a teacher with STEM experience was based at the University of Sydney node and started to develop teacher resources and videos to link ASTRO 3D science with the school curriculum. Unfortunately, Matt could not stay with us, but we now have Tash Marshall on our team.

Matt Dodds with the fibre optic plate from the AAT telescope at Siding Springs

2019 will see Tash developing and delivering workshops with schools and adults which will focus on encouraging girls and women into STEM and highlight entrepreneurial opturnities using their skills.

Students constructing a DIY spectroscope designed to work with mobile phones (adapted from the UNE Dept. Physics & Electronics).



TEACHING ACTIVITIES AND RESOURCES

We have started to develop curriculum-linked ASTRO 3D teaching activities and resources.

Our Outreach Officer at Curtin University, Teresa Slavin-Blair developed an art/STEM activity to help students understand the "bubbles" of the Epoch of Reionisation. Education, Outreach and Communications Manager Ingrid McCarthy adapted a DIY spectroscope developed by University of New England which is designed to be used with mobile phones. She is also working on 3D-printable simulation models of the Universe.

2019 will see these and other activities developed into Units of Study for Primary and Secondary students, Depth Studies for senior students and also YouTube videos developed to support these.

REGIONAL TELESCOPES IN SCHOOLS

In 2018, we reviewed existing Telescopes in Schools programs to see where ASTRO 3D could best add value and reach the most students in need of such a program.

As a result of the extremely successful Stargazing Live program on the ABC and events around Australia, ASTRO 3D is partnering with Dr Brad Tucker from ANU, an Associate Investigator and outreach enthusiast, to deliver telescopes to regional schools and communities in parts of Australia that have shown a keen interest in astronomy and that do not have access to any existing hands-on telescope programs.

ASTRO 3D funded the purchase and delivery of 8-inch telescopes into regional communities in Queensland and northern Western Australia and we are linking schools with their local astronomical societies.

These telescopes are an economical option, that have great light gathering ability, allowing faint objects to be seen relatively easily, and allowing manual methods of finding objects to be learned.

2019 will see an expansion of the program into Victoria, Tasmania, South Australia and southern Western Australia, funding of more advanced telescopes for interested schools and the provision of ongoing teacher education and resources.

Left: Stargazing Live participants at ANU

Right: Brad Tucker demonstrates use of the Dobsonian telescope at Rockhampton, Qld.
IMAGE CREDIT: ANU MEDIA

COLLABORATION HIGHLIGHT

SPACE SQUAD

ASTRO 3D had the opportunity in 2018 to partner with the YMCA Canberra Space Squad, which runs school holiday immersion “camps” for students aged between 12 and 15.

For 5 days, attendees learn all about space exploration and science, as well as meet engineers, astronomers, astrophysicists and scientists who work on all things space-related.

As part of their camp experience, students come to Mt Stromlo (Research School of Astronomy and Astrophysics, ANU), where they are treated to a special ASTRO 3D session!

Students get to listen to an ASTRO 3D astronomer give a talk about their research and find out about their journey - Dr Nell Byler inspired the students by explaining not only her work on how she used thousands of hours of observing time on Hubble Space telescope to date the stars in M31 (aka the Andromeda Galaxy), but also how she believes that to do good science, you need to be creative, artistic and use both sides of your brain.

The students also got to find out more about how ASTRO 3D astronomers collect 3D “datacubes” of spectral information on surveys like SAMI and GALAH, to find out more about the chemical elements, spin and motion of stars and galaxies.

They then had the opportunity to make their own spectroscope and view the different spectra from incandescent and fluorescent light sources, as well as diffuse sunlight and light from mercury and sodium gas discharge tubes.

It’s a great opportunity to inspire our next generation of astronomers!

“The best thing I learnt at Space Squad was how colours and spectroscopes work.” (feedback from Space Squad participants)

OUTREACH AND ENGAGEMENT

Guests enjoy the magnificent outback night sky. ***IMAGE CREDIT:*** Voyages Indigenous Tourism Australia

ULURU ASTRONOMER IN RESIDENCE

ASTRO 3D continued to work in partnership with Voyages Indigenous Tourism Australia to deliver this program in 2018.

Astronomers from our team were in residence from April to October on a fortnightly roster, engaging with the general public, sharing their research, as well as general astronomy knowledge at our booth in the Town Square, at a movie Q&A session and during night-sky tours.

We are excited to continue this program into 2019, with improvements including working with the local community and schools and an exciting new afternoon cocktail event offered to guests of the resort.

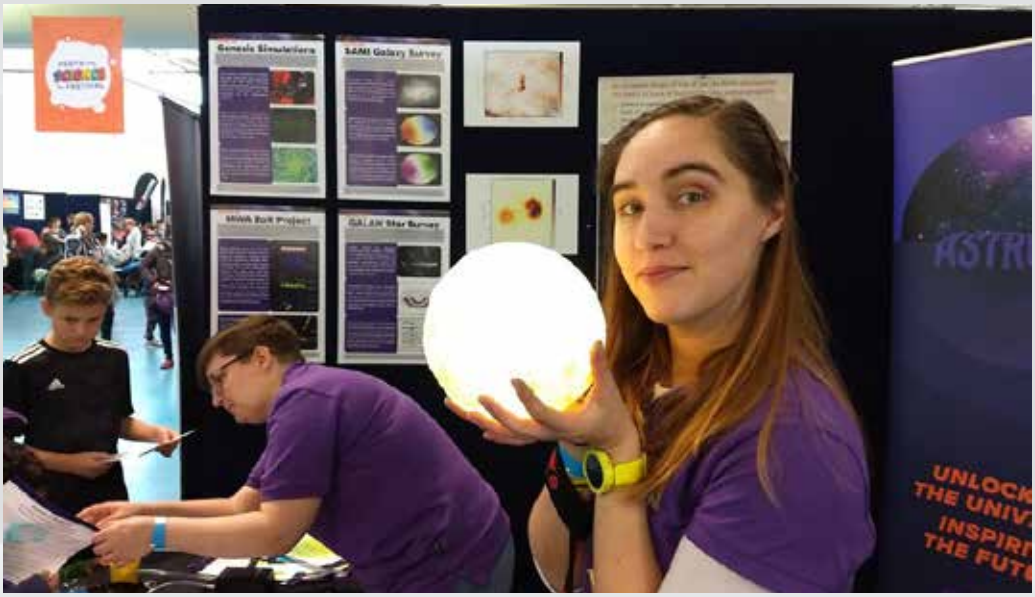
ULURU ASTRONOMY WEEKEND

Over 3 days in September, ASTRO 3D and Voyages Indigenous Tourism Australia hosted the 2018 Uluru Astronomy Weekend.

Director Lisa Kewley, CI Rachel Webster, AI Brad Tucker and Affliliate Ray Norris, hosted by ABC News Breakfast's Nate Byrne, presented the best of astronomy research in talks and discussion panels.

In 2018, we also had a new "Astronomy 101 session" coordinated by Education Officer Matt Dodds, which gave everyone an astronomy primer to prepare them for the talks to come.

Guests also enjoyed a very entertaining Astro-Trivia lunch, the movie Gravity with a Science Fiction vs Fact talk by Brad Tucker and the culmination of the event, the Stellar Starlight Dinner, where the stars of the show were in fact, the stars of the outback southern skies.



ASTRO EVENTS

ASTRO 3D outreach staff had a great 2018 developing activities and stalls for large public outreach events that reached approximately 50,000 people!

2018 Highlights included:

- Sydney Astrofest in July
- Science in ACTion (Canberra) in August
- Perth Science Festival in August
- Astrolight festival (Melbourne) in September
- StarFest at Siding Springs in October

PUBLIC LECTURES, OUTREACH AND MEDIA HIGHLIGHTS

SUBJECT	SPEAKER	EVENT	LOCATION	WHEN
Radio and TV Interviews	Alan Duffy	Various	Australia	Jan-Dec
Radio and TV Interviews	Brad Tucker	Various	Australia,	Jan-Dec
School talks	Brad Tucker	Various	Australia	Feb-Dec
Explaining paralax and ASTRO 3D	Alan Duffy	ABC Breakfast	Australia	Feb
The hunt for the first lights in the Universe	Ronniy Joseph	SciTech Space Academy	Perth, Australia	Feb
Exploding Stars, Dark Energy, and The End of the Universe	Brad Tucker	Royal Society of NSW Southern Highlands Branch	Mittagong, Australia	Mar
Astronomy in the Classroom	Brad Tucker	CONSEAACT	Canberra, Australi	Mar
Paths Forward in 21cm EoR Science	Cathryn Trott	Sexten Centre for Astrophysics Meeting	Sesto, Italy	Mar
Unrevealing the hidden cosmos: a multi-wavelength vision of our Universe	Enrico Di Teodoro	Uluru Astronomer in Residence Program	Uluru, Australia	Apr
From pancakes to soccer balls, new study shows how galaxies change shape as they age	Jesse van de Sande & Nic Scott	ABC Radio appearance with Richard Glover	Sydney, Australia	Apr
ASTRO 3D spectroscopes	Ingrid McCarthy	YMCA Canberra Space Squad	Canberra, Australia	Apr, Oct, Dec
Music of the stars	Dennis Stello	Uluru Astronomer in Residence Program	Uluru, Australia	May
Stargazing Live	Martin Asplund	ANU Stargazing Live	Canberra, Austraila	May
Using Big Galaxy Surveys to study Dark Matter	Simon Driver	Pint of Science Festival	Perth, Australia	May
Stargazing Live	Alan Duffy	ABC TV	Parkes, Australia	May
Stargazing Live	Lisa Kewley	ABC TV interview	Canberra, Australia	May

Continued

SUBJECT	SPEAKER	EVENT	LOCATION	WHEN
Using the Hubble Space Telescope to observe galaxies	Michele Trenti	Cosmos magazine interview	Melbourne, Australia	May
The history of radio astronomy in Australia	Tristan Reynolds	Uluru Astronomer in Residence	Uluru, Australia	May
Research Software Eng. Chapter in AU	Manodeep Sinha	Part of Perth Data Science Week	Perth, Australia	May
Astronomy TV shows for high-school students: about Keck observing	Tiantian Yuan	Scope TV show	Australia	May
When galaxies collide: the inevitable fate of our Milky Way	Jesse van de Sande	Uluru Astronomer in Residence Program	Uluru, Australia	Jun
Shedding Light on Dark Matter	Chris Power	Public Lecture	Hobart, Australia	May
Eduction and Outreach with Science and History	Brad Tucker	Museum and Cultural Studies	Canberra, Australia	Jun
The MWA EoR Project	Cathryn Trott	MWA Project Meeting	Shanghai, China	Jun
What do astronomers do all day (and night)?	Scott Croom	Beecroft Public School	Beecroft, Australia	Jun
The MWA EoR Project	Cathryn Trott	ACAMAR	Chengdu, China	Jun
Oxygen: Breathing in the Stars	Lisa Kewley	ASA Science Meeting - Harley Wood Public Lecture	Melbourne, Australia	Jun
Oxygen: Breathing in the Universe	Lisa Kewley	ASA Harley Wood Public Lecture	Melbourne, Australia	Jun
Where are the oldest stars?	Joss Bland-Hawthorn	Sydney Astrofest 2018	Sydney, Australia	Jul
Telescope Tales	Carolyn Foster	Sydney Astrofest	Sydney, Australia	Jul
The revolution in radio astronomy	Elaine Sadler	CWAS Astrofest	Parkes, Australia	Jul
Stargazing Live	Brad Tucker	ANU	Canberra, Australia	Aug
What do galaxies and shadow puppets have in common?	Jesse van de Sande	Physics in the Pub	Sydney, Australia	Aug
Mount Stromlo Public Observing Night	Kathryn Grasha	RSAA Mt Stromlo	Canberra, Australia	Aug

Continued

SUBJECT	SPEAKER	EVENT	LOCATION	WHEN
Uluru Astronomer in Resident	Kathryn Grasha	Uluru Astronomer in Resident	Uluru, Australia	Aug
Galaxy Evolution in 3D	Lisa Kewley	2018 IAU General Assembly - Invited Discourse	Vienna, Austria	Aug
ASTRO 3D - Female Innovators	Ingrid McCarthy	Lighthouse Business Innovation - Festival of Ambitious Ideas	Canberra, Australia	Aug
Working and observing at the largest telescopes in the world	Carolyn Foster	Public Astronomy Night, Penrith Observatory	Sydney, Australia	Sep
Solving the century old challenge of measuring the true shape of galaxies	Carolyn Foster	Accelerate Computing for Innovation Conference	Sydney, Australia	Sep
Oxygen: Breathing in the Universe	Lisa Kewley	2018 Uluru Astronomy Weekend	Uluru, Australia	Sep
Uluru Astronomy Weekend	Ingrid McCarthy	Interview with ABC Alice Springs	Uluru, Australia	Sep
Panel - How did the Universe begin?	Brad Tucker	Uluru Astronomy Weekend	Uluru, Australia	Sep
Panel - Sounds of Silence	Brad Tucker	Uluru Astronomy Weekend	Uluru, Australia	Sep
Guest Astronomer	Rachel Webster	2018 Uluru Astronomy Weekend	Uluru, Australia	Sep
Astronomy for Fun	Brad Tucker	RSAA Mt Stromlo	Canberra, Australia	Sep-Oct
Uluru scale model of the Solar System	Ingrid McCarthy	Interview with ABC Alice Springs	Uluru, Australia	Oct
What do galaxies and shadow puppets have in common?	Jesse van de Sande	Sutherland Astronomical Society Meeting	Sutherland, Australia	Oct
The Hubble Constant Controversy: Status, Implications and Solutions	Rachel Webster	Berlin Science Week - Wilhelm & Else Heraeus Symposium	Berlin, Germany	Nov
Co-author: "Earthrise, a photo that changed the world"	Rachel Webster	The Conversation	Melbourne, Australia	
Featured in a talk with retired astronaut Steve Swanson, recorded at last year's Mission Discovery program	Rachel Webster	Radio National interview	Melbourne, Victoria	

MEDIA AND SOCIAL MEDIA

During 2018, ASTRO 3D and its members achieved a huge increase in our media coverage, in print, radio,TV and online.

Associate Investigator Alan Duffy appeared on many TV programs across Australia, including a regular slot on ABC News Breakfast, the Project on Ten, The Today Show on Nine and Seven and SBS news. He also regularly talks on radio, including ABC, 2GB, Triple M, Triple J, and the BBC. His year culminated in being awarded the 2018 Eureka Prize for Promoting the Understanding of Science for informing, enthusing and engaging the public.

Prof. Alan Duffy gets ready to present space science at The Project ***IMAGE CREDIT:*** Alan Duffy

Associate Investigator Brad Tucker was also popular in the media, with TV interviews on ABC, Sky News, 7:30, Good Morning Britain, Sunrise, radio interviews on ABC, 2CC Canberra, 6PR Perth, 4BC Brisbane, 2GB Sydney and many public outreach and school talks, including coordinating the 2018 World Record breaking attempt for Star Gazing Live.

Social media engagement grew substantially, with the Centre's Twitter audience nearly tripling to 559 followers and our Facebook page "Likes" increasing 5 times to 179. We also started producing our own social media videos to highlight our researchers and our science. To this end, we now have our own YouTube channel where all our videos are compiled.

The Centre's website www.astro3d.org.au received more than 17,000 page views, after being launched in May 2018. We started to populate the site with news stories and highlights from the Centre's activities.

Media Releases - Highlights

- New research sheds light on Milky Way's Turbulent Past
- Ultra-bright early galaxies may be less common than we think
- 340,000 stars' DNA interrogated in search for Sun's lost siblings
- Galaxies grow bigger and puffier as they age
- Moon to reveal secrets of the Universe

Dr Brad Tucker and ANU Vice-Chancellor Prof Brian Schmidt. ***IMAGE CREDIT:*** Jack Fox, ANU

COLLABORATION HIGHLIGHT

2018 ANNUAL RETREAT

Our second Annual Retreat was held over four days in November 2018 at the Vines Resort, Western Australia. It was another great opportunity for 88 of our ASTRO 3D members from around the country and overseas to update on Theme, Thread and Project/Survey achievments and build on collaborative relationships.

The focus of this meeting was on reviewing 2018 Centre achievements and strategic planning for 2019. Highlights inlcuded:

- Director Lisa Kewley gave an overview of the State of the Centre;
- Chief Operating Officer Sheri Norton updated us on our governance and policies;
- Stuart Wyithe outlined our Year 2 Scientific Strategic Plan;
- Theme/Thread updates by Chris Power and Lister Staveley-Smith;
- Project/Survey updates by Cath Trott, Joss Bland-Hawthorn, Emma Ryan-Weber, Martin Meyer, Scott Croom, and Michele Trenti;
- A very useful discussion on Centre values and behaviour for inclusion;
- Young Faculty update by Brent Groves;
- Postdoc/ECR and Student Committee updates by Rob Bassert and Ellert van der Velden;
- Education and Outreach update by Ingrid McCarthy;
- Updates on Research and Leadership training plans, mentoring program and our Culture Survey;
- A strategic engagement and networking session led by Elaine Sadler and Joss Bland-Hawthorn;
- A well-received session on work-life balance and mental health with Virginia Kilborn;
- Breakout sessions to plan and collaborate;
- Social activities and a very competitive Trivia night!

RESEARCH TRAINING

The ASTRO 3D Research training programs commenced in 2018 as we build our exceptional team of researchers and students.

WRITING RETREATS

Writing retreats were held in May at UNSW and in November at UWA/ICRAR. The retreats are designed to provide an exceptional opportunity for ASTRO 3D members to focus on writing an academic paper in the supportive company of peers from across the country.

The rationale behind a 'retreat' model of writing workshop is that it helps our members to:

- develop a collegial network across the Centre of Excellence;
- become comfortable in a peer-supported culture of academic writing;
- affirm their identity as a research scientist who seeks to communicate their findings; and
- share knowledge, practices and experiences related to writing and publishing.

This five-day slice out of usually busy workplaces was just the thing to get the writing juices flowing:

> "Quite productive and very satisfied about my progress on my paper. Before the retreat I had nothing..."

> "These retreats are absolutely brilliant for finishing those difficult papers that otherwise would not be written. Best use of my time by far!"

> "Definitely more productive as I had the space to fill my brain with the science for the whole week which helped when writing."

SCICODER WORKSHOPS

ASTRO 3D sponsored SciCoder workshops in Perth, Melbourne and Sydney in 2018.

SciCoder is a five-day workshop run by Dr Demitri Muna. The workshops introduce early-career researchers to modern programming practices, languages and tools, specifically applicable to scientific research - and really important to astronomy!

These skills have enabled our researchers to write better code, code faster, and leverage more tools, as well as learning about a range of open source software available.

Workshop topics include:

- programming tools/Python
- code management
- databases
- modern code design
- multiprocessing
- unit testing

MEDIA TRAINING

Conveying the complexity of our research into a 30-second grab for the media can be hard. We are partnering with Science In Public to help our researchers find the story in their research.

The workshop will help our researchers:

- convey the complexity of their research in a 30-second grab
- find the right words to explain their research in a way that works for the media, as well government, industry and other stakeholders
- learn how to work with journalists from television, print and radio
- practice being interviewed in front of a camera for TV and on tape for radio

These are important skills for our researchers not just for their time in ASTRO 3D, but also to provide them with transferable skills that will help them in any direction their careers take them.

ECR WORKSHOP - MENTAL HEALTH AWARENESS WORKSHOP

Before our Annual Retreat started, PhD students and Early-Career Researchers took the opportunity to get together and get to know each other, collaborate and also to participate in a workshop presented by Blooming Minds on Developing a Positive Workplace Mental Heath Culture.

Tasha Broomhall, Director of Blooming Minds WA helped the researchers and students to optimise their mental health and well being as well as support their colleagues who they suspect are experiencing mental health problems.

The workshop had group activities and talks that covered:

- Overview of mental health and wellbeing
- Common mental illnesses
- Strategies for talking about mental health
- Strategies for supporting their own mental health and wellbeing
- Resources and support

PUBLICATIONS

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2018 AWARDS

ASTRO 3D Fellow Dr Emily Wisnioski (ANU) - ASA Louise Webster Prize (for recognition of outstanding research by a scientist early in their post-doctoral career) for her work on the motion of ionised gas at the time of peak galaxy growth

ASTRO 3D Fellow Dr Caroline Foster (ANU) - honourable mention, ASA Louise Webster Prize

Chief Investigator Barbara Catinella (UWA) - ASA Anne Green Prize (for a significant advance or accomplishment by a mid-career scientist) for her unique contributions to the studies of cold gas in galaxies and her leadership of state-of-the-art projects in the field of gas in galaxies and its connection with star formation

Dr Simon Mutch (University of Melbourne)- Science and Technology Australia STEM Ambassador

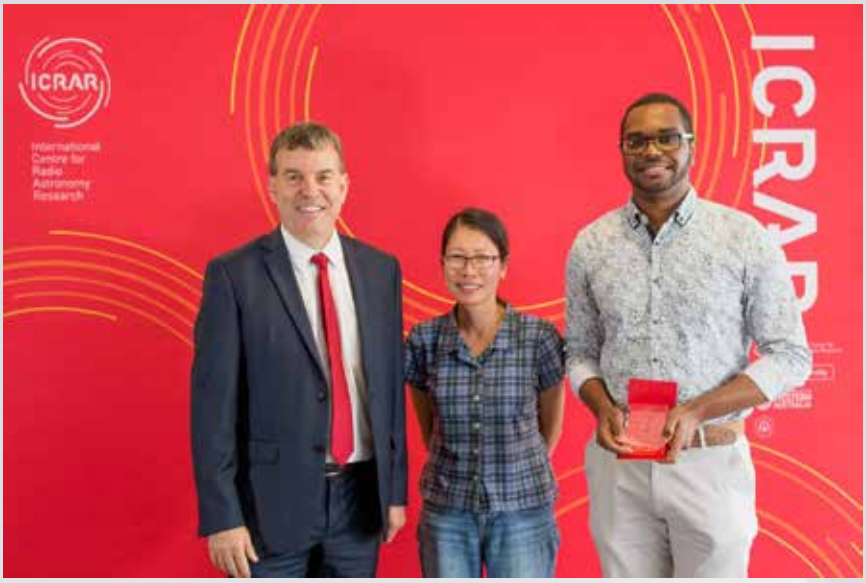
Associate Investigator Alan Duffy (Swinburne University of Technology) - Eureka Celestino Prize for promoting understanding of science

ASA President CI Stuart Wyithe presents Dr Emily Wisnioski with the 2018 Louise Webster Prize.
IMAGE CREDIT: ASA

ASA President CI Stuart Wyithe presents CI Barbara Catinella with the 2018 Anne Green Prize
IMAGE CREDIT: ASA

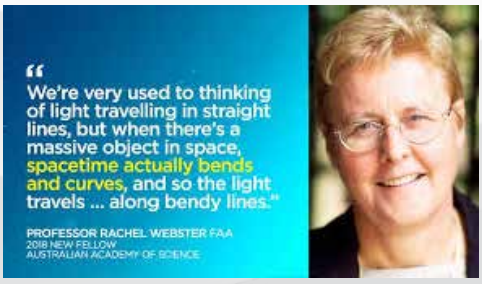
AI Alan Duffy receives his Eureka Prize for promoting understand of science ***IMAGE CREDIT:*** Eureka Prizes/ Salty Dingo

Dr Simon Mutch is announced at one of the inaugural cohort of STA STEM Ambassadors
IMAGE CREDIT: Simon Mutch



WA Science Minister the Hon Dave Kelly presents the 2018 ICRAR/UWA Ken and Julie Michael Prize to Ahmed Elagali, with his supervisor Affiliate Ivy Wong ***IMAGE CREDIT:*** ICRAR

Sue Thomas, CEO of the Australian Research Council and Mr Andrew Laming MP
IMAGE CREDIT: CI Karl Glazebrook



CI Rachel Webster is elected a 2018 new Fellow of the Australia Academy of Science
IMAGE CREDIT: Australian Academy of Science

Chief Investigator Karl Glazebrook (Swinburne University of Technology) - ARC Laureate Fellow

Associate Investigator Julia Bryant (University of Sydney) - ARC Future Fellow

Associate Investigator Luca Cortese (University of Western Australia) - ARC Future Fellow

Associate Investigator Christoph Federrath (Australian National University) - ARC Future Fellow

Associate Investigator Mark Krumholtz (Australian National University) - ARC Future Fellow

Chief Investigator Cathryn Trott (Curtin University)- ARC Future Fellow

Chief Investigator Rachel Webster (University of Melbourne)- Australian Academy of Science Fellow

Ahmed Elagali (University of Western Australia)- ICRAR/UWA Ken and Julie Michael Prize for his PhD thesis on Interacting Galaxies & the Environmental Effects on Their Evolution

PERFORMANCE INDICATORS

PERFOMANCE MEASURE		2018 TARGET	2018 ACTUAL
Number of research outputs	Papers in refereed journals	25	**110**
	Media releases	12	**5**
Quality of research outputs	% of refereed papers in journals with impact factor > 2.5	80%	**100%**
Number of training courses held/offered by the Centre	Professional skills workshop	1	**4**
	Diversity training workshops (one at each node)	4	**6**
	ECR training day	1	**1**
	Writing workshops	4	**5**
Number of workshops/ conferences held/ offered by the Centre	International conference	2	**2**
	National conference/ workshop	2	**2**
Number of additional researchers working on Centre research	Postdoctoral researchers	10	**14**
	Honours students	2	**1**
	Masters by coursework	2	**2**
	PhD students	12	**13**
Number of presentations/ briefings	Public briefings	40	**123**
	Government briefings	4	**22**
	Industry briefings	2	**12**
	Non-government organisation briefings	6	**5**
	Briefings to professional organisations & bodies	4	**36**
	Professional conferences/ workshops	40	**163**
Number of new organisations collaborating with, or involved in, the Centre	New collaborative relationships	4	**7**

Continued

PERFOMANCE MEASURE		*2018 TARGET*	*2018 ACTUAL*
Maintain a collaborative and cohesive structure	Cross-node authorship of publications	85%	**46%**
	Project team meetings with cross-node collaboration	6	**12**
	Centre-wide climate survey	1	**1**
Create a diverse Centre	Females at all levels	35%	**39%**
	At least 35% travel funds to females	35%	**42%**
	Female visitors	50%	**50%**
	Child care at all Centre supported conferences	100%	**100%**
Build the expertise for the next-generation telescopes	Students working on optical GMT pathfinder instruments	20%	**29%**
	Students working on radio SKA pathfinder instruments	20%	**16%**
	Students working on space telescope data	10%	**16%**
	Students with data intensive research experience	20%	**80%**

FINANCIAL STATEMENT

	2018 ACTUAL ($)
INCOME	**$**
ARC Grant	4,378,456
State Government Grants	0
Other Grants	0
University Contributions	1,266,729
Partner Contributions	110,663
Other Income	24, 844
TOTAL INCOME	**5,780,692**

EXPENSES	**$**
Salaries	3,234,318
Travel and Visitor Support	514,202
Equipment	30,117
Workshops and Conferences	114,509
Management and Administration	161,057
Education, Outreach and Communications	28,987
PHD Support	54,043
TOTAL EXPENSES	**4,137,232**
NET SURPLUS (DEFICIT)	**1,643,460**
Brought Forward Balance	4,472,435
CARRY FORWARD BALANCE	**6,115,895**

NOTES TO FINANCIAL STATEMENTS

1. ARC CONTRACT & GOVERNANCE

a) ASTRO 3D involves six Australian Universities and a further ten Australian and International partner organisations. Funding was approved by the ARC for seven years, subject to review after four years. The Centre commenced operation on 1 July 2017, a six month delay on the original 1 January commencement.

b) 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.

c) The Centre's operational and financial affairs are governed under defined policies and procedures.

d) Financial reporting provides institutional expenditure per Node, with the Business Manager for the centre providing Consolidated Financial Reports for review by the Chief Operating Officer and Director.

2. INCOME

a) Income received from the ARC for 2018 amounted to $4.4m, including an amount relating to indexation of $128k.

b) University contributions reflects all funds provided at Node level.

c) A review of the funding agreement identified that the Partner Contribution of $20k per annum, relates to an in-kind contribution for travel costs. Future budgets have been amended to reflect this.

3. EXPENDITURE

a) Expenditure for the year was $4.1m against a budget of $4.6. This variance primarily relates to lower than expected PhD support costs and some professional and research recruitment.

b) A financial re-forecast will be conducted in early 2019, as part of a continued review of expenditure and allocation of funds.

4. FINANCIAL MANAGEMENT

a) As part of a sustained review of financial management practices, a review of financial reporting has been undertaken.

b) A monthly financial reporting process will be implemented in 2019.-